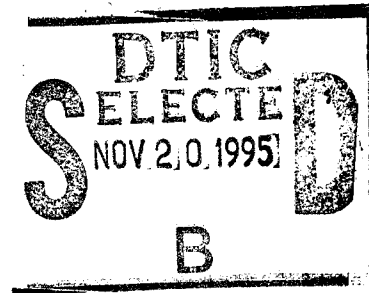


The Society of the
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REINFORCED PLASTICS/COMPOSITES INSTITUTE TECHNICAL REVIEW

**CORROSION-RESISTANT EQUIPMENT
AND PIPING SYSTEMS:
APPLICATIONS, DESIGN, MATERIALS, TESTII**

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This publication is a selection of the technical papers on chemical-resistant equipment as presented from 1971 through 1975 at the Annual Conference of the Reinforced Plastics/Composites Institute of the Society of the Plastics Industry, Inc.

The selection answers the frequent request for a compact, central source for general or representative material on reinforced plastics' technical potential in the corrosion and piping systems applications.

The complete Proceedings of the Conferences mentioned above continue to be available, each 800-page volume containing approximately one hundred papers on all phases of reinforced plastics applications, materials, and research.

The papers selected for reprint here are those requested most often, or have otherwise proven useful to users of RP equipment, purchasing and design engineers, and members of the producer industry itself.

Section Five offers readers suggestions on further sources of information, including recommendations on future publications and activities which are likely to keep up-to-date those interested in the fast developing field of reinforced plastics chemical resistant equipment and piping systems, of which this supplement is but a sampler.

Joseph S. McDermott, Manager
Reinforced Plastics/Composites
SPI - January, 1976

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SECTION ONE

APPLICATIONS AND DESIGN

CORROSION CONTROL FIBER REINFORCED PLASTIC ENCLOSURES

by

RAMESH R. DESAI*

ABSTRACT

An extremely successful concept, namely the use of fiber reinforced plastics, reducing both environmental and electrolytic corrosion is presented. A number of applications including storage and processing tanks, pipes and ducts, and accumulators are discussed in detail with illustrative photographs. The resulting technical and economic advantages are set forth.

A complete discussion of appropriate materials and fabrication techniques is provided. Mechanical properties of various materials are tabulated.

Comparison between the fiber reinforced plastics (FRP) and other materials is provided by way of tank repairs.

The results show that the fiber reinforced plastics provide an economical approach to reduce corrosion and pollution.

INTRODUCTION

Fiberglass reinforced plastic has long been recognized throughout the chemical processing industry as an engineering material that successfully combats both environmental and electrolytic corrosion. Over the years there has been extensive research done on FRP as well as development and manufacturing resources to design and make tanks to solve corrosion problems.

There are over 12,000 fiberglass underground storage tanks installed in place of steel tanks overcoming soil corrosion that previously caused leakage and pollution. There are many above ground tanks being used to-day in the chemical industry, food processing, pipes and ducts, accumulators, paper and pulp mills. Many of these tanks have replaced even expensive alloy tanks which have been known to fail in six months.

As cost accounting has become more proficient and the high cost of maintenance, down time, product loss and repair has become documented, the cost savings of fiberglass reinforced plastic tanks have become more widely recognized. To-day, most engineers are aware that, unlike malleable thermoplastics, fiberglass-reinforced thermoset resins (polyesters, vinylesters, epoxies, etc.) are formed by chemical reaction and are remarkably inert, stable, and strong.

The purpose of this paper is to present various applications of fiber reinforced plastics in the corrosion control field and set forth the resulting advantages. A detailed description of materials is provided with their properties tabulated.

ADVANTAGES

The FRP enclosures offer following advantages.

1. High resistance to corrosion.
2. Light weight.
3. Durability.
4. Good thermal insulation.
5. Ease of maintenance.
6. Fewer joints.

7. Low cost.
8. Ease of fabrication.
9. Attractive appearance.
10. Ease of installation.
11. Can be fabricated into almost any shape.

APPLICATIONS

Tanks and Towers:

Figure 1 presents an 8' diameter x 50' high FRP chlorination retention tower. The tower is green in color and was filament wound using the Atlac 382 corrosion resistant polyester resin. According to Mr. Herb Ershig of Ershig's Inc., the tower weighed 8500 lbs. as opposed to stainless steel construction weighing two to three times as much. While the basic cost of the FRP tower was approximately the same as that of a stainless steel unit, the installation of the FRP system was considerably cheaper thus lowering the overall cost. The unit is being successfully used since September 1970.

Figure 2 shows the unloading of a 14' diameter x 43' high FRP storage tank. Figure 3 shows the same installed. Once again not only has the tank been in service for over two years but has also provided the above-mentioned advantages of light weight and ease of installation.

A Chlorine-Caustic neutralizing tower, 5' 6" I.D. x 43' 6.75" high, is shown in Figure 4. The tower was filament wound strand over a corrosion resistant liner, all saturated with Derakane 411-45 resin. Where corrosion was a problem, even the pipings were constructed in FRP. The tower is in successful operation since December 1970.

The parts and installation of a C10₂ Bleach tower are shown in Figures 5 through 11. The tower consists of:

- a. 8' I.D. x 64' high FRP up-flow retention tower; the construction being two segments, each 32' long, joined at the site.
- b. 8' I.D. x 180° inlet elbow.
- c. 20' 2-1/2" I.D. FRP down-flow tower cover.
- d. FRP stock piping, venturi sections, dilution piping, etc.

The fabrication technique consisted of filament winding strand over a corrosion resistant liner and saturating it with Hetron 197-3 resin. The ease of installation can be noted by the fewer men required. The cover has channels for additional reinforcement. Figures 10 and 11 show the hugeness of the structure.

Figure 12 presents a vertical storage tank fabricated by the Wilson Oilfield Supply Company. According to Mr. Doug Martin, president of Wilson Oilfield, these tanks are gaining a wide acceptance in Canada.

Ducts:

Figure 13 presents the inside view of an FRP duct system for collecting sulfur containing gases which are used for manufacturing sulfuric acid. The dimensions of the ducts are 1200 feet x 10' diameter and 700 feet of 7' diameter plus miscellaneous smaller ducts, transitions, etc. The ducts were fabricated using the filament wound construction, flanged connections, and stiffeners for external pressure. The expansion joints were bellows type.

The materials used were Atlac 711-05A fire retardant liner with Dynel veil; fire retardant isophthalic polyester filament wound structural wall.

The segments of the ducts and completed installation are shown in Figures 14 through 18. It should be noted some of the ducts were installed as high as 100' above ground. The system has been in use since about 1-1/2 years without any problems.

Figure 19 shows another FRP duct system. It was fabricated using hand lay-up process with Hetron 92 resin. According to Mr. Everett Pearson, president of Tillotson-Pearson, Inc., the system has been successfully operating the last four years.

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Teaneck, N.J. 07666

Accumulators:

Figures 20 through 23 show various views of a non-condensable gas accumulator.

- a. Figure 20: Assembled top half unit being lifted from erection platform.
- b. Figure 21: Bottom half of unit just after it was set on support columns.
- c. Figure 22: Top half being lifted on to bottom half.
- d. Figure 23: Complete accumulator loaded on 60' rail car ready for shipment to customer.

According to Mr. Van Ryck, president of the Barthel Chemical Construction Company, the FRP accumulators are performing exceedingly well.

DESIGN

The FRP structures can be basically designed using the conventional theory for cylinders, pipes, spheres, etc. Due consideration must be given to all three parameters namely structural, thermal, and corrosion. There are no hard and fast rules regarding the factor of safety, however, 10:1 is more commonly used.

MATERIALS

The primary criteria behind the selection of materials is their ability to resist corrosion and yet meet structural and thermal requirements. The FRP, as the name suggests, consists of a suitable form of fiberglass and an appropriate resin system.

Various forms of fiberglass are commercially available, e.g. roving, mat, woven roving, cloth, etc. The selection of the type of fiberglass will be dependent upon the fabrication process, application, and the desired mechanical properties. Typical properties of various FRP laminates are shown in Figure 24.

The resin system selected should possess the adequate corrosion resistance and fire retardancy. A number of resins are commercially available and hence the selection should be made so that performance is not sacrificed for a slight addition in cost. It must be remembered that in a usual FRP operation, the labor costs are higher than the material costs.

FABRICATION

The most commonly used fabrication methods are:

- a. Hand lay-up or spray-up.
- b. Filament winding.

The selection of the method depends on the application and the individual molder's preference.

REPAIR OF STEEL TANKS

Successful tank repair by using FRP as a remedy of repair has been accomplished since 1959. With the advanced technology and research which has been carried out since this time, there has been a rapid progress in the field of repairing steel tanks which develop severe leaks in service due to interior corrosion caused by the stored liquids and external corrosion caused by the action of the soil. The combined corrosion deteriorates the tank bottom and creates structural weakness that precludes the use of simple patching repairs.

Steel bottoms are usually replaced by welding new steel plates over the old ones or by first installing a pad of stone aggregate on top of the old bottom, and then rebuilding a new bottom on top of the pad. According to Mr. Randy Schetzle of the Wilson Oilfield Supply Company, the downtime for an operation such as this normally runs 30 days for a 15 foot diameter tank to over 90 days for a 115 foot diameter tank. Cost of labor becomes the major expense. Cost of downtime, although expensive, is difficult to calculate since it can vary from location to location and depends on storage capacity and several other factors. However, repairing steel tanks with fiberglass cuts the downtime to a minimum. For example, from 30 days for a 15 foot diameter tank, the downtime would be approximately 3 to 4 days by using FRP linings. This offers a major saving in costs.

CONCLUSION

Based on the applications cited, it can be surmised that fiber reinforced plastic construction is gaining a significant role in the corrosion field. With the advent of new government rules on pollution, FRP is also penetrating the area of pollution control. Finally, it is strongly suggested that the overall cost of a job which includes manufacturing, installation, and maintenance costs, be considered in selecting the type of material.

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RAMESH R. DESAI

Ramesh R. Desai is an independent consultant in the field of reinforced plastics. He has assisted over 200 prominent FRP companies, in U.S., Europe, and Japan, in reducing costs and increasing profits. His specialties lie in the areas of engineering, manufacturing, and marketing of a variety of FRP products, e.g. tanks, boats, bath-tubs, shower stalls, transportation and construction industries, and a number of industrial molding applications.

Prior to his present position, Mr. Desai has held several executive positions. He has a number of patents and has authored many papers.

Mr. Desai holds an M.S. in Mechanical Engineering, June 1960, from the Illinois Institute of Technology.

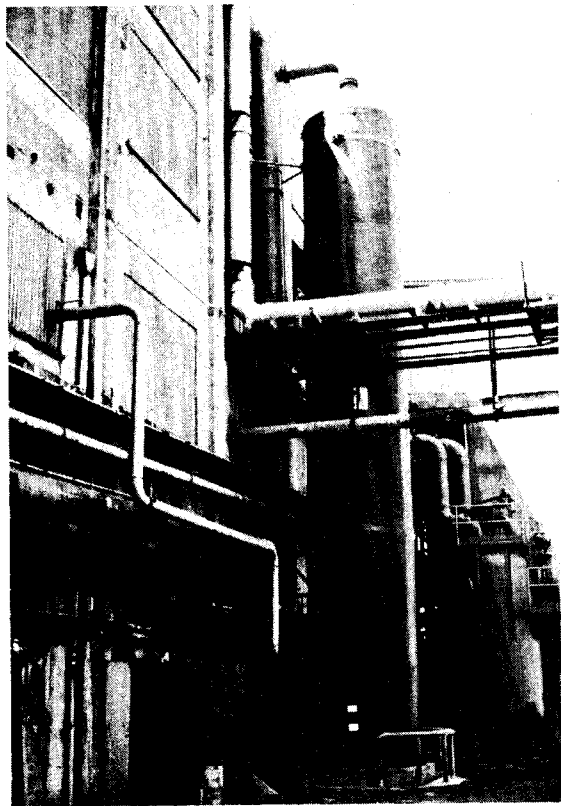


Fig. 1. FRP Chlorination Retention Tower — 8'0" Dia. x 50'0" High. Fabricated: September 1970, Atlac 382 Resin, Green Color. Tower Weight: 8,500#

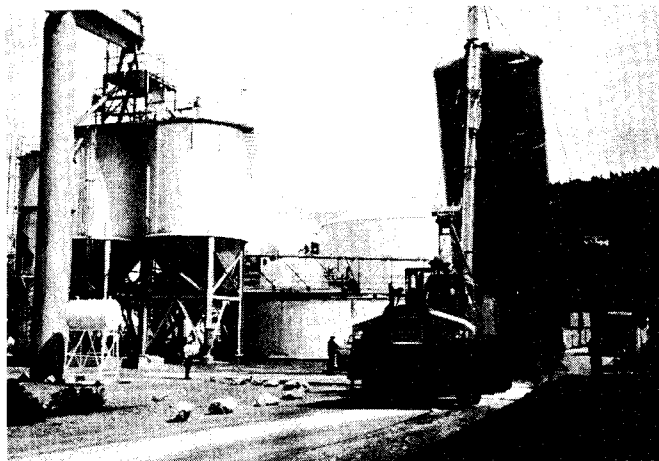


Fig. 2. FRP Storage Tank — 14' Diameter x 43' High.

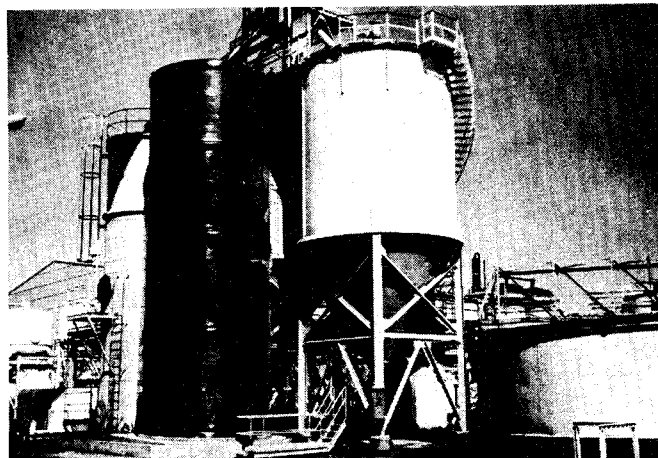


Fig. 3. Installation.

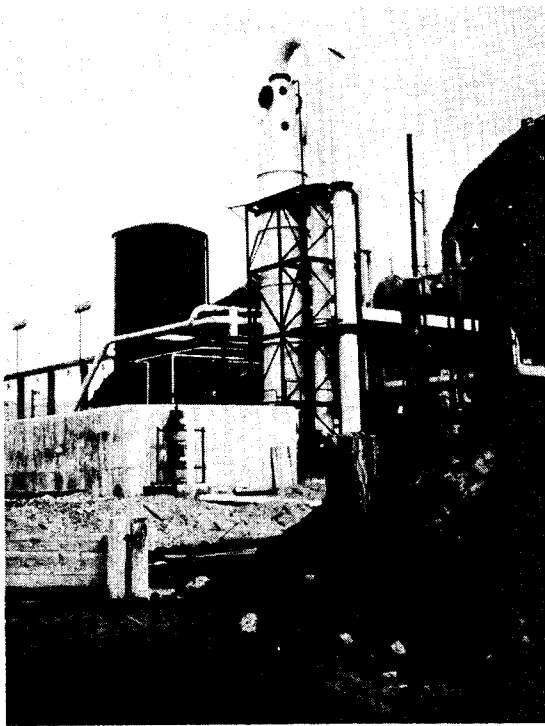


Fig. 4. Chlorine-Caustic Neutralizing Tower — 5'6" I.D. x 43'6-3/4" High Tower. Yorke Demister, Intalox Saddles, FRP Liquid Distributor, FRP Support Plate. FRP Liquid and Gas Piping, as required. Filament wound strand over corrosion resistant liner, all saturated with Derakane 411-45 Resin. Installed: December, 1970.

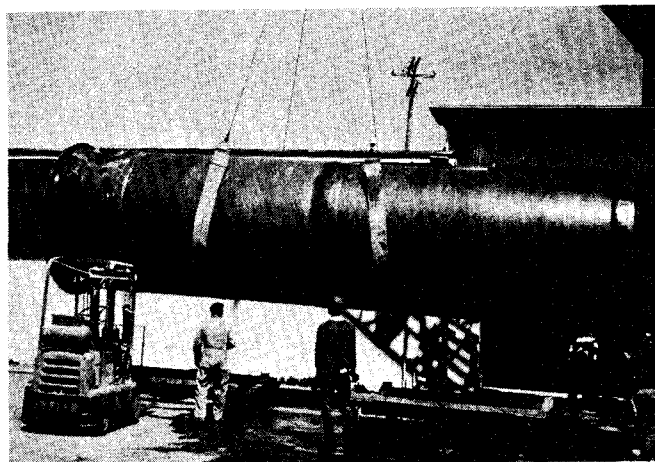


Fig. 5. Tower Section—C10₂ Bleach Tower — 8'0" Diameter x 32'0" long.

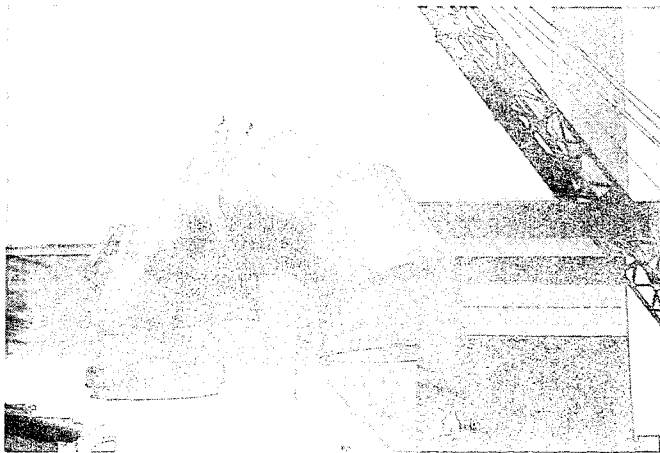


Fig. 6. Inlet Elbow - 8'6" I.D. x 180°.

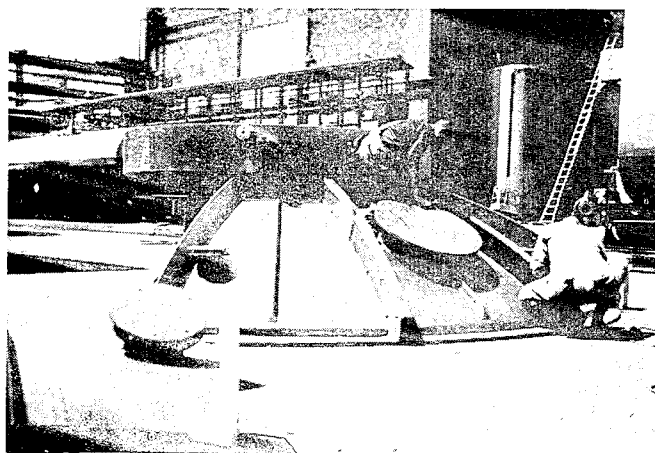


Fig. 7. Assembly - C102 Bleach Tower - 20' 2-1/2" I.D. Tower Cover.

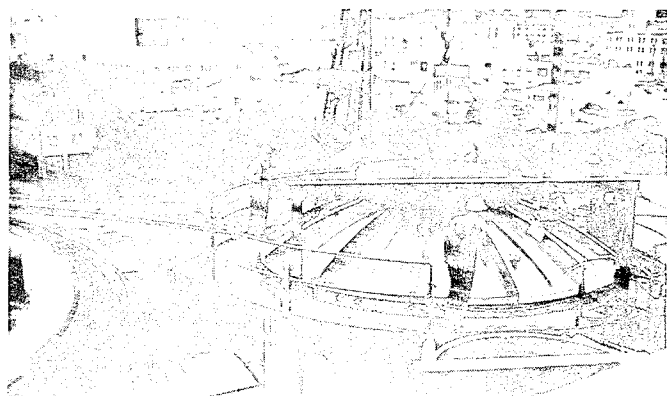


Fig. 8. Tower Cover Installation.

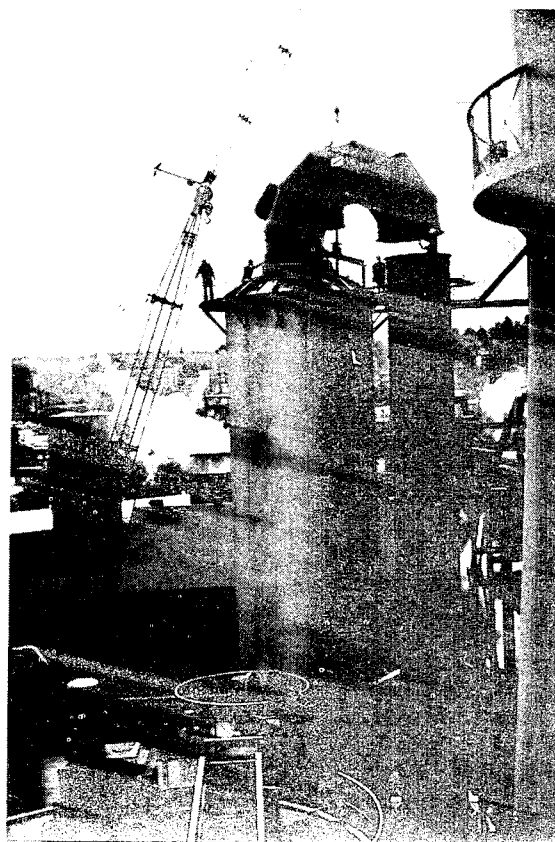


Fig. 9. C102 Bleach Tower - Installation of Inlet Elbow.

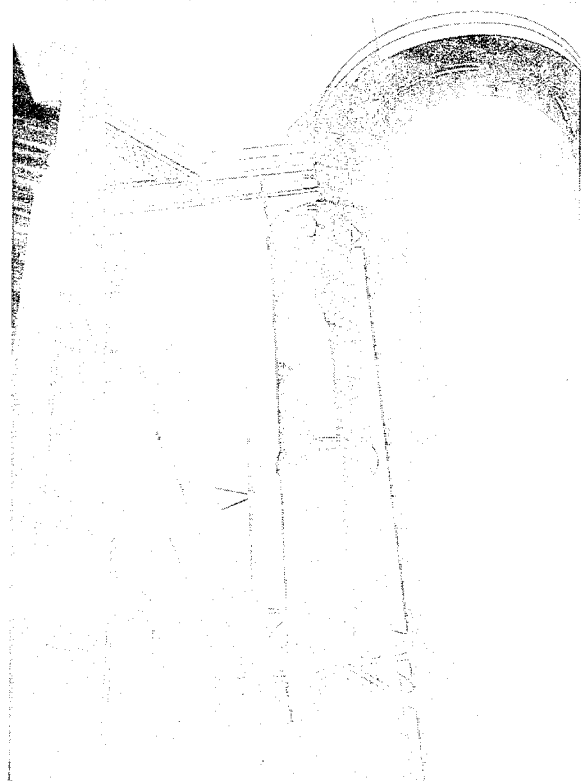


Fig. 10. C102 Bleach Tower - Completed Installation.

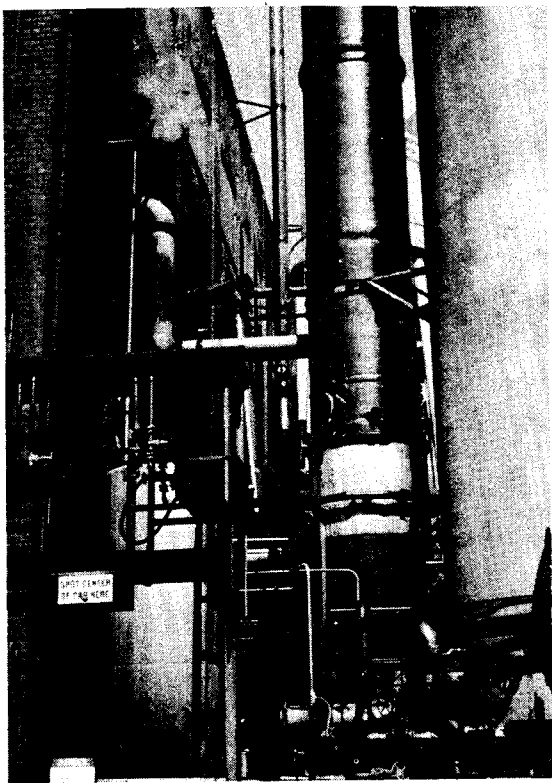


Fig. 11. C102 Bleach Tower — Completed Installation.

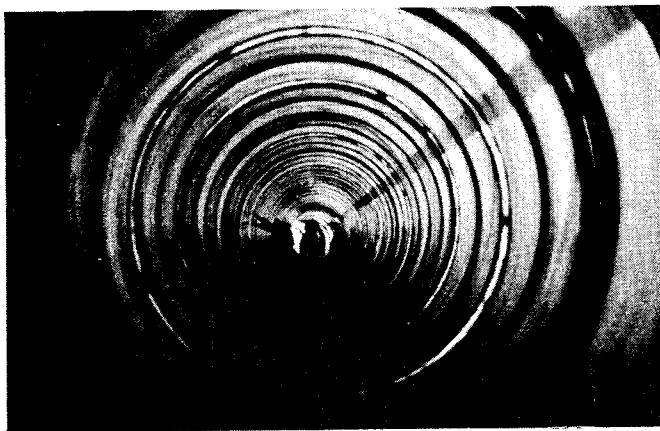


Fig. 13. FRP Duct System — To collect sulfur containing gases, for manufacture of sulfuric acid.

1,200 feet of 10' diameter, and 700 feet of 7' diameter (31 rail carloads), plus miscellaneous smaller duct, transitions, et cetera. Filament wound construction, flanged connections, stiffeners for external pressure, and bellows type expansion joints.

Fabricated with Atlac 711-05A fire-retardant liner with Dynel veil; fire-retardant isophthalic polyester filament wound structural wall.

Some duct installed more than 100 feet in the air. Installation—1971.

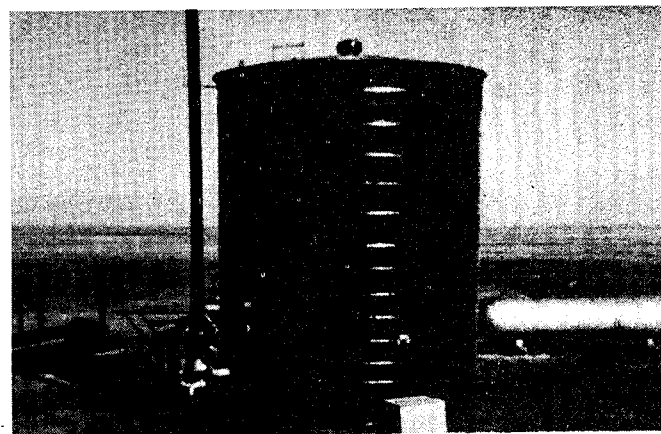
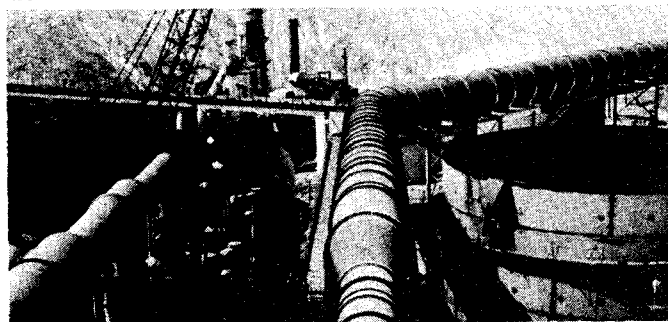


Fig. 12. Vertical Storage Tank by Wilson Oilfield Supply Company.

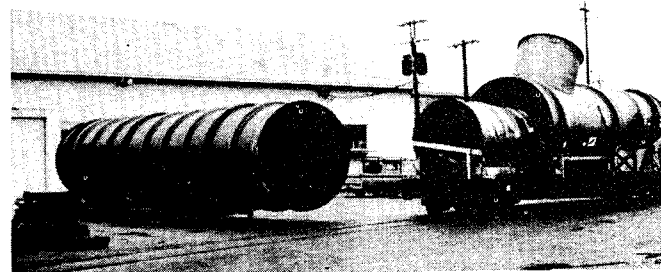


Fig. 14. FRP Duct System — Duct Segments.

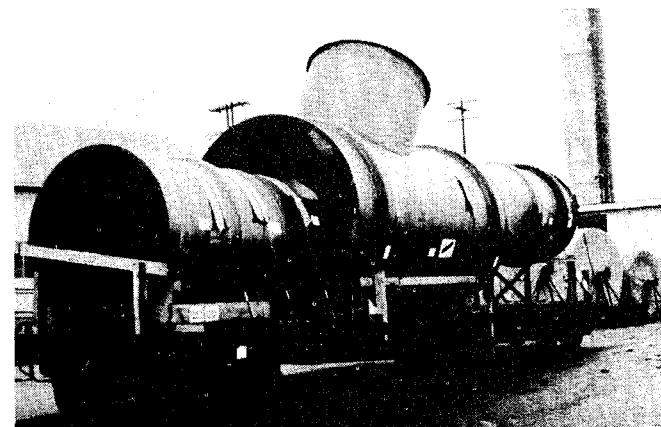


Fig. 15. FRP Duct System — Close-up Duct Segments.



Fig. 17. FRP Duct System — Completed Installation.

Fig. 16. FRP Duct System — Completed Installation.

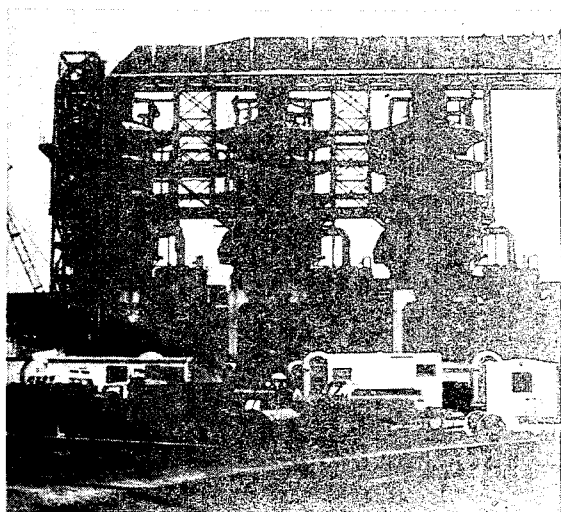


Fig. 18. FRP Duct System — Completed Installation.

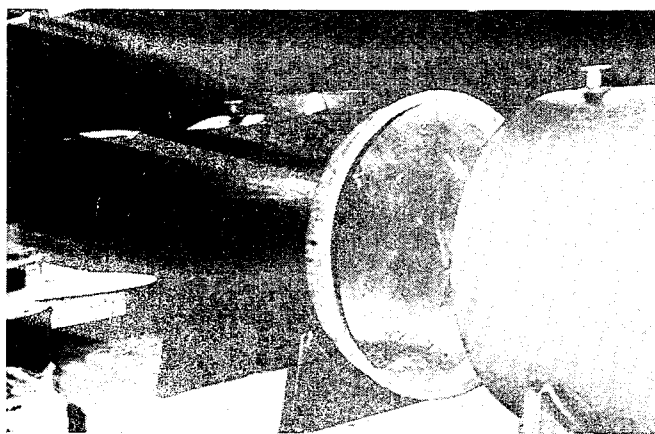


Fig. 19. FRP Duct System by Tillotson-Pearson, Inc.

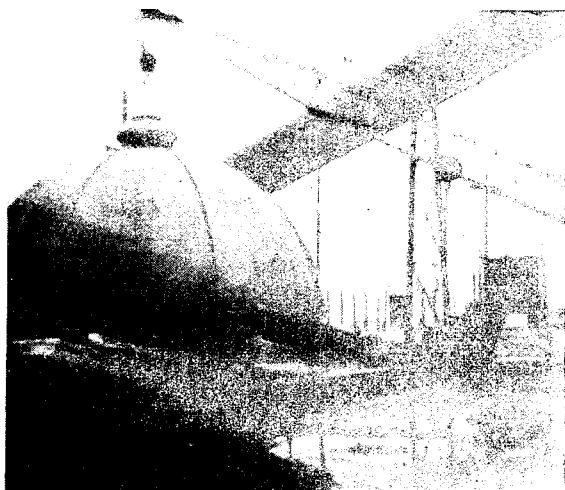


Fig. 20. Top Half of a Non-Condensable Gas Accumulator.

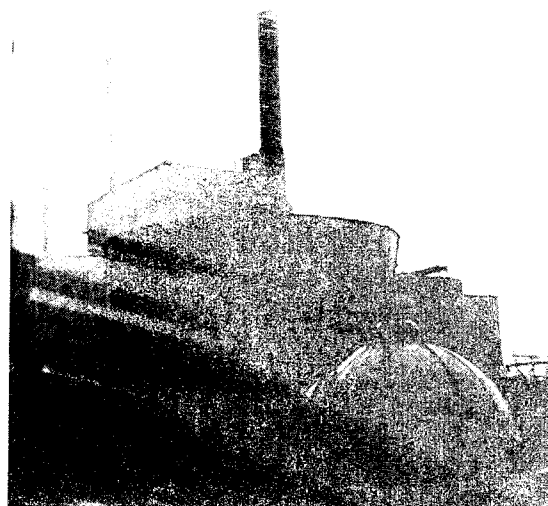


Fig. 21. Bottom Half of a Non-Condensable Gas Accumulator.

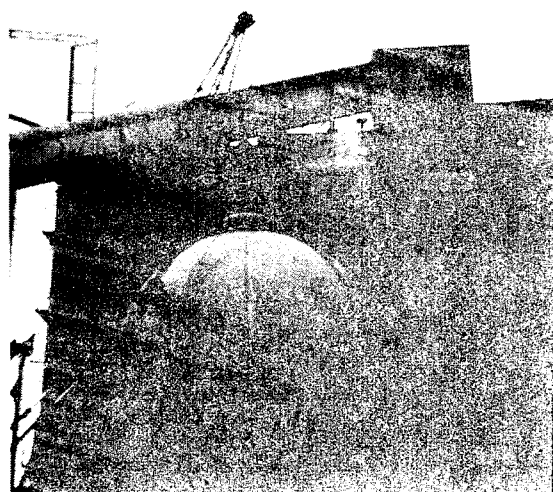


Fig. 22. Non-Condensable Gas Accumulator — Top Half Lifted on to Bottom Half.

By: Barthel Chemical Construction Company.

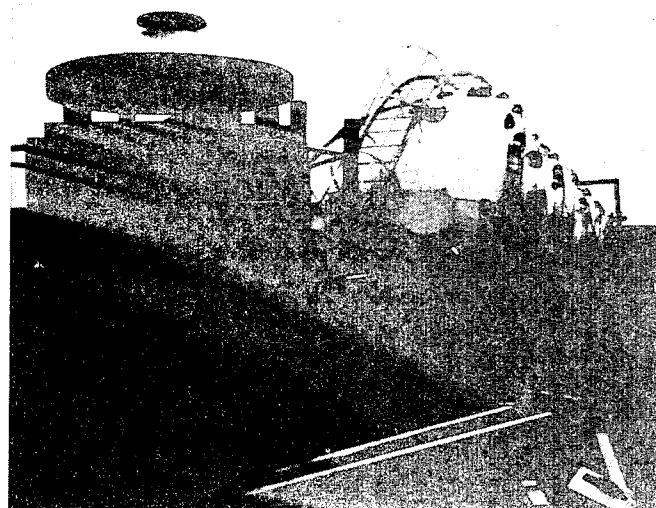


Fig. 23. Non-Condensable Gas Accumulator — Complete Accumulator. Loaded on a 60' Rail Car.

TYPE OF MATERIAL	FLEXURAL MODULUS MILLION PSI	FLEXURAL STRENGTH PSI
FRP Spray-up/Mat - Polyester: 25% Glass	0.8	16,000
FRP LAY-UP MAT - Polyester: 25% Glass	0.8	18,000
FRP LAY-UP-1,000 cloth-Polyester: 45% Glass	1.7	37,000
FRP LAY-UP - Woven Roving - Polyester: 50% Glass	2.0	40,000

Fig. 24. Mechanical Properties of FRP Laminates at Room Temperature.

RECENT MILESTONES IN THE CUSTOM FABRICATION OF LARGE CORROSION RESISTANT FRP STRUCTURES

by

WINSTON J. RENOUD*

ABSTRACT

The purpose of this paper is to discuss the design and production of large complicated corrosion resistant Fiberglass Reinforced Plastics structures. The paper discusses the story behind two large scrubbing systems which were recently completed. Also, there is discussion about the development of large diameter FRP chimney liners.

The paper emphasizes the basic points which we believe were most important in making these projects successful, and it is hoped that this discussion will stimulate others to consider similar projects.

INTRODUCTION—SUMMARY

In the last several years there have been a number of very interesting first-of-a-kind corrosion resistant structures produced from Fiberglass Reinforced Plastics. Some of the early structures were simple, but large. Later structures were not only big, but complicated and difficult in every aspect from basic design engineering through production and installation. These jobs were so very difficult that they would have been nearly impossible without both the earlier experience and the use of the turnkey approach in which one Company has responsibility of total project organization, engineering design, fabrication, and installation. The solutions of yesterday's problems guided by careful, shrewd management, became the critical stepping stones into the unexplored tomorrow.

This paper will discuss several of these structures, their design, fabrication, and installation, in some detail. There will be discussion of a large FRP Absorber-Cooler, at Port Angeles, Washington; and also discussion of a very large, complex, multiple scrubbing system, installed at Hoquiam, Washington. Finally, there will be discussion about design and production of several chimney liners, one of which is 1,215' high. This liner is the largest structure of its kind in the world.

ABSORBER-COOLER, at Port Angeles, Washington

At an ammonia base sulfite pulp mill at Port Angeles, Washington, it was decided to install a 71-foot high 25-foot diameter Absorber Cooler. This absorber cooler was to accomplish three purposes. Sulfur dioxide and heat energy were to be recovered and remaining gases were to exit the scrubber cleaned. This tower was to be free-standing, in a seismic zone three. Complications were increased by the fact that heavy stainless steel internals were located in the top of the vessel, and a large 7-foot by 14-foot inlet was cut out of the base section of the vessel shell (Fig. 1). The cutout was heavily reinforced and a pillar was placed in the center of the 14-foot wide opening to transfer loads from the upper shell to the lower. The stainless steel internals were supported by a central stainless steel column and by ledges on the side of the FRP vessel wall.

This was a large job, but the design and production of the Absorber Cooler turned out to be quite straight-forward. The shell segments were filament wound at our plant in Bellingham, Washington. The shells were produced in four 25-foot diameter by 17-foot high pieces, and one piece 3'6" high. These pieces were transported from the plant to a nearby barge, which was towed to the mill site at Port Angeles. The parts were assembled with alignment bells and overlay joints (Fig. 2). The top cover was a pie-segmented dished head (Fig. 3).

Valuable experience was gained from this project in handling and joining large diameter cylindrical structures. This experience was extremely valuable in subsequent projects, such as the horizontal scrubber vessel at Hoquiam, Washington, and the large chimney liners which were to be later conceived, designed, and built.

SCRUBBER SYSTEM, at Hoquiam, Washington

A pulp mill at Hoquiam, Washington, planned to install a scrubber to handle recovery boiler stack gases that have already been processed by a conventional electrostatic precipitator. The precipitator is about 85% efficient in reducing the contaminants from the gases. The new scrubbing process, will satisfy current Washington State, and Federal, Air Emissions Standards.

The gases leaving the precipitator are at about 350F. To reduce this temperature to an acceptable range for FRP components, the gases pass through a 9-foot diameter 90°FRP elbow quench section. Next the gases pass down through a venturi scrubber 8-foot by 20-foot in cross section, and about 22-foot long. In this venturi scrubber there are two parallel throats, each 20-foot long. The venturi was produced in three parts at the Bellingham plant, and assembled in one piece at the jobsite, before installation. The gases then pass horizontally through the 18-foot by 25'6" rectangular crossflow packing bed. At this point, the cleaned gases pass out of the primary vessel and are carried by a duct a short distance to the chimney breeching. Each of these four basic sections were isolated structurally by expansion joints, and were supported independently.

The basic engineering problems were first that the scrubbing process was rectangular with large flat panels proposed throughout the structure. The initial design pressure was one pound per square inch. The packing effective pressure was four pounds per square inch at the bottom. These two pressures are high and very large forces were generated by them in the structure.

The second basic area of problem was fabrication. The installation was required to be completed in a short period of time. The design had to use simple, effective structures which could allow fast production and make the best possible use of the homeplant and available sub-contractors. This would all demand attention in tailoring the design of the vessel to available production capabilities.

The third basic problem area was that of movement and installation of the parts at the millsite. The basic segments, especially the primary scrubbing vessel, were very large. The site for installation was in the center of the crowded mill at the edge of the river. This spot was inaccessible except from the water. The cradles positioned the bottom of the vessel three stories above the ground, with a road running under the cradles. The cramped position, and cranes available, made definite size and weight limitations on any one piece.

This summarizes the set of circumstances which faced the turnkey project group which had to develop a plan that satisfied all these design, production, and installation restrictions, in the short time available.

The design of the scrubber is as follows:

The outer scrubber vessel wall and pressure bulkhead was chosen to be a cylinder 31-feet in diameter and 41-feet long, with dished pie segment heads on either end, for several reasons. The cylindrical vessel was structurally ideal for containing the one pound per square inch internal pressure and the weight of the packing and process fluid of the vessel. The second reason for choosing a cylindrically

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shaped vessel was that our Company had the ability to quickly and easily field fabricate, handle and join such a structure. We had gathered valuable experience by participating in moving and joining big sections on recent projects. This horizontal shaped vessel was a strong beginning, because it saved man hours and money.

The cylindrical structure was produced in three segments (Fig. 4) at a plant site a short distance upstream from the mill. The three pieces were produced with their centerlines vertical. The parts of the vessel were to be barged to the mill (Fig. 7). The three shell pieces were to then be rotated 90° so that the centerlines were horizontal (Fig. 8), and lifted into the three story high perch, which consisted of four 120° cradles (Fig. 9). Three parts made acceptable sized pieces for handling, and were also as big a piece as could be produced in the field factory building available. The three piece division of the cylinder worked out excellently.

This is the basic design approach which was taken to confront the design problems. We tried to incorporate into the design and planning consideration of the process, fabrication, handling and installation, good engineering principles, and cost. We tried to integrate these considerations to produce optimum design.

There are several areas of interest worthy of detailed discussion. First, the job started at a very fast pace, out of necessity. Three days after receiving the job, production drawings were in the shop; six weeks after starting, the pie segmented dished end domes were assembled at the field plant, and being filament wound onto the cylindrical scrubber vessel sections (Fig. 4).

The field plant was of special interest, the site being several miles up-stream of the mill, on the mill side of the river. In less than six weeks a large awning was converted into a well organized plant. Utilities were brought in, a paved floor was installed, tools, machinery and raw materials were delivered, and set up. Sides were added to the building so that the plant environment could be better controlled.

The field plant was used for producing the outer shell of the scrubber, then installation of certain internal sub-assemblies. These sub-assemblies were produced at the Bellingham plant, and at a sub-contractor's plant. This distributed the work load in such a way as to minimize the total project time, given the resources available. This effective production organization was a strong influence in the smooth progress, and success of the total project.

The internals for the scrubber were completely FRP, and a very interesting part of the project. These internals primary purpose was to contain and support the packing (Fig. 5), and process fluids and carry these loads to the lower cylinder wall, then to the cradles. The internals also directed the flow of gases through the packing. A secondary purpose for the internals was to give overall longitudinal and lateral strength to the vessel and to provide support and stability to the outer cylinder skin. During the moving, the internals took on a third role. Support was necessary at various points throughout the structure during movement, and joining of the vessel. Portions of the internals were designed to give extra support necessary to the segments of structure and to specific high stress lifting points. The packing structures which were installed in these areas were also designed so that the position of the center of gravity and total weight could be controlled. If the center of gravity was to have moved into certain areas of the structure, moving of the structure would have become very difficult. Also, it was rather difficult to keep the weight of the entire structure low enough so that one of the largest cranes in the Puget Sound area could lift the parts into place.

All the structure which was to be in the central area of the vessel, which would restrain the packing areas from moving horizontally, could not be installed until the vessel had been lifted into place, for reasons of weight and center of gravity control, as just mentioned. This consisted of a fairly large portion of the internals. These internals then had to be installed very quickly after installation of the vessel, so that the remainder of the project would not be held up.

The use of the internals for added strength and reinforcing for moving, center of gravity and weight control, were important considerations for the system design.

The lifting and rotating of the vessel is of special interest. The vessel segments were produced with the centerlines vertical, yet the parts were to set in the cradles with centerlines horizontal. This obviously indicated that the lugs (Fig. 6) not only lifted the vessel, but had to allow rotation (Fig. 8) of the vessel in a smooth, controlled, predictable, manner. As indicated earlier, internal parts were juggled to position center of gravity and control weight. This made the moves possible if the lugs would support the mass and allow it to rotate smoothly. The lugs were thin hinges which were designed to stay in as close as possible to the wall to minimize the bending moment on the tank shell, yet be strong enough to support 30,000 pounds each safely (Fig. 6). These lugs were imbedded in the vessel wall in a highly reinforced laminate. This laminate was a total of 2-13/16" thick of steel plates and FRP. This thick laminate transferred load into sections of internal structures and outer shell.

This project was unusual in its size and complexity. The job demanded the skill, effectiveness, and dispatch of an experienced total project oriented company. As before, past experience made this project's success possible, and this experience prepared us for yet bigger and more complex projects in the future.

CHIMNEY LINERS

Large industrial chimney columns have been built since the early 1800's. The earlier columns were made of brick; inside this outer structural column there was a corrosion resistant brick lining. The brick chimneys, and linings, are very susceptible to damage from tensile loads caused by wind and earthquake. What really holds a brick structure together is gravity with mortar sealing around each brick. Traditionally this mortar was damaged by the corrosive environment inside the chimney and leaking would start through the mortar to the outside of the lining of the chimney. Later, about 1904, the first concrete chimneys were built. These new chimney columns were very strong structures, but were still lined with brick, and had the same problems with the lining that the old brick stacks had.

The concrete chimney columns are very strong, reliable structures. For example, after the atomic bomb was dropped on Hiroshima almost the only structures left standing were several chimneys. In corrosive applications there has been, in the past, no reliable strong liner available which would start to compare with the strength and reliability of the outer chimney column. As exhausts from factories were becoming wetter and more corrosive as a result of scrubbing, a new durable, reliable, highly corrosive resistant lining for chimney columns was needed.

Early in 1973 a new 300-foot chimney was being installed at Port Angeles, Washington, at a pulp mill which would have wet corrosive gases passing up this new stack from the Absorber Cooler discussed earlier. The liner was to be 270-feet tall, 7'6" diameter, supported vertically at the 70-foot level, and with lateral support at the 160'6" level and 287' level (Fig. 10). There were to be two 4'6" x 12' breechings made, one just above (Fig. 11) and the other just below the vertical support at the 70-foot level.

This design was such a simple application for filament wound structures, that it was a very straight-forward job of design and fabrication. The liner had to support 230-feet of itself in compression, at the 70-foot level. With lateral support at about every 100-feet, no wind loads, and very small earthquake induced lateral loads, and small external pressure to design for, a very conservative structure was easily obtained. Both the structural wall and the corrosion resistant lining of this liner was produced from polyester reinforced with glass fiber. This is a very commonly used laminate, of proven reliability. This FRP stack liner certainly appeared to be an optimal solution to the lining of a chimney column such as this.

The liner sections were produced at our home plant, and the 60-foot sections were transported to the jobsite. The installation was accomplished by lifting the liner from the top, during assembly of the pieces in the bottom of the chimney (Fig. 11). The top 40-feet of liner, with rain cover, was produced in one piece, with a weight of 6,500#. The installation was completed by lifting this final piece into place by helicopter, (Fig. 12). The high strength-to-weight ratio of FRP, and, as a result, light weight of the filament wound structure, simplified the installation of the lower sections and made possible this convenient helicopter lift of the large final top piece.

This chimney lining project provided design and installation experience which was to prove very valuable in the future design of large chimney liners. In addition, FRP appeared to be a reliable, strong, and highly corrosive resistant lining for chimneys.

THE TALLEST CHIMNEY LINER IN THE WORLD

If chimneys are high enough, their plumes are capable of penetrating through temperature inversion levels and allow factory, smelter, or mill gases to escape above the stagnant atmospheric conditions beneath the temperature inversion. Recently, a 1,200-foot high by 124-foot diameter at the base chimney was designed for this purpose. By the nature of the corrosive wet exhaust gases, and the necessity of the chimney system being very reliable, a FRP liner was chosen. This liner was to be 1,215-feet tall and 24-feet in diameter.

Traditionally the chimney liner is supported from the base. The initial design of this large FRP liner was with support from the base, which produced a very thick wall section. The weight of the base supported liner would have been at least three times that of the final design used. This would have caused the cost of the liner to be prohibitive. This was just one of several reasons why this base supported design bordered between unreasonable and impossible. This was quite obviously not an acceptable design approach.

The basic problem with the base supported chimney liner was compressive elastic stability. The longitudinal flexural modulus at elevated temperature, the large diameter, and the high compressive stress at the base dictated this very thick wall to resist elastic instability in compression. Because the modulus and diameter could not be conveniently changed, the height of a section must be reduced to drop stress levels. This philosophically means, that at least for chimney liners, and probably for most structures, given the ultimate stress and modulus of elasticity, there is an ultimate unsupported structure size. This is especially true when the structure is in compression and has small curvature (large diameter). A length of 300-feet per vertical support with lateral support every 100-feet (Fig. 13) was chosen because of historical precedent from the earlier FRP chimney liner discussed (Port Angeles), and it fit nearly evenly into 1,215-feet. Primarily this length greatly reduced the stress, thus thickness, and was a good compromise between convenience and cost.

The next thing to be considered was the location of the vertical support for this 300-foot long tube. When designing a structure such as this, there are only two basic methods of failure. The first basic mechanism by which failure could start is fracture or ripping of the material. The second method of initiation of failure is by buckling or wrinkling of the structure because of excessive compressive deflections. This is called elastic instability, which is dependent on geometry and modulus of elasticity. Much of the time elastic stability is the limiting factor in larger FRP structures. If there is no compression in the structures then there can be no elastic instability. Therefore the vertical support was placed at the top of each 300-foot section. This might seem quite trivial, but a major batch of problems are eliminated by hanging the liner from the top in this fashion. This puts the entire (nearly) structure into tension and provides greater structural stability. Trusses at this top position transferred these compressive loads to the strong concrete external

column which is much more able to handle these compressive loads. This provides an optimal piece of equipment from the structural aspect and is a simple and reliable design even in extreme conditions. This also makes use of the strongest aspects of the FRP liner and the concrete chimney column, to produce a strong total package.

The installation is simplified by the 300-foot section lengths and the lightness, strength, and flexibility of the FRP liner. Lifting is done from the top vertical support, which is also the final permanent support system. Lifting could be potentially a problem, but again by the top supported sub-assembly design we have the lifting lug built into the system at the proper spot. Each sub-assembly is lifted from the top and the 33-foot liner sections are installed at the bottom. When a 300-foot sub-assembly is completed, it is lifted up into its position in the chimney column and permanently secured in place. This completely finishes the liner installation to the bottom of that sub-assembly. Assembly of the next long section would then start on the chimney floor.

A well planned organized field plant was again, as in the past, a strong asset. This field plant was to produce about thirty-seven cylinders 34-feet long, 24-feet in diameter, and weighing 16,000 pounds each. The building we constructed on site was the quality of a permanent plant building, which contained the resin storage, mixing and production operation.

This large chimney liner project was changed from a very difficult project into a straight-forward job by the practical application of powerful management and engineering tools to produce a substantial design and a smooth functioning turnkey project. Recent experiences as described throughout this paper were all prior to this chimney lining. Each job, almost without our planning, prepared us for the next more difficult job. Each past problem had to be solved in a thorough, complete fashion, so that this solid experience could be applied to new, different and more advanced projects in the future. In addition, each of these projects benefited from the fundamentally powerful efficient turnkey project approach in which project management, engineering and production all come from under the same roof.

CONCLUSIONS

These last few years have been exciting years, filled with today's new problems and difficulties, and whose solutions are the cornerstone of tomorrow's productivity. Through good management of research and development, design problems are solved, new products emerge, and what was difficult or impossible yesterday becomes straight-forward today. With top quality production management, equipment, and workmanship, these new ideas have become the front line pieces of equipment in our nation's plants, mills, and smelters.

WINSTON J. RENOUD

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Worked at Boeing in Research and Development, in the Propulsion and Mechanical Laboratories, for the Commercial Airplane Division, and left Boeing to become a staff member in the Physics Department of Western Washington State College. Currently employed at Ershigs, Inc., in Engineering, and Product Research and Development.

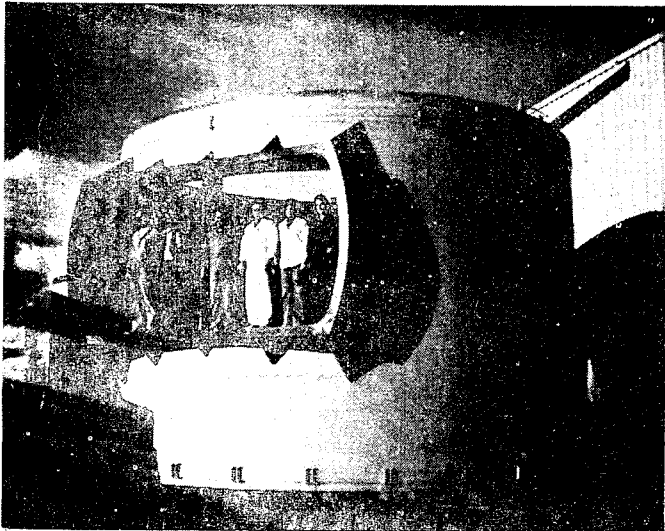


Fig. 1. Filament wound bottom section of Absorber-Cooler, ready for shipping.

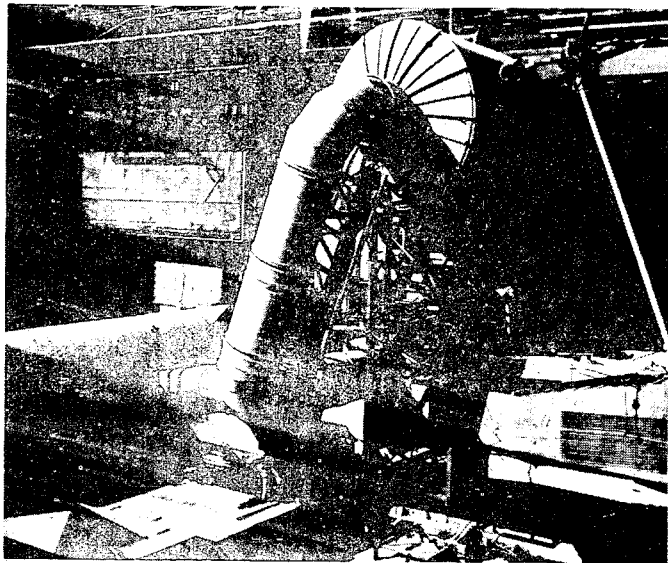


Fig. 3. Absorber-Cooler, Water Seal, and Ductwork nearly complete.

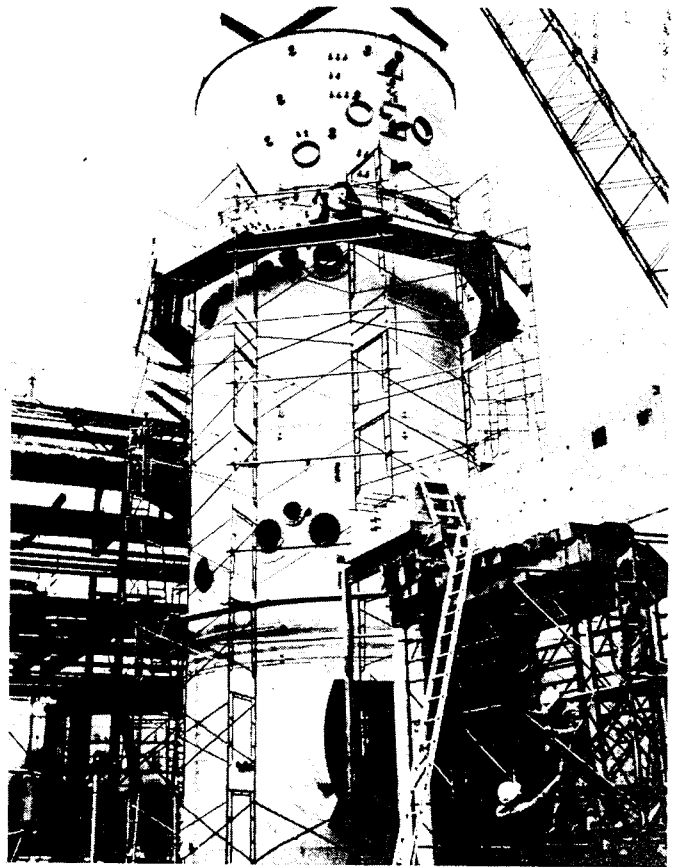


Fig. 2. Absorber-Cooler during assembly.

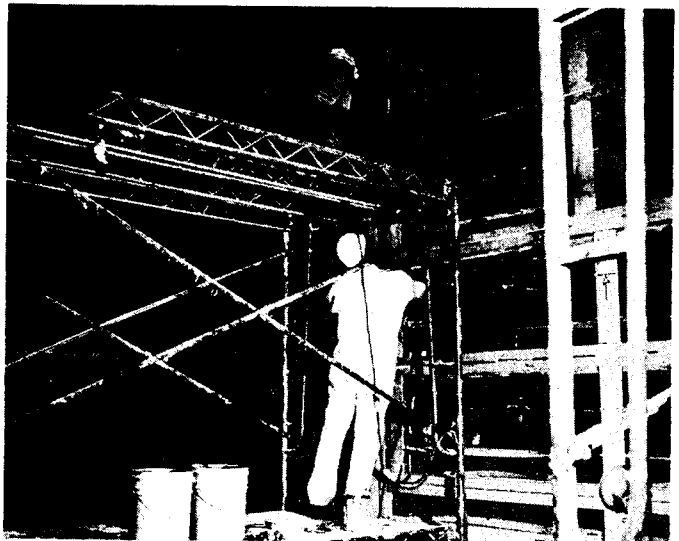


Fig. 5. Start of installation of FRP grating over floor beams and baffle system, center section, Hoquiam scrubber.

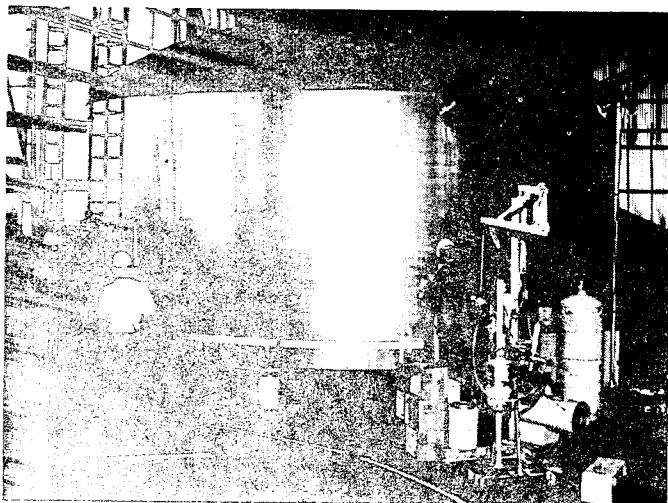


Fig. 4. Filament winding of Hoquiam scrubber section.



Fig. 6. Scrubber hinged lifting lug.

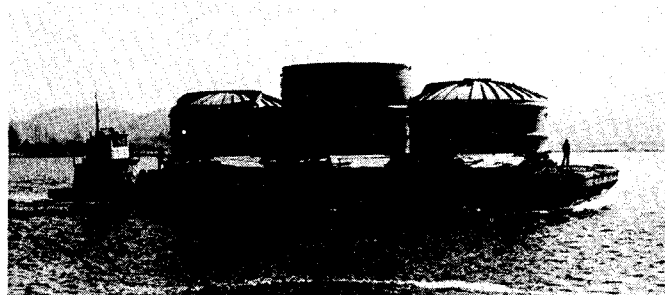


Fig. 7. Barge transport of Hoquiam scrubber segments.

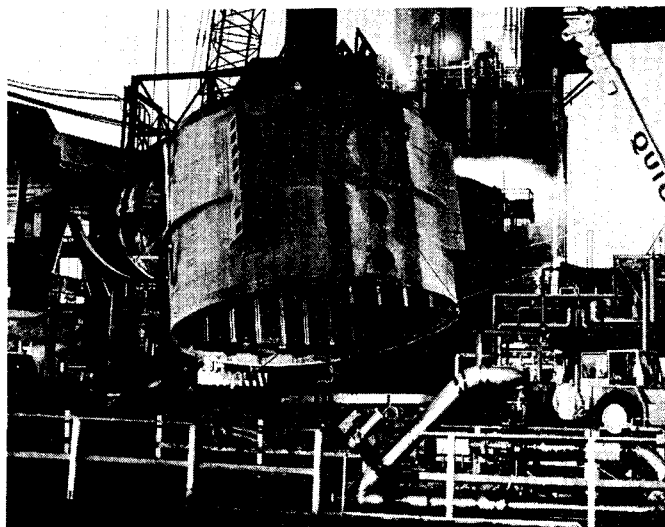


Fig. 8. Rotation of Hoquiam scrubber sections, just prior to positioning parts in cradles.

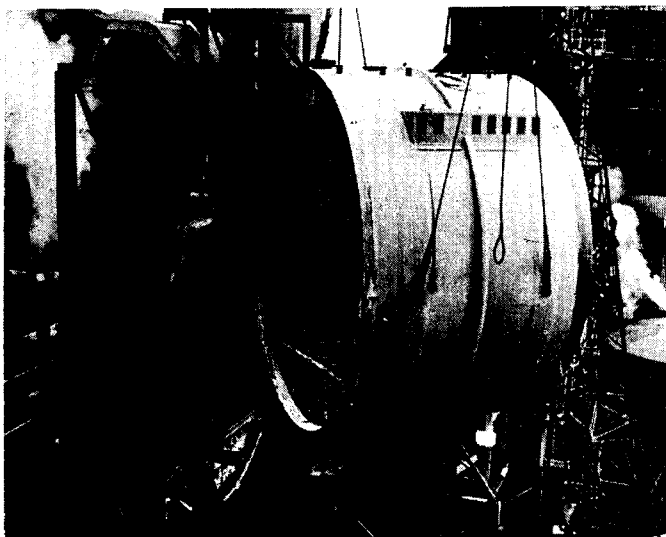


Fig. 9. Hoquiam scrubber during positioning of center section.

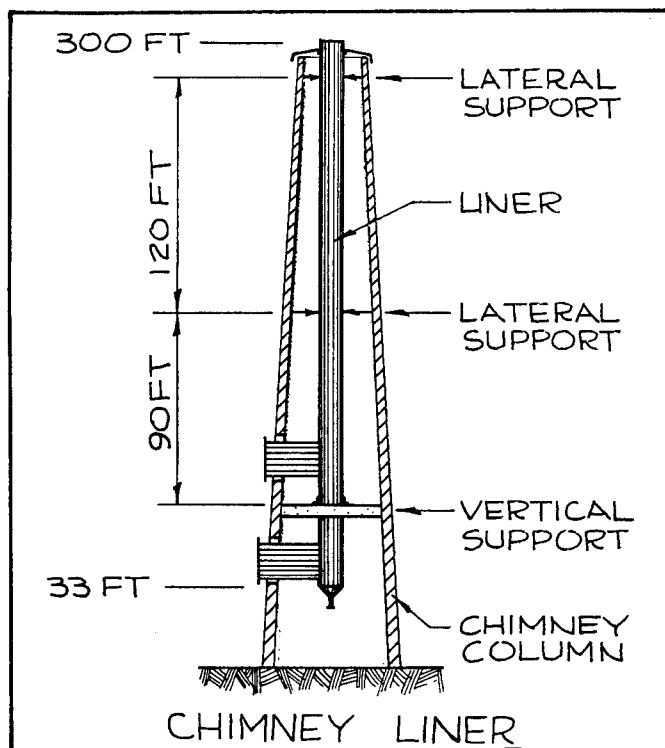


Fig. 10. Basic arrangement, Port Angeles, 300-foot FRP Chimney Liner.

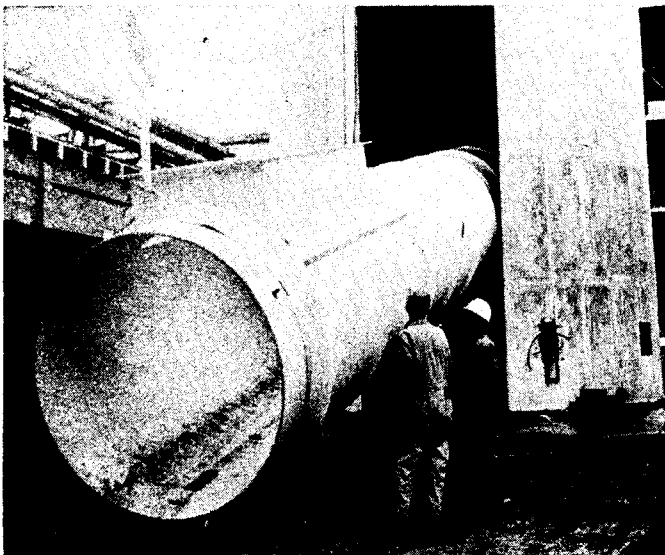


Fig. 11. Installation of bottom 230-foot of Port Angeles Chimney Liner.

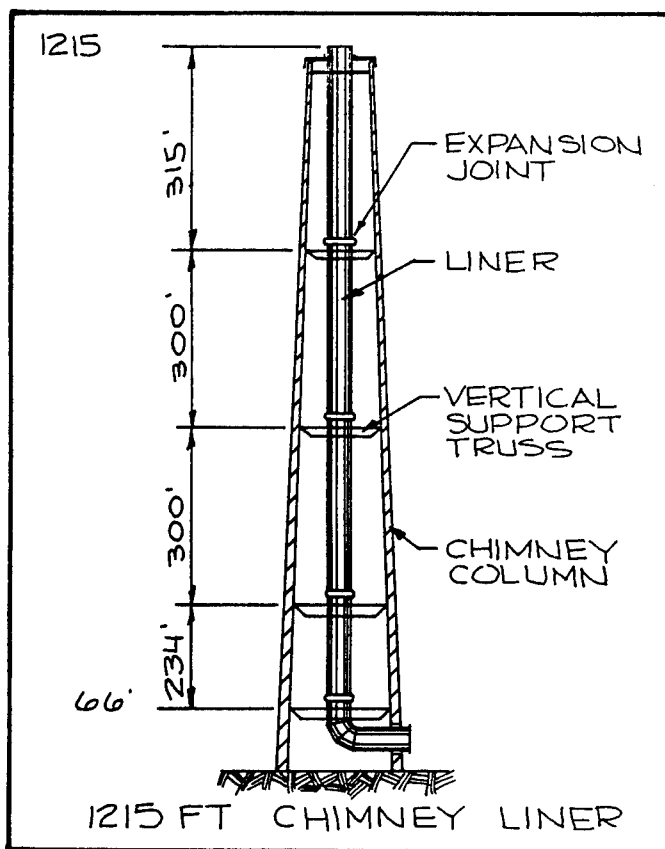


Fig. 13. Basic arrangement of 1,215-foot filament wound chimney liner, currently being installed in Utah.

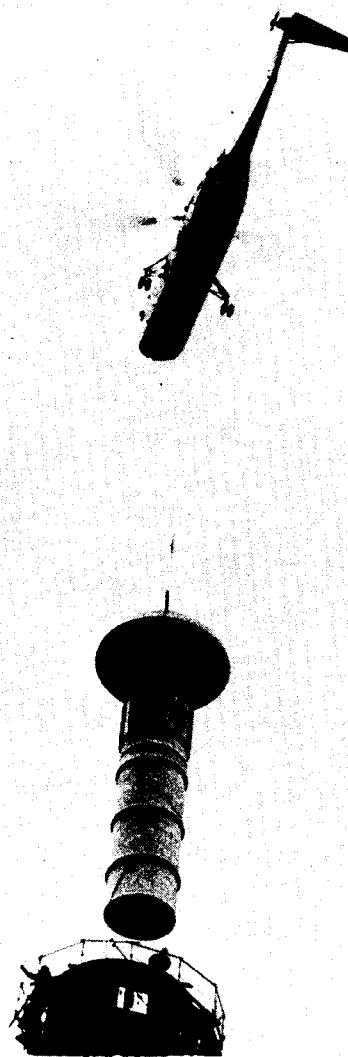


Fig. 12. Installation of top 40-feet of liner and rain cover by helicopter, Port Angeles, Washington.

REINFORCED PLASTICS — THE BRIDGE TO LOW COST POLLUTION CONTROL

BY

THOMAS F. ANDERSON, RAYBURN F. STAVINOH
DAVID L. RUSSELL

ABSTRACT

The specific ways in which four types of industries and a municipal waste disposal operation are using reinforced plastics in their pollution control program for water and air are detailed in this paper. Included are comparative costs, installation times, and other key factors that made reinforced plastics the most suitable construction material for many of the projects.

INTRODUCTION

When some of the leading companies in pollution control in the petroleum and petrochemical, pulp and paper, metal smelting and refining and chemical industries began taking steps to reduce their emissions to the environment, several facts became obvious while handling the materials which had previously been diluted with air or water and then disposed of. They found that (1) many of these wastes had to be concentrated in order to be treated effectively, (2) these concentrated wastes created special corrosion problems because they often consisted of strong acids or alkalis coupled with organics and, (3) the more conventional construction materials used in the processes themselves often were completely prohibitive from a cost point of view when applied to the large special structures used in the waste treatment and disposal operations. In fact, in some cases, the use of the more conventional high cost materials of construction would have thrown the economics so far out of line that the only answer would have been to shut down the plant or process. The high cost of controlling the emissions would be so great as to make the plant economically infeasible. An equally difficult situation exists for a municipal complex which needs to burn a great many of the waste materials that it accumulates. Because many of the waste materials contain halogens, the burned gasses that must be scrubbed will contain halogen acids, such as hydrochloric and hydrobromic that corrode even the better grades of stainless steel very rapidly. How reinforced plastics provided a low cost bridge to these people in helping them effectively solve their pollution control problems is detailed in the discussion of the unique approaches that were made by some of these industry leaders. It is hoped that in understanding their problems and solutions, many companies in the same or related industries which are facing similar clean up problems will be able to economically solve their own pollution problems.

DISCUSSION

To facilitate companies with similar pollution control problems in finding the information on the process most pertinent to their own needs, we have broken down the discussion of the engineering studies and final solutions by the type of industry. Within that industry, the breakdown by the chemical environments being cleaned up is made. In each case, the alternate materials which would handle the chemical

environment are examined. Their relative costs and the importance of other factors which also pointed to reinforced plastics as a major solution to a tough problem are covered in some detail. The places where reinforced plastics are helping to handle corrosion problems in each of these industries could occupy almost a book in its own right so that these discussions are necessarily very brief summaries of only certain parts of the pollution control efforts in each of these industries.

PETROLEUM AND PETROCHEMICAL

Environmental Protection Agency

A major problem the petrochemical industry is experiencing is the treatment of waste effluents. Eight major petrochemical companies (PPG, BASF-Wyandotte, Foster Grant, Allied Chemical, Monochem, Vulcan Materials, Dow Chemical and Hooker Chemical) are cooperating with the EPA and Louisiana Commerce and Industries Commission in building a cooperative pilot plant effluent waste treatment system. The concept of this unique system was formulated at the Robert S. Kerr Environment Research Laboratories in Ada, Oklahoma. The eleven tanks, reactors, and separators were built of FRP fabricated from Derakane® 470 vinyl ester resin. Cost was a major reason for turning to FRP, but another very important reason was that the pilot plant unit needed to be constructed of a material that could easily be scaled up to full-size production units. The material had to have characteristics that made it easily repairable in the field. Because the unit is portable, the weight factor becomes very important. The equipment will be exposed to tough environments of acidic water, chlorinated solvents, and aromatic organics. Figure 1 shows the anaerobic container and Figure 2 shows a series of aerobic-anaerobic filters.

MUNICIPAL WASTE

Southeastern Oakland County

The problem of disposing of municipal wastes has actually become a twofold problem. Besides just getting rid of the wastes, it must be done in a manner that will not pollute the air with decomposition products. The Southeastern Oakland County Incinerator Authority is accomplishing this by equipping their incinerator system with RP scurber-demister systems to clean up the flue gas coming out of the furnace. Figure 3 shows the 40' high, 14' diameter demisters before they were installed.

The combination of cost plus the corrosive environment played the major role in having the decision made to use RP. Materials such as Hastelloy "C" would handle the environment, but their cost would be prohibitive. Rubber lined steel could not be used because temperatures during upset conditions would be far beyond what the rubber could handle. The system will be exposed to hydrogen chloride gas and entrained hydrochloric acid plus water vapor at 165°-175°F. The life of stainless steel would be severely limited by chloride stress corrosion. Reinforced plastic lined steel would handle the environment, but fabrication problems prevent it from being used. Taking all factors into account, reinforced plastics becomes the most suitable material of construction. The two scrubbers and demisters were fabricated from Derakane® 470 vinyl ester resin. Figure 4 shows a schematic diagram of the scrubber-demister system.

PULP AND PAPER

International Paper Company

When the International Paper Company built new facilities for manufacture of pulp, they decided to take a revolutionary step in the direction of reducing costs and cutting down pollution at the same time. The industry methods in the past had consisted of having the pulp washing step inside a building and many different materials had been used for open hoods which could even be aluminum since the corrosive elements of water vapor, chlorine gas, chlorine dioxide and

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caustic all were diluted with large volumes of air due to the open construction. International Paper Company engineers decided to build the pulp washing step completely outdoors eliminating the cost of the building. This necessitated having totally enclosed washer hoods to prevent dirt of any kind in the atmosphere from getting into the pulp. Examination of the materials of construction that would stand up under this closed hood type system eliminated rather quickly the main candidates for the corrosive environment; these being Hastelloy "C" and titanium with costs that ran from 4-12 times the cost of the reinforced plastic hoods made out of Derakane® 411-45 vinyl ester resin which was the resin selected for the application. The hoods which are shown in Figure 5 and the downdraft duct fume takeoffs were made of the same material. The 30" and 36" diameter headers which collected the fumes from these hoods are shown in Figure 6.

The performance of this no-building, totally enclosed washer and fume handling system was so successful at the Mobile mill that an entirely new plant which was put in operation in Texarkana, Texas in 1972 and 1973 used the same system and again Derakane 411-45 was used for the construction of all the reinforced plastics fume handling equipment.

Rayonier Canada

Three 13'8" diameter, 65' high cooling towers were installed at the Rayonier Pulp Mill in Woodfibre, B.C. to handle the clean-up of kraft mill gases and particulates from the recovery boilers (Figure 7). The design of the reinforced plastics plus the internal supports at the top of the towers made them capable of withstanding 100 mph wind and Zone 3 seismic loads. Figure 8 shows two large sections before assembly. The entire structures, including the complicated series of internal piping, trays, and beams were fabricated with Derakane 411 vinyl ester resin. Reinforced plastics were chosen as the construction material, not only because of its capability of handling the environment, but also because suitable metal materials were priced far out of range. Weight reduction and easy installation were also primary reasons for using RP. The large structures were transported by barge and a considerable amount of handling was involved in getting the equipment in place.

METAL SMELTING AND REFINING INDUSTRY

Cominco Ltd.

When the acid-proof brick lined concrete stack at Cominco Ltd. in Trail, B.C. started to fail after many years of excellent service, their Engineering and Management groups were faced with a real tough problem. The stack which was 26' in diameter inside at the base, and tapered to 21' in diameter at the top, was 400' tall. On investigating the cost and time factors, they found that the relining of the present stack would have it out-of-service for a period of 8-12 months. It was estimated to cost $\approx$ \$ 3/4M. Another approach checked out was that of continuing to operate with the stack then in existence and build a new acid-proof brick lined stack of smaller size. When the new stack was built, the fume dispersing would then be transferred over to the new stack. This approach would eliminate the need to operate the plant with a serious pollution problem for a period which might run as long as one year. However, the cost estimate on this smaller all new stack was well over \$1 million.

It had been determined that because of pollution control measures which had been installed in the plant, the volume of gasses had been dropped from 500,000 cu. ft. per minute to a rate of only 150,000 cu. ft. per minute or sometimes even less. This made it very desirable in order to still get high gas velocity, and thus good dispersion in the upper atmosphere, to decrease the diameter of the stack. A reinforced plastics stack, 11' X 3" in diameter, was estimated to cost $\leq$ \$ 1/2 M installed. Cominco Ltd. went about finding out enough information to determine what the proper resin for construction should be. As a result of their checking, it was decided that the stack itself would be

made of Derakane 510 fire retardant vinyl ester resin. The decision was made to use the old stack with the brick torn out as a supporting structure and to install the inner RP stack from the bottom up by the unique system that is shown in Figure 9. Figure 10 shows the actual installing of one of the 45' long stack sections. The total job was carried out in a little over four months with the major part of this time involved in tearing out the old brick and putting in the steel structures. The actual reinforced plastics installation took three weeks time and total cost for the project ended up being even less than estimated or a net savings to Cominco, Ltd. in both out-of-service time and many hundreds of thousands of dollars. Figure 11 shows the completed stack.

CHEMICAL

FMC Chemicals

The most effective waste control system with the most economical maintenance was the goal FMC Chemicals was aiming for when the decision was made to use RP equipment in their chlorine-caustic neutralizing tower in Squamish, B.C. The presence of chlorine gas, hydrochloric acid, and caustic, along with the formation of hypochlorites, make this a very corrosive environment. Other materials that would handle the job were not even considered because of cost. The time to get this equipment into service was also a key factor. It was determined that the RP equipment could be fabricated and installed faster than equipment made from the more expensive materials. The light weight of the 43'6" high, 5'6" diameter tower minimized the transportation and installation difficulties. The tower, the support plate, weir trough distributor, and related liquid and gas piping and ducts were fabricated with Derakane 411 vinyl ester resin. Figure 12 shows the complete unit.

Dow Chemical USA

The problem of treating very large volumes of waste effluents to bring down their BOD to acceptable levels before they can be discharged into streams and rivers is plaguing the chemical industry. The Dow Chemical U.S.A., Texas Division, is treating ten million gallons per day in two 15 acre biological solids waste ponds, (Figure 13). A special strand of bacteria was found that would biologically degrade the organic wastes. Compressed air is bubbled into the pond to furnish bacteria with required amounts of oxygen to do its work. The bubbling air is also used to constantly mix the ponds. The air handling piping (Figure 14) operates at 180°F and 10 psi. The two sections, both 1100' long, one being 24" in diameter and the other 30" in diameter, are constructed of RP fabricated from Derakane 411 vinyl ester resin. All the equipment is exposed to a salt solution and high humidity conditions. The major reason for using RP was because metal piping would require constant maintenance. External metal piping has shown severe corrosion after only a short time in operation. It was also feared that the titanium dioxide pigment in the coatings required for this maintenance would have an adverse effect on the bacteria.

SUMMARY

To facilitate the finding of pertinent information on specific applications, the following table has been formulated as a summary to this paper.

CONCLUSION

In conclusion it has been shown why reinforced plastics is the most suitable material for the construction of much pollution control equipment. In some cases, it was the only reasonable material that could be used because of a variety of factors. The basic trend of this paper has shown how reinforced plastics has lowered the cost of pollution control for several industries because of (1) lower material cost, (2) lower maintenance cost, (3) equipment design and (4) relatively easy and fast installation.

THOMAS F. ANDERS

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He has worked in Research, Development and Commercial Development on: plastic explosives and propellants; polyester resins and molding compounds; phenolic furane, epoxy and polyester systems for corrosion resistant and aerospace applications; Teflon for wire insulation and tape; laminates and molded parts for electrical insulation.

He has publications on "Plastic Materials in Structural Applications" and "Polyester Fiber Glass Equipment for Corrosion Applications".

He holds patents on polyester stabilization, polyester molding compounds, plastic tank trucks, methods of extracting glass fibers, insulated nestable containers and methods of making same.

He is a member of ACS, Reinforced Plastics Division of SPI, NACE, ASTM, AICHe, SPE, IEEE, TAPPI.

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<u>Industry</u>	<u>Equipment</u>	<u>Environment</u>	<u>Key Reasons for Using RP</u>	<u>Alternate Materials and Approximate Cost Factors</u>
Petroleum and Petrochemical Environmental Protection Agency	Eleven tanks, reactors, and separators	1. Acidic water 2. Chlorinated solvents 3. Aromatic organics	1. Scaling up to production unit must be reasonable from a cost and fabrication point of view. 2. Must be easy to field repair. 3. Must be lightweight because the unit is portable.	1. Reinforced Plastics - \$35M 2. Hastelloy "C" - \$400M 3. Titanium Lined - \$250M 4. Lined carbon steel eliminated because of fabrication problems.
Municipal Waste Southeastern Oakland County	Scrubber-Separator (2 units) 14' diameter and 40' high.	1. Hydrogen chloride gas 2. Hydrochloric acid entrained 3. Water vapor 165°-175°F (450°F at upset)	1. Suitable metal alloys too expensive. 2. Fabrication problems with lined steel. 3. Chloride stress corrosion problem with stainless steel. 4. Rubber lined steel could not handle upset conditions. 5. Metals would have higher maintenance cost.	1. Hastelloy "C" - 6-8 times more cost.
Pulp and Paper International Paper Company	Washer hoods, 12' X 6', downdraft duct	1. Water 2. Chlorine 3. Chlorine dioxide 4. Caustic	1. Other materials too expensive. 2. Reduced building cost. 3. Rapid installation.	1. Hastelloy "C" - 6-8 times more cost. 2. Titanium - 5-10 times more cost.
Rayonier	Scrubbers, 65' high and 13' X 8" in diameter.	1. Kraft mill gases 2. Particulates from recovery boiler	1. Other materials too expensive. 2. Easy installation. 3. Weight factor	1. Titanium - 5-10 times more cost. 2. S/S only marginally acceptable.
Metal Smelting Cominco Ltd.	Stack, 400' high and 11' X 3" in diameter.	1. SO ₂	1. Alternates more expensive. 2. Down time had to be within reason.	1. New brick stack - " 2. New brick lin. 3. RP liner
Chemical FMC Chemicals	Neutralizing tower, 43' X 6" high and 5' X 6" in diameter.	1. Chlorine gas 2. Hydrochloric acid 3. Caustic	1. Cost of other materials too high. 2. Time element was of highest importance. 3. High pH and presence of hypochlorites.	1. Hastelloy "C" - 6-8 times more cost. 2. Titanium - 5-10 times more cost.
Low Chemical	Piping for biological waste pond, two sections 24" and 30" in diameter, each 1100' long.	1. Air - 180°F, 10 psi 2. Salt solution 3. High humidity	1. Impossible maintenance required with metals.	1. Steel - lower initial cost, but the maintenance would be costly.

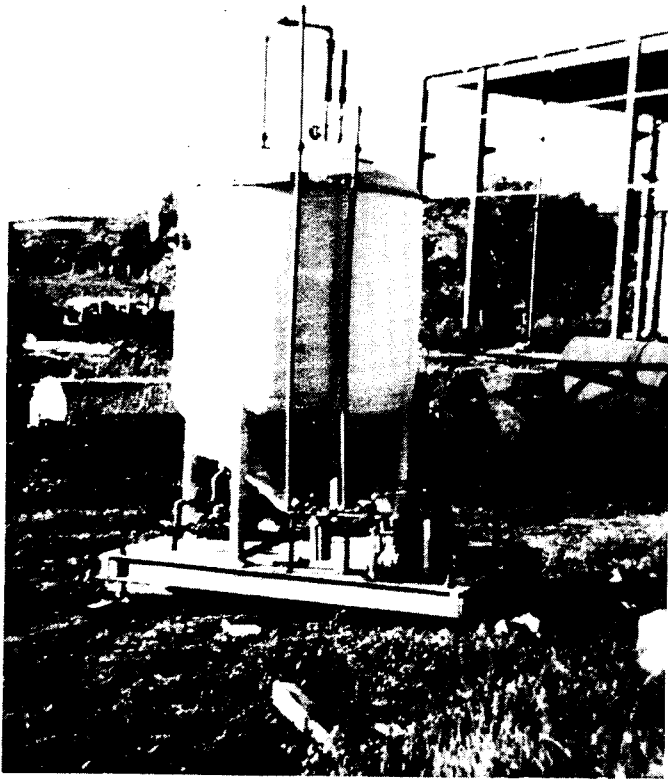


Fig. 1. EPA - Anaerobic Contactor



Fig. 2. EPA- Aerobic - Anaerobic Filters

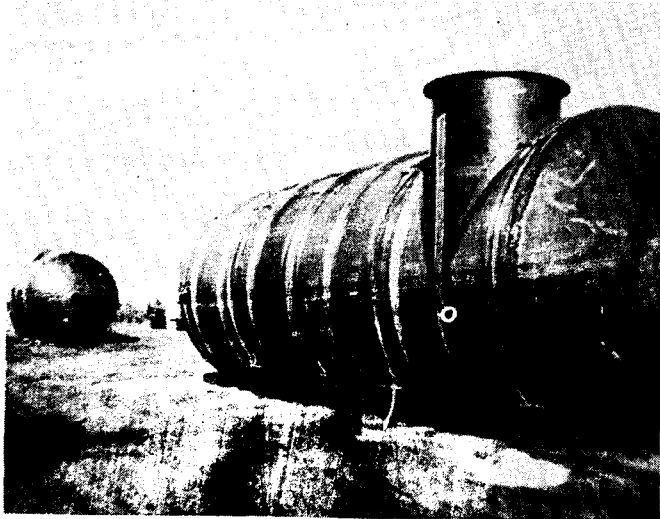


Fig. 3. Southeastern Oakland County - Demisters

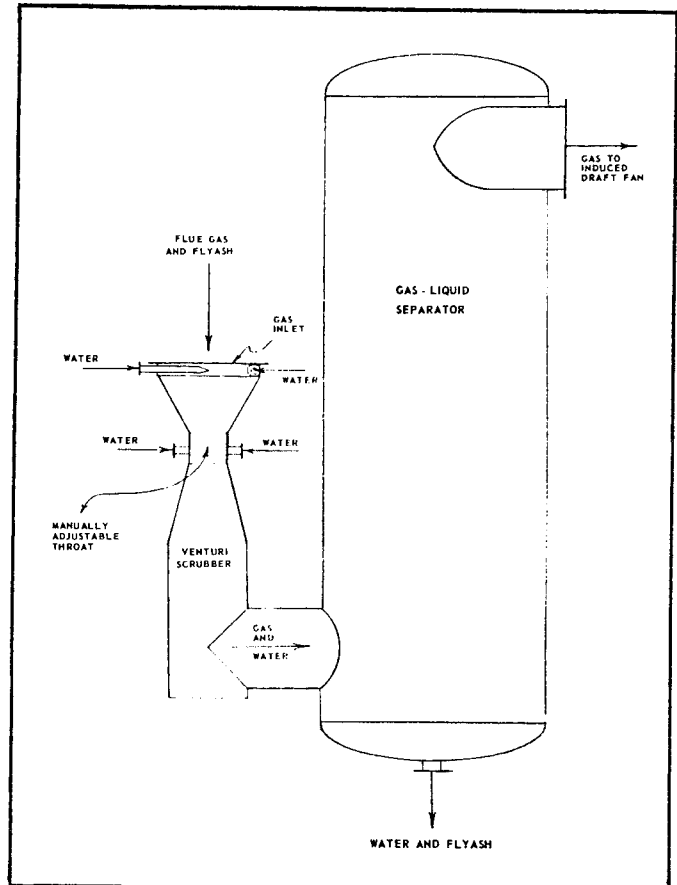


Fig. 4. Southeastern Oakland County Scrubber-Demister System

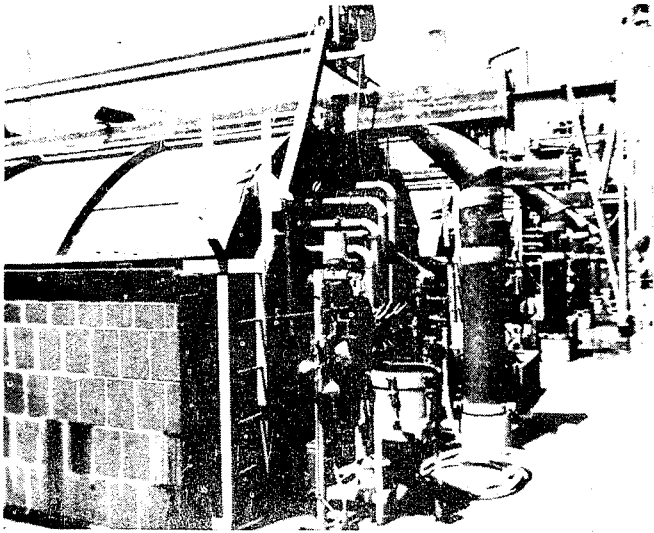


Fig. 5. International Paper Company Washer hoods and Downdraft Duct

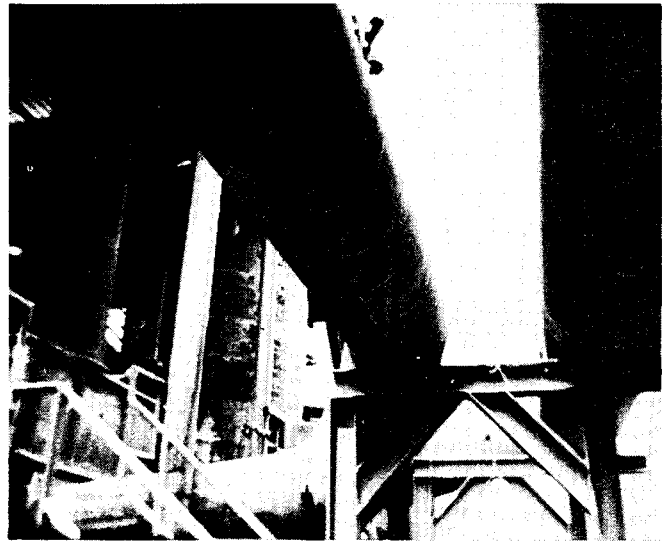


Fig. 6. International Paper Company 30" and 36" Diameter Headers

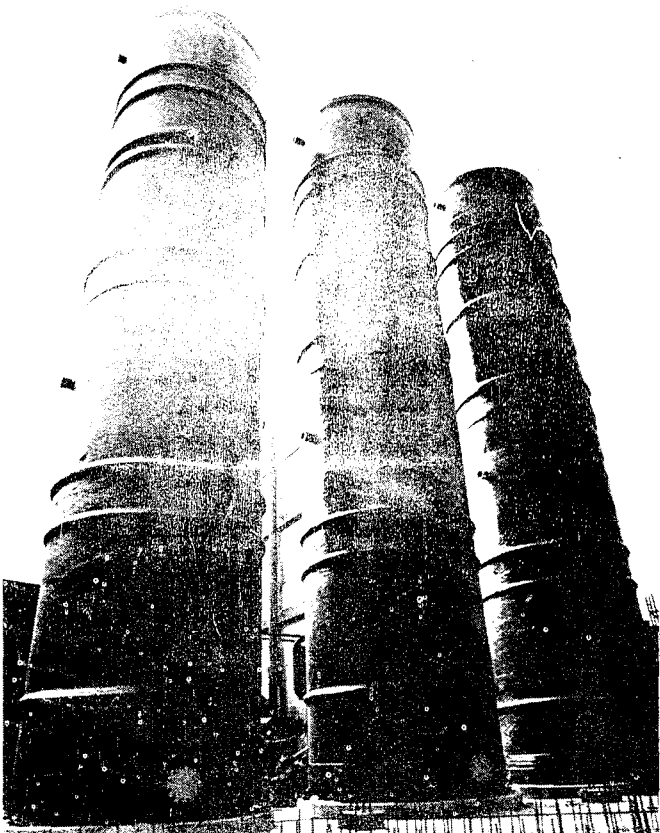


Fig. 7. Rayonier - Cooling Towers, 13'8" Diameter, 65' High

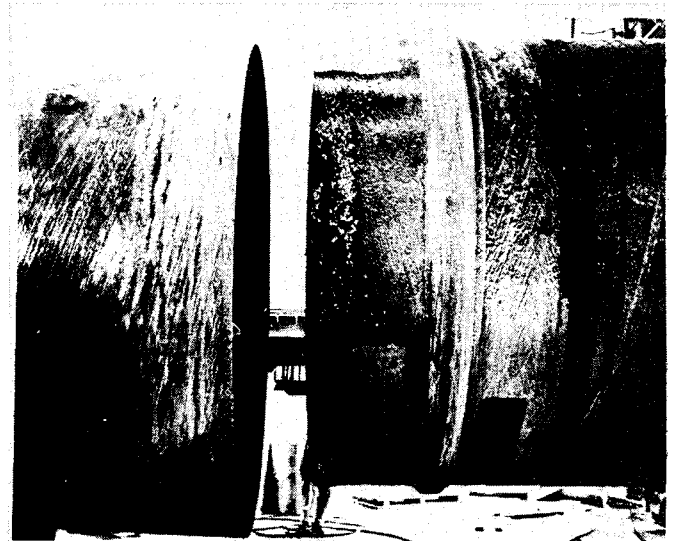


Fig. 8. Rayonier - Sections Before Assembly

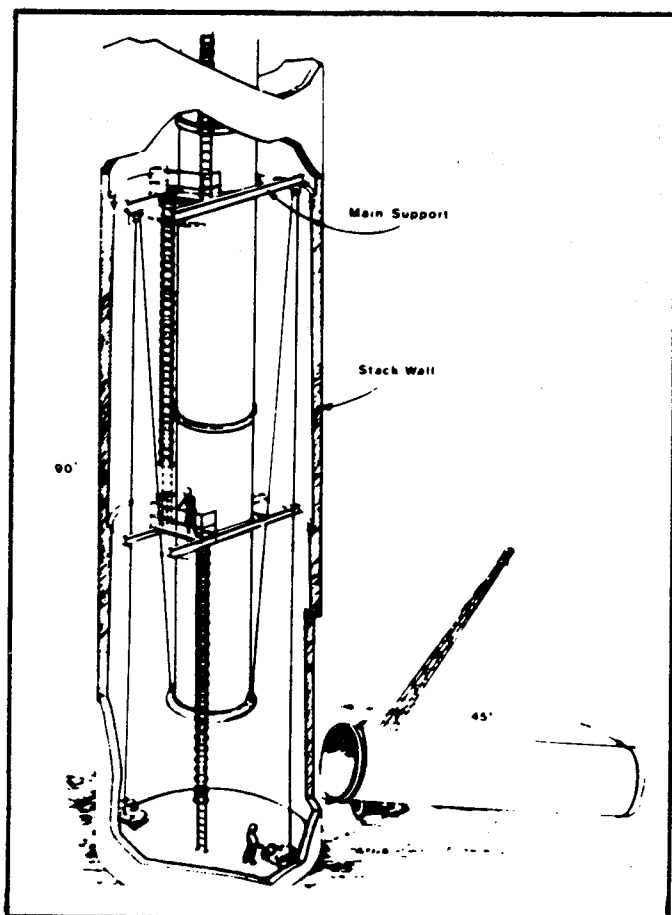


Fig. 9. Cominco Ltd. - Schematic of Installation Method

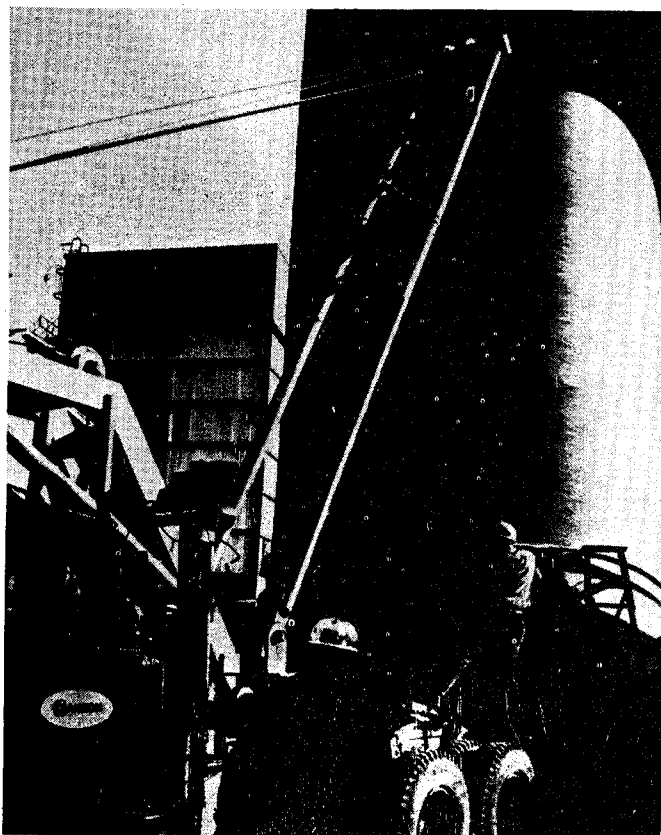


Fig. 10. Cominco Ltd. - Installation of 45° Section



Fig. 11 Cominco Ltd. - Completed Stack

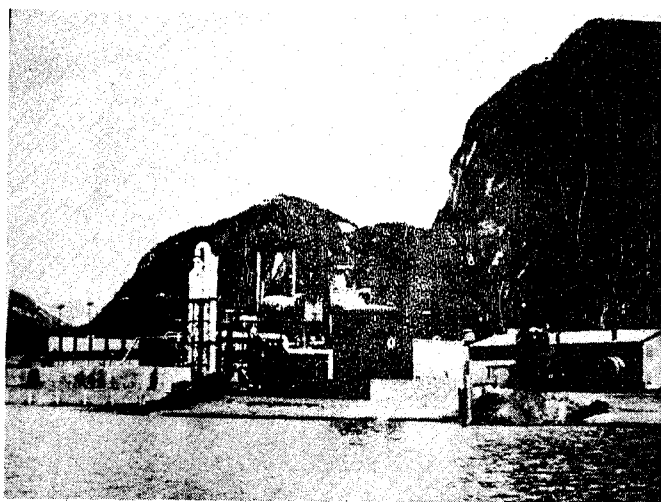


Fig. 12. FMC Chemicals - Chlorine-Caustic Neutralizing Tower

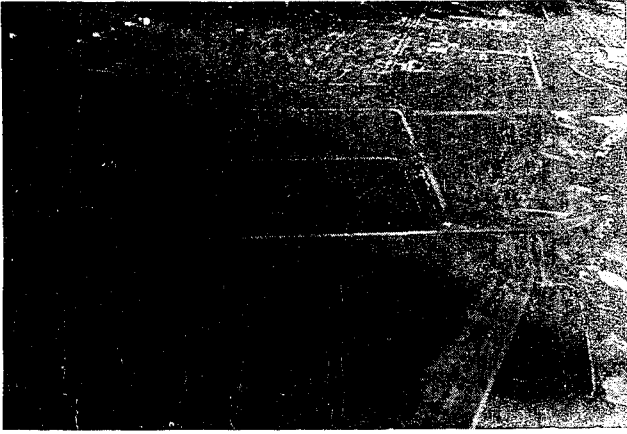


Fig. 13. Dow Chemical - Biological Solids Waste Pond

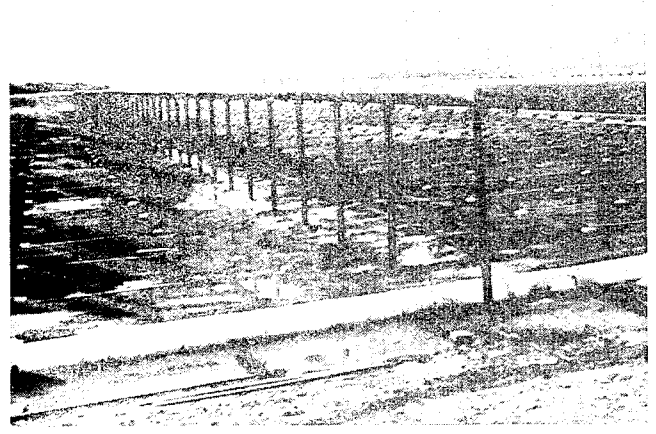


Fig. 14 Dow Chemical - RP Air Handling Piping

(Sec. 8-E) (pp. 1-13)

DESIGN CRITERIA FOR BURIED RIBBED CYLINDER

by
AGNAR GILBU*

ABSTRACT

When dealing with buried ribbed pipes, in high pressure or non pressure applications, it is very important to consider stresses as well as deflection. General guidelines for design are given. Special consideration is given to strain development on the distance of the neutral axis.

Design criteria is given for maximum internal pressure, center distance between ribs, length of ribs, stiffness factor required for various buried depths, rib height to width ratio, rib shape limitations, rib-wall bond, pipe wall thickness.

A special study of 96 different soil pipe structures was conducted using three different rib height. The maximum performance study showed that the lowest in height possible to meet the stiffness requirement had the best general performance.

INTRODUCTION

Reinforced plastic offers the design engineer an enormous freedom for optimum utilization of properties. The material can be fabricated into almost any shape desired. This freedom has been effectively utilized by engineers in many areas.

For buried structures, especially pipes, there is still much to be done before ultimate utilization of material properties will be achieved. Most pipes are made by filament winding, a process that offers a product with very high tensile strength and modulus, but which is not necessarily the best structure when exposed to other forces.

In the past, pipe design has been basically governed by deflection criteria developed by Spangler back in the later 1930's. It was used, to a large extent, as design basis for corrugated steel pipes.

For steel pipes that have the ability to yield, and thereby redistribute stresses, one did not concern oneself too much with the stress aspect, for FRP however, which cannot yield, the stress criteria are very important.

In most cases in considering the standards which govern design of reinforced plastic pipe, the stiffness factor has been given a significant place. By stiffness factor we mean: Stiffness factor (SF) = $E \cdot I$, where

E - Young's modulus of pipe

I - Moment of inertia

For non-pressure pipe it is an important factor, but should only be considered relative to pipe strength.

DESIGN CONSIDERATIONS FOR BURIED PIPES:

In order to design a buried pipe each pipe manufacturer should check his pipe for:

Deflection

Moments

Stresses due to moments

Stresses due to pressure

*Process and Product Development Manager;
Owens-Corning Fiberglas Corp;
Jefferson Chemical Road;
Conroe Plant, Conroe, Texas

Stresses due to thrust

Combined stresses

Buckling, caused by soil load and vacuum.

The following formulas can be applied and have proven to be suitable for reinforced plastic structures.

Deflection

We prefer to use Molin's formula since he carried out all his work on reinforced plastic pipes and he defined the constants used in his formulas very well. The formula is modified from Spangler's and reads: equation 1. (Molin's formula)

$$\frac{dv}{D} = 0.033 \cdot Q \cdot \left[\frac{E \cdot I}{E' \cdot R \cdot S} + 0.122 \right] \quad \text{where}$$

$\frac{dv}{D}$ = Vertical deflection

Q = Load on the pipe psi

R = Radius of pipe

E'_s = Modulus of soil reaction

E = Hoop, flexural modulus of pipe

I = Moment of inertia

The most important single factor in the formula is E'_s = modulus of soil reaction. If that factor can be controlled, we can control the deflection. That is, one has to control the backfill conditions. It should be noted that deflection should not be controlled by increasing the stiffness of the pipe. Both Spangler's and Molin's formula show how insignificant the pipe stiffness is in relation to deflection.

The following curve shows relation between pipe stiffness (P.S.F.) $\frac{E \cdot I}{0.149 \pi^3}$ and deflection of the pipe. See figure 1.

From figure 1 it is obvious that the compaction of backfill has much more influence on deflection than has the stiffness factor. As we will see later a high stiffness, especially by utilization of ribs, might have a bad effect on the pipe stresswise.

Moments and stresses due to moments

The moment equation has been arrived at on the same basis as the deflection formula. We prefer to use Molin's equation since his more clearly defines the constants for FRP pipe and since his work was all on FRP pipes, the equation reads:

Equation 2

$$I \frac{M}{QR^2} = \frac{0.25S + 0.003}{S + 0.122} \quad \text{for } S > 0.012$$

Equation 3

$$II \frac{M}{QR^2} = \frac{0.50S}{S + 0.122} \quad \text{for } S \leq 0.012 \quad \text{where}$$

$$S = \frac{E \cdot I}{E' \cdot S \cdot R}$$

M = Moment
 E_s = Molin's modulus of soil reaction
 Q = Soil load expressed in psi
 R = Radius of pipe
 I = Moment of inertia

The relation between moment and stress is given by the following formula.

Equation 4

$$\sigma = \frac{M C}{I} \quad \text{where}$$

σ = Stresses
 M = Moments
 C = Distance from neutral axis
 I = Moment of inertia

In examining ribbed structures, it can be seen that stresses due to moments are very high, and therefore, have to be dealt with using special considerations.

Buckling

Buckling is a very important factor to deal with for buried flexible pipe and is the determining factor for the required stiffness. The buckling formula used is the one developed by Lusher and shown below.

Equation 5

$$Q_{crit} = \sqrt[2]{\frac{B C M_s E I}{r^3}} \quad \text{where}$$

$$B = \frac{1 - \left(\frac{r}{R}\right)^2}{\left(1 + \nu_s\right) \left[1 + \left(\frac{r}{R_o}\right)^2\right] - 2\nu_s}$$

$$C = \frac{(1 + \nu_s)(1 - 2\nu_s)}{1 - \nu_s} \quad \text{where}$$

Q_{crit} = Critical buckling pressure
 M_s = Constrained modulus of soil
 E I = Stiffness of pipe
 ν_s = Poisson's ratio for soil
 R_o = r + H
 H = Soil cover above the top of pipe

The formula is valid for the following conditions:

Medium to well compacted backfill
 Backfill material should be coarse sand
 Burial depth at least 1 pipe diameter.

There are still a lot of uncertainties in the buckling behavior of buried cylinders. Because of that we have to set the F.S. against buckling rather high and in the magnitude of 7. That is

$$Q_{crit} : Q_{actual} = F.S.$$

Based on this we can calculate the required stiffness of the pipe from the buckling equation. Since we have decided that deflection is not the governing factor from which the stiffness requirement should be determined we should use the following formula derived from the buckling equations.

Equation 6

$$E I = \frac{Q^2 r^3}{4 B C M_s} \times (F.S.)^2 \quad \text{where}$$

F.S. = Factor of Safety, buckling
 Q = Soils pressure in PSI

The E I determined by the buckling equation will then be used both in the deflection and moment equation.

SPECIAL CONSIDERATION IN CONNECTION TO RIBBED STRUCTURES

Before one makes the decision whether to use ribs or not one has to consider the pipe's internal operation. Ribs should only be used if the main requirement is of a stability nature. That is, in cases where direct stresses are minor and the pipe stiffness requirement, because of buckling, is the governing design criteria. If considering the special properties of reinforced plastic one will find that as the internal pipe pressure is increased filament winding becomes the best material to use.

The following graph shows the relationship between strength and stability requirements for various wall thicknesses or stiffness factors (See figure 2 and 3). The figures show that the buckling resistance is near proportional to stiffness at the same time the bending compressive stress increases lowering the F.S. for thicker wall pipe.

An interesting point is that a higher strength and high modulus pipe as shown in figure 3, does not have higher F.S. in bending compression than does the low strength, low modulus pipe.

Pressure considerations for rib structures

For the low pressure case (up to 25 psi) we are not concerned with the F.S. for bending tensile. When the pressure is increased, as shown, we can see that the F.S. in bending tensile is the single most important criterion. This supports the previous statement that ribs should only be used on pipes when stability (buckling) is the main criterion for the design and internal pressure is not overriding. This is the case for pressure pipes up to 25 psi as shown in Figure 2. This structure can be made advantageously with ribs to obtain an equal stiffness. This will normally reduce the F.S. in bending compression on the rib crown, but that does not matter as long as the F.S. stays within desired lower limits. Where tensile strength is required as by pressure pipes for 75 psi and above one will find that the pipe stiffness obtained by designing the pipe for pressure, is sufficient without the addition of ribs.

Variables in Rib Structures

Figure 4 shows a typical cross section of a rib structure. From a geometric point the following parameters might be varied.

Center - center distance between ribs - (a)
 Width of rib crown (b)
 Width of rib foot (c)
 Height of rib (d)
 Thickness of wall (t)
 Angle of rib wall (α)

Besides the geometric configuration one might also use different types of laminate build up for the wall and the ribs. For example:

The wall might consist of:
 chopped fibers
 filament winding
 any mix of chopped fibers and filament winding

The ribs might consist of:
 solid filament winding
 hollow rib covered with filament winding
 hollow rib covered with mat or chopped fibers
 hollow rib with combination of chopped fibers and filament winding.

It should also be remembered that soils parameters and load factors including:

- burial depth
- degree of compaction
- location of water table

have an important influence on the final performance of the ribbed pipe.

If one wanted to vary all the parameters in order to optimize the soil pipe system, an infinite number of structures and trends would have to be evaluated. If only about four different numbers for each of the mentioned parameters were considered it would mean about 4 billion pipe soil structures should be developed. This could possibly be conducted on a computer, but even then the evaluation would be difficult. There are, however, a few short cuts to make. These will be discussed in the next sections.

DISCUSSION OF NEUTRAL AXIS AND MOMENT DISTRIBUTION

Neutral Axis

When dealing with a solid wall reinforced plastic pipe, the neutral axis is normally thought to be localized at the center of the wall. This is not really true, but in most cases the assumption is close enough. For a ribbed pipe, however, the situation is very different. The neutral axis may happen to be much farther away from the rib crown than from the inside of the wall. This will affect the strain in the wall as well as the ultimate stress distribution.

It is important in the design, as will be shown later in this paper, that the neutral axis be so located that a balanced strain in tensile and compression is obtained in cases when the ring is exposed to bending.

Moment Distribution

In order to properly design for this requirement it is important to know how the moments are distributed on a deflected pipe.

In a deflected pipe, the change in curvature determines the magnitude of the moment. In general, a buried pipe will have approximately the same moment distribution as a pipe ring as when exposed to deflection between two parallel plates. Figure 5 shows the moment distribution of a deflected ring. In the illustration, both positive and negative are shown. Negative moments mean that the external part of the wall is exposed to compressive stresses while the internal wall is exposed to tensile stresses; opposite for positive moments. The equation for moment distribution around the deflected ring is shown below:

$$M = P \cdot r (0.3183 - 0.5 \sin x) \text{ where}$$

M = Moment

P = Load

x = Location on the ring in degrees.

From the formula, it can be seen that the strain at 0° and 180° angle is about 1.7 times the strain at the springline. The moment distribution in a buried pipe will vary slightly from this, but a good idea about the general trend is shown.

Stress-Strain Discussion

Since the maximum strain will occur at the top and bottom, we can see that the ribs will be exposed basically to compressive stress and strain in those areas. The tensile stress and strain are much lower and are located at the springline.

Therefore, a ribbed pipe design should consider the following:

Bending tension at the wall

Bending compression at the rib crown.

The importance of separating the stresses into its components is based on the fact that reinforced plastic has different modulus and strength for the different types of exposure. For example, filament

winding might have:

Tensile modulus	4.0 mill psi
Tensile strength	60,000 psi
Compressive modulus	3.0 mill psi
Compressive strength	45,000 psi

Chopped fiber laminates might have:

Tensile modulus	700,000 psi
Tensile strength	10,000 psi
Compressive modulus	1.0 mill psi
Compressive strength	15,000 psi

When plotted on a common graph curve (see figure 6), it can be seen that both types of construction have about the same ultimate strain, namely 1.5 per cent. This means that while different strengths exist about the same ratio between strength and modulus is present. This is a very important finding for buried structures, in which stiffness does determine percent of deflection. Actually, it can be concluded that stress development in buried pipes will be proportional to the E-modulus; that is, a pipe with high E-modulus will therefore require a relatively higher strength in order to obtain the same F.S.

DETERMINATION OF NEUTRAL AXIS:

Solid Wall Structure

The neutral axis for a solid wall laminate will first be determined. The structure to be studied is composed so that the E-modulus in tensile is half of the E-modulus in compression. Ultimate strain for both exposures is the same.

Figures 7 and 8 illustrate the location of the neutral axis and the distribution of the stress and strain for this structure. In determining the neutral axis, two principals must be fulfilled:

Naviers hypothesis that calls out a linear relationship between strain and distance from the neutral axis. (plain section remains plain after bending).

The sum of compressive forces and the sum of tensile forces have to be equal as shown below in equation No. 7.

Equation 7:

$$\sum \sigma_t + \sum \sigma_c = 0$$

According to these principles, the stress-strain distribution through the wall will be shown in Figure 7.

The location of the neutral axis can be made by trial and error calculation or by using the following formula:

Equation 8:

$$a_1 \cdot b \cdot \frac{a_1}{2} \cdot E_1 = a_2 \cdot b \cdot \frac{a_2}{2} E_2 \text{ where}$$

a_1 is the distance from the outer fiber to the neutral axis.

a_2 is the distance from the inner fiber to the neutral axis.

b is the width

E_1 is the modulus in compression

E_2 is the modulus in tensile

(See Figure 8)

By setting $N = \frac{E_1}{E_2}$ we can convert the presented equation 8 and solve it for a_1 as shown below.

Equation 9:

$$a_1 = \frac{N + \sqrt{N^2 - 1}}{N - 1}$$

If we are to solve the equation for $E_1 \div E_2 = 2$, where E_1 is compressive modulus and E_2 is tensile modulus, we will find that the distance from the compression side to the neutral axis is

$t \times 0.41$ where
 t = wall thickness.

An important consequence of this evaluation is that in order to utilize all properties to the same degree the tensile strain should have been: $E_{\text{tensil}} = \frac{E_{\text{compressive}} 9.59}{0.41} = 1.5 E_{\text{compression}}$.

Since this is not the case, one will find that the failure mode will be in tensile.

This study also clearly shows that it is more important to deal with strain than stress.

For solid wall fiber glass sections we determine the strength and modulus by actual testing of the laminate and calculate the properties as if the neutral axis was located in the center of the laminate. This considers the equal on each side of the test specimen while this is not exact the results are close enough for design formulas.

Neutral Axis, Ribbed Structure

When dealing with ribbed structures, the neutral axis must be located. The location of this axis can be easily determined by a trial and error calculation. It is relatively easy to solve the complex problem in this manner.

In solving for neutral axes we must make use of the following assumptions and principles:

The distance between rib centerlines shall not exceed the value determined in the following equation:

Equation 10:

$C-C = 4 \cdot t \cdot r$ (St. Vernont's principle) where

t = wall thickness of cylinder

R = radius of pipe

If this requirement is fulfilled the neutral axis will make an almost straight line between and through ribs parallel to the pipe wall. If the distance is longer between ribs than allowed by St. Vernont's principle the neutral axis will tend to move towards the center of the pipe wall between ribs. (See Figure 9)

The strain at any point is proportional to the distance from the neutral axis.

The sum of compressive and tensile forces equals zero.

The neutral axis will be determined only for the case where the rib crown is in compression which is the severest design problem.

The following example, which solves a typical problem, we have considered a structure buildup of 3 different compositions:

- Pipe wall
- Rib wall
- Rib crown

For determination of the neutral axis, we only need to consider the E moduli in compression and tensile for the various compositions. The properties are assigned as follows:

Wall	E_{wt}	tensile modulus
	E_{wc}	compressive modulus
Rib wall	E_{rt}	tensile modulus
	E_{rc}	compressive modulus
Rib crown	E_{ct}	tensile modulus
	E_{cc}	compressive modulus

Figure 10 graphically explains the trial and error method for locating the neutral axis for ribbed structure.

In solving the neutral axis problem we must first assume the neutral axis to be at the outer surface of the pipe wall. Using equation 11 and Figure 10 we can obtain our first neutral axis trial and error answer.

Equation 11:

$$E_{wt} \cdot A_1 C_1 = 2 (E_{rc} \cdot A_2 \cdot C_2) + (E_{rc} \cdot A_3 \cdot C_3) + (E_{cc} \cdot A_4 \cdot C_4)$$

If the sum of one side of the equation shows up to be larger than the other, the next calculation in solving the equation should be conducted

after moving the neutral axis in such a direction, (toward the inside of the pipe or rib crown) so as to equalize the equation. By the time two to three calculations are made the neutral axis has been determined.

Strain Relationship with Neutral Axis

It has been previously stated that the strain in a structure is directly proportional to the distance from the neutral axis. If we have selected a structure with relatively high ribs; for example, the distance from the outer fiber on the rib crown to the neutral axis is about three times the distance from the inner wall fiber to the neutral axis. Therefore, the strain in the outer fiber on the rib crown will then be about three times that of the wall, when the structure is exposed to bending. Based on that it can be understood that failure mode for the ribbed structure most likely will be a compressive failure at the rib crown. This illustrates the higher the rib the greater the probability of stress problems in the rib crown.

In order to help this problem, it is possible to move the ribs closer together and while making them lower. While this is done it is important that the same stiffness is maintained. Usually, as shown later, both performance and cost will be improved. Another possible solution in cases where the rib has a low safety in compression is to use a greater amount of high modulus material at the rib crown. In this case the improvement is gained because the neutral axis moves closer to the rib crown reducing the strain and, as a result, the stresses. (Not because it makes the rib stronger).

From this discussion, it is clear that very high ribs should be avoided. The rib should be so designed that the bending strain developed at the rib crown will be not more than twice that of the wall; i.e. the rib height should be not more than two to four times the thickness of the wall. This is an important restriction and helps us to narrow in on the number of possible rib structures.

STIFFNESS FACTOR CALCULATION:

In this paper we will not deal with Stiffness Factor (S.F.) in any detail since the intent is only to give some guidelines. The S.F. for rib structures is defined as:

$$S.F. = \sum_{i=1}^n E_i (I_i + A_i C_i^2) / I, \text{ where}$$

I is moment of inertia for the various sections around their own axis.

E = the E modulus for each section

A = area of each section

C = distance from centroid of each section to neutral axis.

The moment of inertia for an irregular cross section is defined as the sum of the moment of inertia for all the cross section elements or:

$$I_{tot} = \sum (A \cdot C^2) \text{ where}$$

A = the area of each segment

C = is the distance from the centroid of the segment to the neutral axis.

Based on these statements, the S.F. for a ribbed pipe per unit length will be as follows:

Equation 12:

$$SF = E_1 [I_{wall} + A_1 C_1^2] + 2E_2 [I_2 + A_2 C_2^2] + E_2 [I_3 + A_3 C_3^2] + E_3 [I_4 + A_4 C_4^2]$$

Figure 11 explains how stiffness factor for ribbed structures are determined. In this example we have assumed the neutral axis to be located on the outer wall.

RIB STRUCTURE CRITERIONS:

In the previous sections of this paper, we have established various design criteria that have to be met by rib structures in order to insure good performance. The following summarizes those criteria.

Internal Pressure: It can be clearly shown that as the internal pressure increases, the advantages of a rib structure decreases. The break-even point will be between 50 and 75 psi.

Center-Center Distance Between Ribs: In order to get good load distribution and avoid large discontinuity stresses, we have used St. Venant's principle to determine maximum center distances between ribs. (See formula 10). In Figure 12, we have shown the maximum distance between ribs for various pipe diameters and wall thicknesses.

Height of Rib: The height of the rib should not be more than 2 - 4 times the wall thickness in order to avoid too high strain at the rib crown.

Stiffness Factor: The stiffness of the pipe should be based on the buckling criterion by using a proper safety factor. In regard to this criterion we have established in our work that for pipes with diameter from 48 inches and above and for burial depths of up to 15 ft. The pipe stiffness should be calculated as follows:

$$\text{Pipe stiffness} = \frac{SF}{0-15} = \frac{7}{0.149 \cdot r^3}$$

For cases where the burial depth is 15 ft. through 25 ft. we have determined the following:

$$\text{Pipe stiffness} = \frac{SF}{16-25} = \frac{11}{0.149 \cdot r^3} \quad \text{where}$$

SF - stiffness factor according to formula 12

R - pipe radius

Therefore the safety factor against buckling will then be about 7 - 10 dependent on burial depth and water table.

Rib Height to Width Ratio: In order to prevent local instability problems it is important to establish a criterion for rib height to rib width ratio. Since there are many possible solutions to rib design, we have taken a general approach to this problem, and have established the following criterion:

Rib foot width - 2 rib height. This ratio does also allow the designer to put special high strength or high modulus material like filament wound fiber glass at the rib crown.

Rib Shape: Ribs can be shaped in a variety of ways. In general it offers economical advantages to make them hollow. However, as the discussion on rib height showed, it is not wise to develop a high and narrow rib because of serious crown problems.

Rib-Pipe Wall, Bond: The bond between the pipe wall and the rib is important. The bond area will basically be exposed to shear stresses which will be at their highest at the neutral axis, and where the greatest change in curvature is present.

When dealing with reinforced plastic, one should be aware of the low inter-laminate shear properties obtained by use of filament wound roving or woven roving as the only material to bend the rib to the pipe wall. Therefore, any design should always provide for a mat like material to bond the rib to the pipe wall. Figure 13 shows the relationships between rib height and bond area.

Wall Thickness: In order to give reasonable limitations to the cylinder wall thickness, we have to consider a few factors:

a) **Handling:** The thickness required for handling is dependent on total weight of the pipe, which is indirectly related to the pipe diameter and type material used.

Our practical experience has shown that for laminates using chopped fibers, the thickness requirement varies. These values are shown in Figure 14.

The value on this handling figure is based on experience more than mathematical evaluation. Therefore the minimum wall thickness will depend greatly on how the pipe is handled in the field and manufacturing control on this.

b) **Local Buckling:** The local buckling phenomenon is dependent on:

Distance between ribs

Thickness of wall

Diameter of the pipe

The external pressure the structure is exposed to.

When assuming the pipe to be used at a burial depth of 15 ft. (cover above the top), we have found the relation between diameter and wall thickness to be as shown in Figure 14 to insure that buckling does not occur. This relation assumes other criterion for rib structures is followed, especially Vernont's principle.

c) **Axial Strength Requirement:** This is again a very difficult subject to deal with. The axial strength requirement is dependent basically upon:

Differential Settlement in the ground and beam bending stresses resulting from the settlement.

Thermal Stresses caused by differential compression resulting in the pipe moving axially.

Since the axial stress is generally dependent on the differential settlement, soil properties of the trends cause major concern. Since we are dealing with a large soil load, relative to the strength of the pipe, we should assume that the pipes will have the same axial deflection regardless of the strength and modulus properties. This means the axial strength requirement is proportional to the axial modulus of the pipe, that is a high modulus pipe will develop higher stresses than does a low modulus pipe.

If we again assume that all reinforced plastic structures will have almost the same ultimate strain, we will see that the required wall thickness is independent of the strength and will be almost the same for all types of structures. The thermal stresses are only important to consider if the structure is used above ground. The thermal stresses are independent of wall thickness and length; the buckling failure that might be caused by thermal stresses is related to the wall thickness.

As it can be seen from the three curves shown in Figure 14, the minimum cylinder wall thickness is mainly dependent on handling. That is, the handling criterion should be used for minimum wall thickness.

EXAMPLE CALCULATIONS: In the following examples we have made a few calculations and by means of curves show how different parameter changes effect the F.S. for stability and stresses of a typical pipe.

The buckling criterion has been used for calculation of the required stiffness. We will establish a minimum performance criterion allowing a new **Factor of Safety in buckling of 7.5.**

Pipe Design Considerations

Diameter of pipe 96 inches

Thickness of wall 0.2 inches - 0.4 inches

Strength and modulus of wall for structure I - III (see following table)

TABLE I WALL STRENGTH AND STRUCTURES

	STRUCTURES	
	I	III
*E - modulus mill. psi	1.4	2.8
Compressive str. psi	25,000	35,000 psi
Flexural strength psi	25,000	30,000 psi
tensile strength psi	12,000	28,000 psi

*Flexural modulus has been used to simplify the calculations.

Properties of rib wall materials are:

E - modulus (flexural)	2.4 mill psi
Tensile strength	15,000 psi
Compression strength	20,000 psi
Bending strength	20,000 psi

Filament winding is used at the rib crown. The numbers of strands are varied to help in achieving the proper stiffness factors for a given configuration of the ribbed pipe. The properties used for filament winding are:

E - modulus	6 mill psi
Tensile strength	60,000 psi
Bending strength	60,000 psi
Compression strength	50,000 psi

Rib shape - In order to show how stresses and F.S. vary with rib height, we have used three different shapes on the rib:

- High profile
- Medium profile
- Low profile

Rib spacing - we have used two different center distances between ribs, namely 10 and 20 inches which is well within our criterion for this diameter.

The following Figure 15 gives an idea of the shapes used in the program.

Soils Properties Considerations

Compaction - We have used two different degrees of compaction, namely,

- 85 percent modified Proctor
- 95 percent modified Proctor

Burial depth - selected to be 15 ft.

Water Table - Location of the water table has a large influence on the performance of the structure so we have selected the worst case, namely to have the water table above the pipe.

In evaluating the pipe in this example we will develop 96 structures to compare.

In order to be able to compare these structures in a reasonable way, we have selected to compute Factors of Safety for the various stresses and stability aspects and compare those and read the trends.

In order to do so, we have calculated the following:

E_s based on degree of compaction, burial depth and water table.

M_s based on degree of compaction.

Load on pipe in psi.

Deflection of pipe in percent of diameter.

Critical buckling pressure.

Compression stress at wall.

Tensile stress at wall.

Maximum moment

Bending stress at wall.

Bending stress at crown.

Tensile stress at crown.

Compressive stress at crown.

We have developed Factors of Safety for the following:

Buckling

- Bending/compression at wall (Super-imposed)
- Bending/tensile at wall (Super-imposed)
- Bending/compression at rib crown (Super-imposed)
- Bending/tensile at rib crown (Super-imposed)

In order to calculate the superimposed Factors of Safety (FS) we have used the following equation:

Equation 13:

$$F.S._{bc} = \frac{1}{\frac{\sigma_b}{\sigma_{bult}} + \frac{\sigma_{comp}}{\sigma_{cult}}} \quad \text{where}$$

$F.S._{bc}$ = Factor of safety in bending-compression

σ_b = Bending stress

σ_{bult} = Ultimate bending strength

σ_{comp} = Compression stress

σ_{cult} = Ultimate compression strength

Stiffness Factor: As stated earlier the buckling criterion will be the governing factor for the determining stiffness. We have decided to use a F.S. against buckling equal to 7.5. The stiffness factor necessary to achieve this is dependent upon the following:

Burial depth

Degree of compaction

In addition the Stiffness Factors, for the example, will be according to the following Table II for 15 ft. burial depth.

TABLE II	
Degree of compaction	Stiffness Factor
85% Mod. Proctor	18,000 lbs. in ² /in.
95% Mod. Proctor	100,000 lbs. in ² /in.

This Table shows two different stiffness factors. One for each degree of compaction. Since we have pointed out that pipe deflection is determined by soils compaction then all structures will deflect for 85 percent Modified Proctor and 1.82 percent for 95 percent modified Proctor. The same or 2.48 percent.

The following tables III and IV show the F.S. in relation to the variables used.

Discussion of Tables:

In Table III and IV we have compared the different variables for a pipe under a given set of conditions. The most important conclusions are:

In all cases the F.S. in bending compression on the rib crown is the lowest; that is, we have to use that as the governing factor for our judgement of the usefulness of a given structure.

For ribs that meet the same stiffness criterion the lower rib has a higher safety factor against stress. It is very dangerous to judge a rib structure based on stability criterion alone. The safety factor in regard to buckling is as high as 7.5 while stresses for the high rib, have a factor of safety of only around 2 in all cases.

A few other general trends noted are as follows:

An increase of the distance between ribs does not change the F.S. as long as the same S.F. is obtained.

The F.S. is generally higher for the lowest modulus pipe wall composition because the neutral axis then is closer to the rib crown. For the pipe dealt with in the example we could have balanced the structure even better by using a lower modulus pipe wall composition or a thinner wall. However, a thinner wall could be dangerous from a handling point of view.

The F.S. is generally higher for a thinner wall. That is only true, however, within certain limits. If we had selected a wall thickness of

0.1 inch for example, the F.S. in wall bending compression would have been critical.

The wall thickness of the rib has a negligible influence on the safety factors. The only criteria in rib wall thickness is to insure that the rib has sufficient thickness for local stability. That is generally obtained if the shape is right and the wall thickness of the rib wall no less than 0.1 inch.

The influence of soil compaction is not very large on the F.S. as long as the F.S. in buckling is kept constant. That means however, that the pipe's stiffness factor can be dropped about 40 percent where the compaction is increased from 85 percent mod. Proctor to 95 percent, which means less material consumption while the same stability performance is obtained; in addition the deflection will further be reduced. If, however, we had calculated the F.S. of the same design structure in 85 percent modified Proctor and 95 percent modified Proctor, we would have found a much better performance in the higher compacted material. It is also noteworthy that the lower rib structure gets slightly less F.S.'s for stresses at 95 percent modified Proctor than for 85 percent while the higher rib profiles react oppositely. This can be explained by the relative location of the neutral axis in the two cases.

Another important variable to look into is the amount of material used. An attempt is made to show this by the variation in the filament winding at the rib crown, variation in pipe - and rib wall thickness. That is, all the structures can be priced rather easily for cost comparison. From the two tables it looks like the low profile uses more material than the other. This is partly true and dependent on the rib shape. The low profile rib uses more filament winding but less total material in the rib wall and has a much higher F.S. In order to look thoroughly into this, curves are included showing the relation between Factors of Safety for the various types of ribs versus stiffness factors and material usage. See Figure 16, 17, 18, 19.

EXPLANATION OF FIGURES

The curves show that F.S. buckling increases proportionally to the stiffness of the pipe.

The F.S. for bending-compression at the wall decreases as the stiffness factor increases. Both F.S.'s for stresses at the rib crown increase as the stiffness factor increases. It is generally clear that the lower rib has a better performance than the other structures relative to the lowest F.S. Based on this fact, we compared rib structures and performance based on material usage. Figure 19 shows this. The conclusion from this curves is that on a cost performance basis the lowest rib is best.

CONCLUSION:

In order to study performance of buried reinforced plastic pipes, it is of great importance to consider stresses as well as stability. Stiffness factor for a pipe should be governed by the buckling criterion.

For ribbed structures, it is important to consider the high strain developed at the rib crown, caused by the distance to the neutral axis. F.S. for compression at the rib crown is the single most important design criterion. The following variables greatly influence on the performance of a ribbed structure and this paper proposes the following limitations.

- a) Maximum internal pressure - 75 psi
- b) Center-distance between ribs according to St. Vernon's principle.
- c) Rib height to width ratio 2:1.
- d) Rib-wall bond length equals 2 times rib height.
- e) Wall thickness of pipe, governed by handling.

Based on the same material usage, a low rib gives better performance than the other alternatives studied.

AGNAR GILBU

Agnar Gilbu, a chemical engineering graduate in 1962 at Bergen, Norway, was engaged in alkyd and polyester resin development for Joton A/S; later he worked at the Central Institute for Industrial Research studying influences of food products on plastics and vice versa.

In 1964, in a research program at the Free University of Berlin, he studied plastics/paper combinations.

From 1966 to 1971, Mr. Gilbu was project manager of the plastics division of Vera Fabrikker A/S Norway, principally working in FRP pipe and tanks. In 1971 he joined Owens/Corning Fiberglass Corporation where he is Process and Product Development Manager at the Conroe, Texas plant of the Non-Corrosive Products Division.

TABLE III

FACTORS OF SAFETY IN RELATION TO RIB-BUILD UP
AND SOILS PROPERTIES

85% MODIFIED PROCTOR

REF.	DEFLECT.	STIFFNESS FACTOR	FACTOR OF SAFETY - RIBS																												
			NUMBER OF 450 YIELD ROVINGS AT RIB CROWN				WALL STRUCTURE PIPE		PIPE WALL THICKNESS		RIB WALL THICKNESS		CENT. BETWEEN RIBS (INCH)		HIGH RIB				MEDIUM RIB				LOW RIB								
			HIGH	MEDIUM	LOW	I	III	0.20	0.40	0.1	0.15	10	20	BCW	BTW	BCR	BTR	BCW	BTW	BCR	BTR	BCW	BTW	BCR	BTR						
1			50	200	500	X		X	X	X	X	6.7		1.9	2.6	6.1		3.1	5.4	5.7			5.0	10.1							
2			150	460	1100	X		X			X		6.6		1.9	3.0	5.9		3.2	6.3	5.5			5.2	13.0						
3			20	130	400	X		X			X		6.6		1.9	2.7	6.3		3.0	4.8	5.8			4.6	8.9						
4			125	350	1000	X		X			X		6.4		1.9	2.9	6.1		2.9	5.5	5.4			4.9	11.6						
5			20	100	200	X		X			X		9.3		1.6	2.8	8.6		2.7	3.6	8.4			3.5	4.2						
6			90	240	450	X		X			X		9.6		1.8	2.3	9.0		2.5	3.7	8.6			3.4	4.4						
7				60	160	X		X			X		STIFFNESS FACTOR TOO HIGH WITH THE GIVEN RIB WALL THICKNESS				8.7		2.6	3.5	8.4			3.4	4.0						
8			60	185	380	X		X			X		9.5		1.7	2.2	9.0		2.5	3.5	8.5			3.2	5.0						
9			35	150	300		X		X		X		6.5		1.9	2.4	6.0		2.9	4.1	5.7			4.0	6.3						
10			120	350	725	X	X	X			X		6.6		1.9	2.5	5.9		2.6	4.3	5.4			4.1	7.0						
11			10	100	250	X	X	X			X		6.4		1.9	2.4	6.0		2.8	3.9	5.6			3.9	6.0						
12			90	275	600	X	X	X			X		6.5		1.8	2.4	6.0		2.7	4.0	5.5			3.6	6.3						
13			10	75	150	X	X	X			X		6.2		1.8	2.1	7.6		2.6	3.1	7.6			3.3	4.2						
14			80	190	360	X	X	X			X		8.5		1.8	2.1	8.2		2.5	3.1	7.6			3.2	4.2						
15				30	100	X	X	X			X		STIFFNESS FACTOR TOO HIGH WITH THE GIVEN RIB WALL THICKNESS				7.7		2.5	3.0	7.5			3.2	4.0						
16			40	140	300	X	X	X			X		8.5		1.7	2.0	8.1		2.4	3.0	7.7			3.1	4.0						
DEFLECTION FOR ALL - 2.48 %																STIFFNESS FACTOR FOR ALL - 180,000 LBS. - IN ² /IN ⁴ 4%															

BCW - FACTOR OF SAFETY BENDING-COMPRESSION WALL

BTW - FACTOR OF SAFETY BENDING-TENSION WALL

BCR - FACTOR OF SAFETY BENDING-COMPRESSION RIB CROWN

BTR - FACTOR OF SAFETY BENDING-TENSION RIB CROWN

FACTOR OF SAFETY IN BUCKLING IS 7.5 ± 0.20 FOR ALL THE STRUCTURES

DIAMETER - 96"

BURIAL DEPTH - 15 FT.

COMPACTION - 85% MODIFIED PROCTOR

OPERATING PRESSURE - 0

WATER TABLE - ABOVE PIPE

LIVE LOAD - NONE

TABLE IV

FACTORS OF SAFETY IN RELATION TO RIB BUILD UP
AND SOILS PROPERTIES

95 % MODIFIED PROCTOR

REF.	DEFLECT	STIFFNESS FACTOR	NUMBER OF 450 YIELD ROVINGS AT RIB CROWN		WALL STRUCTURE PIPE		PIPE WALL THICKNESS		RIB WALL THICKNESS		CENTER DIST. BETWEEN RIBS(INCH)	FACTOR OF SAFETY - RIBS												
												HIGH RIB			MEDIUM RIB			LOW RIB						
												BC _w	BT _w	BC _r	BT _r	BC _w	BT _w	BC _r	BT _r	BC _w	BT _w	BC _r	BT _r	
17			25	52	150	X	X	X	X	X	X	8.4		2.3	4.0	8.0		3.4	7.0	7.7			4.5	12.5
18			50	175	350	X	X	X	X	X	X	8.2		2.2	4.3	7.9		3.2	8.4	7.4			4.2	15.9
19				20	100	X	X	X	X	X	X	TOO HIGH STIFFNESS FACTOR FOR THE GIVEN RIB WALL			7.9		3.4	6.6	7.7			4.4	11.0	
20			25	135	275	X	X	X	X	X	X	8.1		2.2	4.1	7.8		3.2	7.8	7.6			4.1	13.8
21			10	10	60	X	X	X	X	X	X	12.3		2.3	3.2	11.8		3.2	9.0	11.5			4.0	7.1
22			18	80	170	X	X	X	X	X	X	12.5		2.2	3.2	12.2		3.0	9.1	11.8			3.8	7.5
23					15	X	X	X	X	X	X	TOO HIGH STIFFNESS FACTOR FOR THE GIVEN RIB WALL			TOO HIGH STIFFNESS FACTOR FOR THE GIVEN RIB WALL			TOO HIGH STIFFNESS FACTOR FOR THE GIVEN RIB WALL						
24				35	120	X	X	X	X	X	X	TOO HIGH STIFFNESS FACTOR FOR THE GIVEN RIB WALL			12.1		3.0	4.9	11.8			5.7	6.8	
25			20	35	100	X	X	X	X	X	X	8.5		2.4	3.5	8.1		3.4	9.6	7.8			4.4	8.4
26			38	140	270	X	X	X	X	X	X	8.5		2.3	3.5	8.1		3.3	9.9	7.8			4.2	9.0
27				5	60	X	X	X	X	X	X	TOO HIGH STIFFNESS FACTOR FOR THE GIVEN RIB WALL			7.9		3.4	9.3	7.7			4.5	7.8	
28			5	100	230	X	X	X	X	X	X	8.4		2.3	3.4	8.0		3.2	9.6	7.7			4.1	8.4
29			5	30	25	X	X	X	X	X	X	11.2		2.4	2.9	10.9		3.3	4.4	10.6			4.0	5.7
30			5	50	125	X	X	X	X	X	X	11.4		2.3	2.9	11.2		3.2	4.2	10.9			3.9	6.7
31						X	X	X	X	X	X	TOO HIGH STIFFNESS FACTOR FOR THE GIVEN RIB WALL			TOO HIGH STIFFNESS FACTOR FOR THE GIVEN RIB WALL			TOO HIGH STIFFNESS FACTOR FOR THE GIVEN RIB WALL						
32				15	75	X	X	X	X	X	X	TOO HIGH STIFFNESS FACTOR FOR THE GIVEN RIB WALL			11.0		3.1	4.1	10.8			3.8	5.4	

BC_w - FACTOR OF SAFETY BENDING - COMPRESSION WALLBT_w - FACTOR OF SAFETY BENDING - TENSILE WALLBC_r - FACTOR OF SAFETY BENDING - COMPRESSION RIB CROWNBT_r - FACTOR OF SAFETY BENDING - TENSILE RIB CROWNFACTOR OF SAFETY IN BUCKLING IS 7.5 ± 0.20 FOR ALL THE STRUCTURES.

DIAMETER - 96"

BURIAL DEPTH - 15 FT.

COMPACTION - 95 % MODIFIED PROCTOR

OPERATING PRESSURE - 0

WATER TABLE - ABOVE PIPE

LIVE LOAD - NONE

FIGURE 1
RELATION BETWEEN PIPE STIFFNESS
AND DEFLECTION FOR VARIOUS DEGREES OF COMPACTION

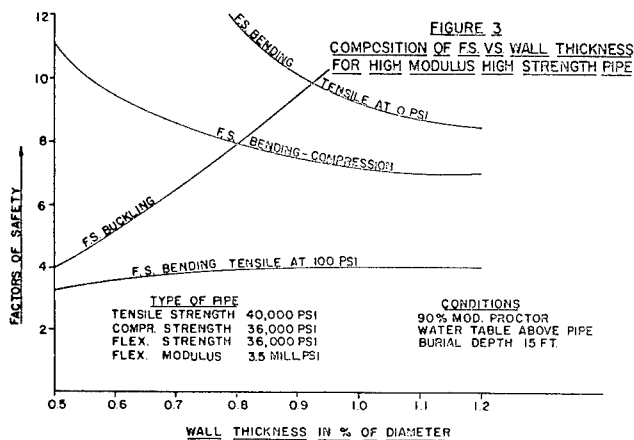
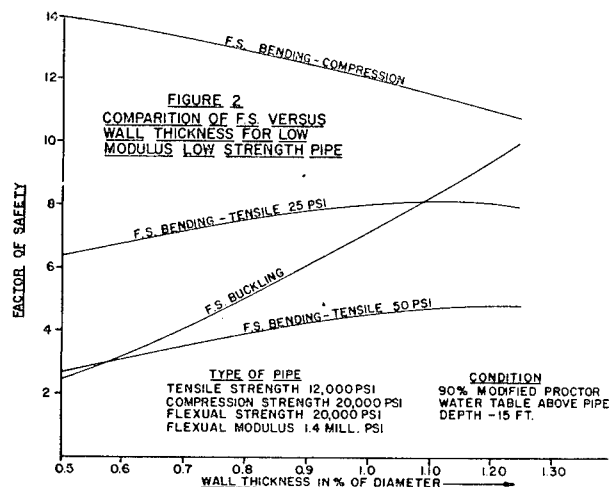
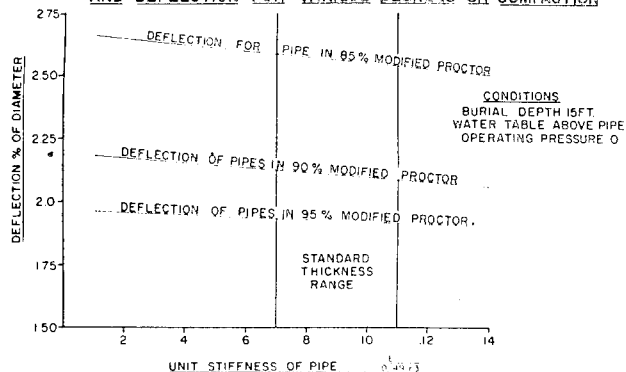
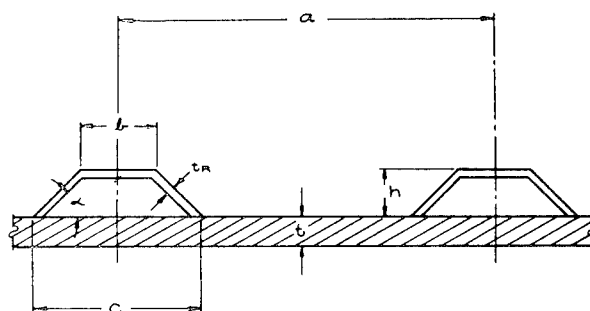
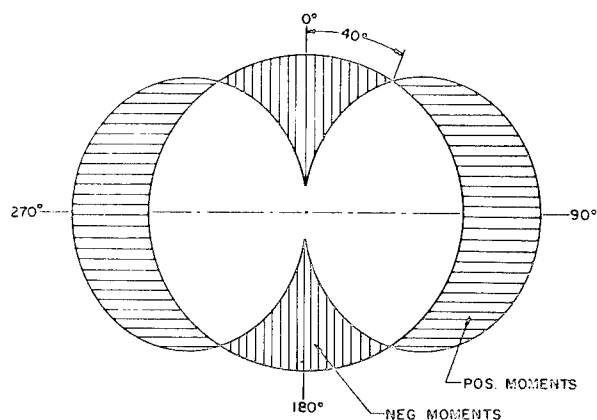


FIGURE 4
TYPICAL CROSS-SECTION
OF RIB STRUCTURE



a - CENTER DISTANCE BETWEEN RIBS
 b - WIDTH OF RIB CROWN
 α - ANGLE OF RIB
 c - WIDTH OF RIB FOOT
 t - WALL THICKNESS
 t_n - WALL THICKNESS OF RIB
 h - HEIGHT OF RIB

FIGURE 5
MOMENT DISTRIBUTION AROUND
A DEFLECTED RING



RELATION MAX NEG. MOMENT TO MAX. POS. MOMENT IS 1.74 TO 1
MOMENT EQUATION $M = PR(0.3103 - 0.5 \sin X)$

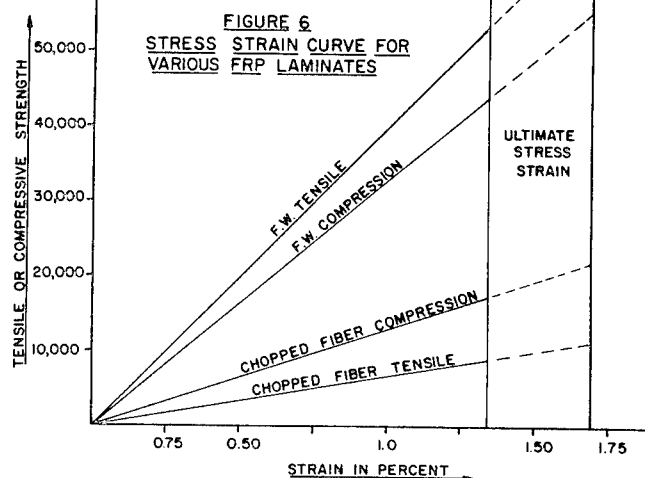


FIGURE 7



FIGURE 9



FIGURE 11

STIFFNESS FACTOR

WHERE $I_{wall, 1, 2, 3, 4}$ ARE THE MOMENTS OF INERTIA
FOR THE VARIOUS ELEMENTS ABOUT THEIR OWN
CENTROIDAL AXIS PARALLEL TO THE WALL.



FIGURE 8



$$E_1 + E_2 = 2, q_1 + q_2 = 0$$

FIGURE 10



$$E_{\text{enc}} \cdot A \cdot C_1 = 2 A_2 \cdot C_2 \cdot E_{\text{enc}} + E_{\text{enc}} \cdot A_3 \cdot C_3 + E_{\text{enc}} \cdot A_4 \cdot C_4$$

FIGURE 12



FIGURE 13
DIFFERENT RIB SHAPES AND RELATION BETWEEN HEIGHT AND BOND AREA

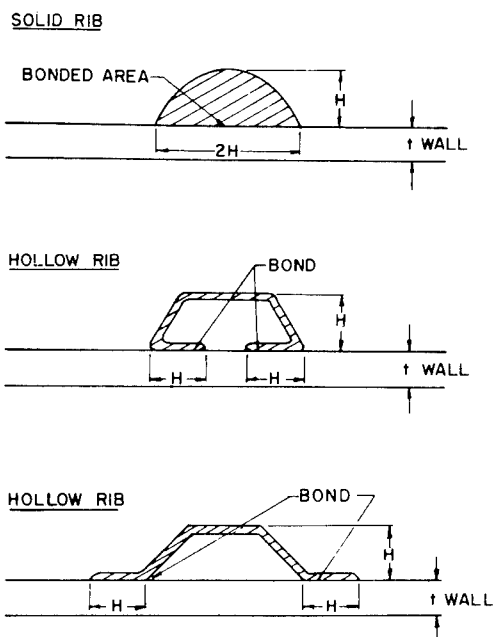


FIGURE 15
CONFIGURATION OF RIBS USED IN CALCULATION

RIB HEIGHT RELATION: HIGH RIB = 1.75 INCH
MED RIB = 1.25 INCH
LOW RIB = 1.00 INCH

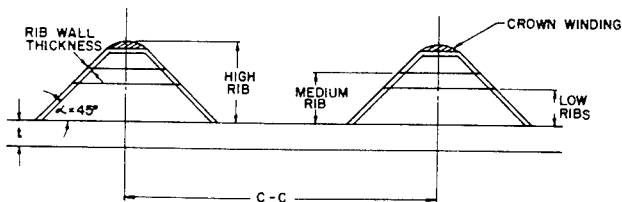


FIGURE 14
RELATION BETWEEN MINIMUM WALL THICKNESS AND PIPE DIAMETER FOR HANDLING LOCAL BUCKLING AND AXIAL STRENGTH

NOTE: TYPE OF LAMINATE: CHOPPED FIBER
ONLY MINOR SOIL SETTLEMENTS CONSIDERED

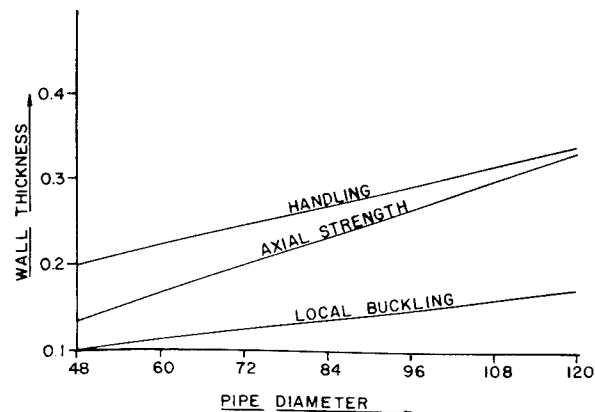
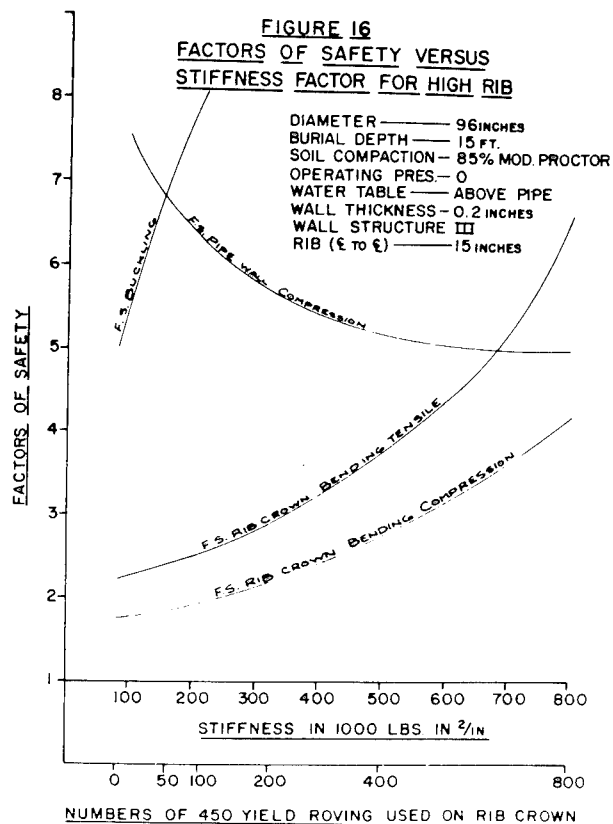
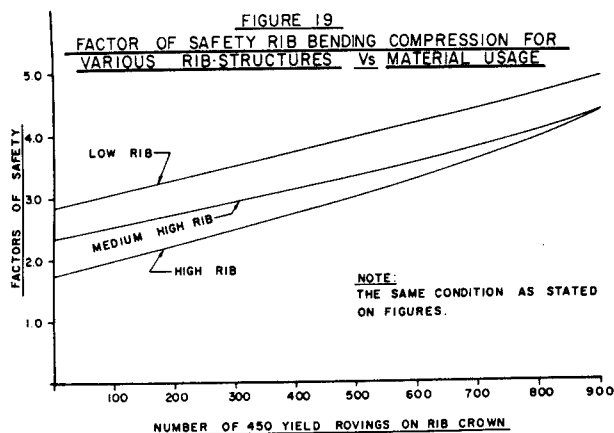
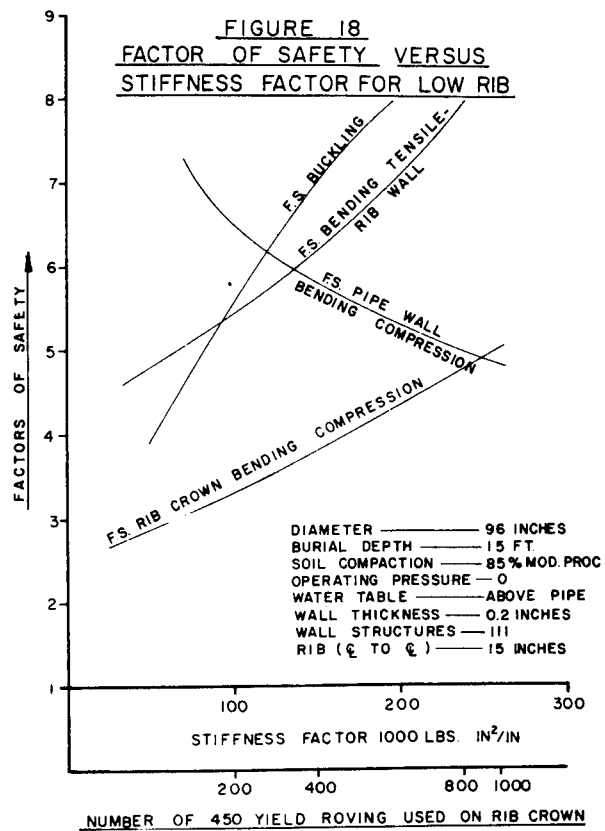
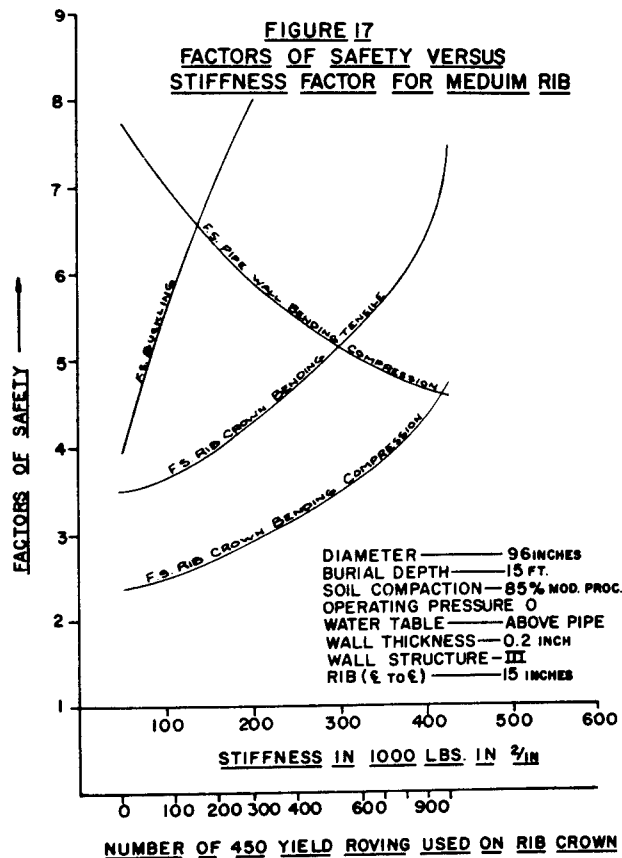


FIGURE 16
FACTORS OF SAFETY VERSUS STIFFNESS FACTOR FOR HIGH RIB





FIRE RETARDANT FRP IN CORROSION CONTROL: DESIGN AND CODE CRITERIA

by

R. J. LEWANDOWSKI and D. M. LONGENECKER*

ABSTRACT

Corrosive conditions in chemical process plants often make the use of metals impractical or too expensive, but FRP has found wide application in fume handling equipment. However, use of FRP duct has been questioned because of fire risks. This paper summarizes available information on this subject, including a review of past performance of FRP equipment, fire test methods, current codes including the recent revision of NFPA No. 91, and engineering of fire safeguards. Specific case histories will be discussed.

INTRODUCTION

The corrosion-resistant equipment market has been one of the steadiest areas of growth for the plastics industry for many years. The performance of Fiber Reinforced Polyester (FRP) in corrosive environments is well proven and need not be documented for an audience at The Society of The Plastics Industry.

One problem area, however, that is receiving more attention is the fire risk. All plastics, being organic materials, will burn under certain conditions. There have been enough fires reported to make underwriters proceed cautiously in this area. Several fires have involved substantial loss, and perhaps have unduly influenced current decisions. We feel that our industry has lost many opportunities because the end user (equipment purchaser), designer, or underwriter was either unaware of all the facts or, not wanting to bother with sprinkler systems and the like, chose the easiest or least troublesome solution to a given problem. ICI America cannot guarantee the efficacy of a system design or the qualifications for insurance coverage, but a review and summary of available information in this area will be helpful to the industry.

THE LINK BETWEEN CORROSION AND FIRE RESISTANCE

Corrosion resistance cannot be separated from fire retardancy in dealing with FRP process equipment. If ordinary mild steel such as thin-walled duct will suffice for a given application, it is the easiest and cheapest and most practical material for routine use. It is only when corrosive conditions would quickly attack most metals that FRP should be considered. Our basic premise is, "Where there is no corrosion problem, use steel; for corrosive environments, consider FRP." This applies to all kinds of equipment, including tanks and pipe where fire hazards are normally not a consideration.

Air moving equipment, particularly duct, is another matter. All duct, including concrete, steel or other materials, can present fire hazards because of sulfur, grease, organic materials or other solids which collect on the duct walls, and in a high velocity air stream, a fire can spread rapidly. By definition, therefore, we face

a dual problem and require a material that shows excellent resistance to both fire and corrosion. But if this is true, what standards exist for defining the degree of fire retardancy?

FIRE TESTING

In an excellent recent article, Steingiser¹ points out the shortcomings of present efforts, and the multitude of tests that now exist, listing over 30 methods for measuring surface flammability. He notes that, "much of the industry's efforts . . . have been to develop test methods for a particular product to show it to be better than some other material. What is forgotten is that under real conditions, they all burn, and that under another set of conditions, a complete reversal of test ratings can be achieved!"

Terms like flameproof, non-burning, self-extinguishing, flammable, non-flammable, fire-retardant, flame retardant, fire resistant, non-combustible, and many others are confusing and contradictory. They may be defined, but only as pertaining to a specific test method. Different test methods often yield startlingly different ratings for the same materials.

Among the many tests for fire retardancy or flame ratings of building materials, the test with widest industry acceptance is the Steiner Tunnel Test, adopted as ASTM E-84. This test is recommended by the SPI and is included in the Department of Commerce Product Standard 15-69 for Hand Lay-Up Equipment. Although the apparatus is cumbersome (the test chamber is 25 ft. long), and the calculations complicated, the test is preferred by most workers in the industry for several reasons.

a. Experience indicates that this test, within a given facility, is reproducible and reliable. Ratings are on a numerical scale from 0 to 100, not in vague descriptive terms.

b. The test is large scale so that conditions simulate a real fire as closely as any test yet devised.

c. The test has been used for many common building materials whose flammability is well understood. The performance of plastics in this test is thereby more meaningful.

While this test has received some criticism—it is not as precise as some would like—it is, in our opinion, the best yet available. Our policy for several years has been to urge buyers of FRP equipment to demand Tunnel Test Data.

Because of the complexity of the Tunnel Test, a number of smaller laboratory-scale tests have been developed for evaluation of resins. Several of the most popular of these were evaluated for sensitivity, reproducibility, and possible correlation to Tunnel Test results. Standard 1/8" SPI-type laminates were tested.

The tests evaluated were:

ASTM D-635	(Bunsen Burner)
ASTM D-757	(Globar)
ASTM E-162	(Radiant Panel)
HLT-15	(Vertical Bunsen Burner)
ASTM D-2863	(Candle or Oxygen Index)

As we previously reported in a paper before the SPI,² these tests did not show reproducibility, reliability, and correlation to Tunnel Test results. Several of them merely use general terms such as "Non-Burning" for ratings, and while they distinguished general purpose resins (such as boat resins) from the fire retardant group, they were unable to make gradations within the latter group. The Oxygen Index (Candle) Test was the most promising in that it does use concrete numerical ratings, and results correlate fairly well with Tunnel Test results.

The Ceilcote Co., a major fabricator, has developed a test designated T-341 which is simpler than the E-84 Tunnel Test, but applicable only to duct. A similar test is that developed by the Factory Mutual Research Corp. This test does not develop ratings, only a "pass/fail." Because of the design of this particular

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test (small diameter duct, low air velocity and long ignition time) it is a difficult test for plastics to pass.

The fire retardant bisphenol-A polyester Atlac 711-05, in several series of E-84 Tunnel Tests, has averaged a rating of 10 with a maximum of 15. Snuff-out times on the Ceilcote duct test have averaged 11 seconds, a very favorable score. No polyester has passed the Factory Mutual test as of this time.

As already mentioned, correlation of results from any test to real life is difficult. No material is isolated in a test chamber, but is part of a structure, a system which includes many elements that react and interact with each other in unpredictable ways. Therefore, the newly revised NFPA code, which we discuss later, places certain restrictions on reinforced polyester structures.

No material is impervious to damage, not even steel. As Steingiser remarks, "In a holocaust, it is not unusual to see 24-inch steel girders or I-beams 30 to 40 feet in length twisted like pretzels . . . Even though steel does not burn, in a constrained system, it becomes an important parameter."

Again, we state that all plastics can burn under some set of conditions. But several resins have been developed that have excellent flame spread ratings and, when properly used, exhibit excellent performance.

SAFETY RECORD OF FRP

A few cases of fires involving FRP duct have been extensively reported. This has generated a negative reaction in many people, even though some of the equipment involved was not even made with fire retardant resins. This is particularly true of equipment installed prior to 1969, when ATLAC 711 became commercially available. A scanning of reports from insurance investigative groups reveals that many of the reported fires could have been avoided. For example, there are five reported cases of FRP tanks running dry with an immersion heater operating in them. The resulting tank fires spread to associated FRP ducts. Obviously, this kind of fire is unnecessary and could have been avoided with a simple automatic shut-off device on the heater.

PRODUCT STANDARD AND RECOMMENDED INSTALLATION PRACTICES

Almost everyone in the industry is by now familiar with the Product Standard 15-69 published by the Dept. of Commerce. Relative to this discussion, this standard cites the ASTM E-84 Tunnel Test as the mechanism to measure the burning characteristics of building materials. Incidentally, laminates made from Atlac 711 meet all the strength requirements and other physicals called for in the product standard.

In addition, the SPI has published a set of Recommended Installation Practices for equipment of the type described in the Product Standard 15-69. Concerning ductwork, the document states, in part:

"2.3 The duct composite shall have a flame spread rating of 25 or less as measured in accordance with ASTM E84."

The document, in addition to several recommendations concerning capacity and routing of the duct, also states,

"5.4 All hoods and air-moving equipment (AME) which are part of the system shall have flame spread rating equal to the material of the duct system . . ."

Provisions for safety shut-down are essentially the same in the revised NFPA code (see below) but the importance of the flame spread rating is evident.

NFPA CODES NOW RECOGNIZE PLASTIC

Many have been under the erroneous impression that FRP duct would force intolerably high insurance rates or even that FRP was "forbidden." This is not true.

The most widely accepted standards are those issued by the

National Fire Protection Association (NFPA). The applicable Code in most of these situations is No. 91, which covers Blower and Exhaust Systems.³ A revision of the 1961 Code has now been published and, according to present information, will be included in the NFPA "Red Book" in 1973. This document recognizes that corrosive environments often dictate use of materials other than metal. The new Section 500 covers systems involving plastic materials. We quote (in part) several applicable paragraphs from this code:

"5101. Duct systems of plastic material may be used to handle only nonflammable corrosive fumes and vapors when conventional duct systems will not be adequate."

The new code further states:

"5102. The plastic shall have a flame spread rating of 25 or less as measured in accordance with NFPA No. 255, Standard Method of Surface Burning Characteristics of Building Materials (UL 723, ASTM E-84-68)."

To insure adequate protection against fire, the new code states:

"5109. Automatic protection shall be provided at the duct intake, hood, canopy, and immediate areas thereof to quickly extinguish source fires."

Most state and local building codes and Federal (OSHA) regulations are in agreement with or cite the NFPA codes.

ENGINEERING SAFEGUARDS

What "automatic protection" is intended by the new code? Some of the procedures for adequate fire protection, such as automatic shut-offs and sprinklers, are really only common sense. An excellent reference work on the subject is "Chemical Plant Design with Reinforced Plastics" by John H. Mallinson.⁴ Mr. Mallinson points out that there are four basic steps in combatting or preventing fires in air handling equipment such as duct.

1. Remove fuel when possible. This is why all duct and exhaust systems should be cleaned out on a reasonable schedule.

2. Cut off air flow, to reduce available oxygen.

3. Inhibit the flame chain reactions. The presence of a halogen in the fire retardant resin formulation lowers combustion enthalpy, thus lowering flame temperatures.

4. Cool the area. Duct systems should have sprinklers in the system or overhead. Sprinkler heads, when exposed to corrosive vapors, must be of stainless or other resistant alloy, or protected with wax, pyroxylin or similar material. The cost of a sprinkler system must be weighed against the value of the duct system and the potential danger of spreading a fire. Suggested sprinkler spacings:

Duct Size	Sprinkler Spacing
to 36"	25 ft
to 60"	20 ft
above 60"	15 ft

Another technique successfully used in actual plant installations is a steam injection line, actuated by an automatic valve tied to a fire detection device. The steam snuffs out the fire when pulled through the system. In this case, the system is not automatically shut down, but this would also seem to be permissible under the newly revised code, for paragraph 5109 further states:

"Sensing elements provided at the aforementioned sources shall be arranged to shut down the blower system. This automatic shutdown may be waived if fire control can be improved through continued operation."

The new code further requires that plastic installations be completely labeled as to manufacturer, type of material, flame spread rating, and smoke development rating, and that equipment of thermoset resins (such as Atlac 711-05A) meet all the physical requirements contained in the provision of PS 15-69. It can thus

be seen that the NFPA code and the SPI Recommended Practices are essentially in agreement.

CHOICE OF RESIN FOR SPECIFIC APPLICATION

Choice of resin is a critical factor for equipment intended for corrosive environments. Several resin products display good chemical resistance but will not meet the requirement of a 25 rating or lower in the ASTM E-84 Tunnel Test. Atlac 711 with 3-5% antimony trioxide added as recommended, exceeds that, with a maximum of 15 and a low of 5. It will not support combustion; and when ignited from other sources, will extinguish itself when the ignition source is removed.

No corrosion resistant polyester has passed the stringent Factory Mutual test as of this time, as mentioned above. The effect of this is simply that the material cannot be used without including adequate sprinkler systems or other devices in the system design to guard against fire. It is a common misconception that materials which do not appear on the published "approved" list cannot be used at all.

On the other hand, several resins display good fire retardancy, but remember our basic premise: you should not consider FRP in the first place unless faced with a corrosion problem. Even a fire retardant resin has limited value if attacked by aggressive chemicals. For example, a widely promoted duct based on a phenol-formaldehyde system has passed the Factory Mutual test for fire resistance, but it does not have the chemical resistance of the Atlac resins nor does it meet the minimum physical property requirements of PS 15-69. In our files is a private communication addressed to a factory insurance group from a well-known engineering specialist responsible for the design and use of FRP duct in a large chemical plant. His letter says in part:

"...our chemical tests on this resin system have shown it to be unsatisfactory and (it) would not be acceptable for use in our duct system specification."

The requirement, therefore, is a resin that exhibits the best combination of necessary properties, including performance at the elevated temperatures that are often encountered in duct, scrubbers, and stacks.

CASE HISTORIES

One of the breakthroughs in high temperature applications for FRP occurred several years ago in a situation originally reported in a TAPPI paper.⁵ The Owens-Illinois plant at Valdosta, Ga., faced a serious corrosion problem in the breechings from their electrostatic precipitator. Plastic had never been considered for applications such as this because of high temperatures, to 340°F and fire hazards, but the only metals which would stand up to the corrosive conditions would have been impossibly expensive. Tests by O-I engineers, which included suspending coupons on candidate materials in the gas stream of the deteriorating equipment, showed that FRP made with an Atlac resin to be the best candidate. The installation (Fig. 1) required no additional insulation because of the plastic's naturally low coefficient of heat transfer, and the plastic unit gave many years of successful service before replacement due to plant modification. Because of the laminate's poor heat transfer, the interior of the laminate which contains most of the fiberglass and supplies the strength, retained its integrity.

This successful "first" drew much attention in the industry, and led many other mills to install similar units. Figure 2 shows a similar unit during installation at St. Regis Paper Co. in Jacksonville. This mill had gone through two metal units previously. Observe on the left in the photo a section of the new plastic breeching with edges sanded for field welding, and on the right a section of the old metal duct with fire blackened interior. This illustrates the point made earlier that the real danger is not so

much from the unit itself than from the materials which collect on the interior surfaces, in this case a fly ash that forms a salt cake with a high sulfur content. An additional benefit of FRP has been reported informally to us by several mills. The smooth surface of the FRP duct is much easier to clean. The cake used to cling tenaciously to the pitted steel surface of the previous unit, and had to be hacked and chipped away by hand by work crews. But the material is pressure-hosed off easily from the FRP duct. As stated earlier, flammable materials that build up in an air handling system should be cleaned out on a regular basis. This is an important part of any safety program.

Fig. 3 is a diagram of the extensive new pollution control system reported at the Crown Zellerbach mill at Camas, Wash.⁶ FRP made with Atlac 711 was used extensively for:

- SO₂ duct
- Tank tops
- Three Venturi scrubbers
- Fortification tower
- Stack
- Tail gas tower
- Acid sewer lines (made with regular Atlac 382)

Fig. 4 is a view of the Crown Zellerbach installation which has been responsible for a 70% reduction of the Biological Oxygen Demand (BOD) discharged to the Columbia River. The mill now meets present and anticipated state and federal water pollution control regulations. The mill utilizes the Magnefite* pulping system which uses magnesium bisulfite as the pulp cooking liquor. This is made from SO₂ and magnesium hydroxide; these two chemicals are recovered through the system, to be recombined again and again.

SUMMARY

Several fires have occurred in air moving equipment made of FRP. Some of these have received wide publicity and attention, even though the duct systems were fabricated many years ago without proper engineering safeguards as used today, and using resin systems that were not fire retardant. With increased emphasis on fire safety, several fabricators and end user plants have reported some resistance to FRP on the part of various underwriters and/or building code inspectors. Several cases have come to our attention where FRP was avoided in order to take the most troublefree course and not be bothered with sprinkler systems and other details. Or steel was selected for duct systems even when the engineers knew, in some cases, that the anticipated service life would be very brief and the system would have to be soon replaced. Obviously, this course is far more costly in the long run.

We are suppliers of a resin raw material to the industry, and cannot offer advice on system design or insurance problems, but we have summarized the current situation here, so that fabricators and others are aware of these basic points:

1. The performance of FRP duct and other equipment under corrosive conditions has been good. Analysis of reports indicates that many of the fires that have been reported could have been avoided; and further, several that occurred prior to 1969 involved resin systems that were not fire retardant.

2. Design and installation of equipment utilizing a chemical resistant and fire retardant resin such as Atlac 711-05A can be accomplished with proper engineering safeguards so as to meet requirements of PS 15-69 and the NFPA 91.

3. The majority of state building codes are also in agreement with or cite the NFPA codes. Duct and other equipment fabricated with Atlac 711-05A should gain approval by state and local officials.

4. There are four requirements of FRP equipment under

*Babcock and Wilcox TM

NFPA No. 91:

- Flame spread rating of 25 or less per ASTM E-84.
- Fire protection through sprinklers, steam injection, automatic shutdown, etc.
- Fabrication and installation standards of Product Standard 15-69.
- Adequate labeling as provided by the Code.

5. The new Federal legislation in this area, the Occupational Safety and Health Act (OSHA) will have far reaching effect on many businesses. However, OSHA presently cites NFPA 91; therefore, compliance with one presently constitutes compliance with the other.

In conclusion we offer this suggestion. In requesting quotations, purchasers and designers of fume handling equipment are encouraged to:

1. reference 15-69 and NFPA No. 91, and
2. specify choice of resin as well as content of antimony trioxide or other additives.

In this way, confusion will be avoided and the purchaser will be able to compare bids on a realistic basis.

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*Available at \$1.25 from NFPA, 60 Batterymarch St., Boston, Mass. 02110.



Fig. 1. First installation of its type was this breeching and stack at Owens-Illinois plant at Valdosta, Ga.

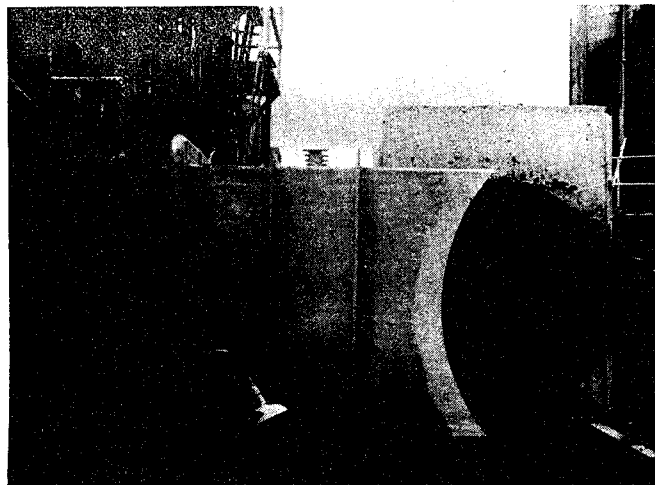


Fig. 2. New fiberglass breeching at left with sanded edges ready for field welding of joints. Section of old duct is at right.

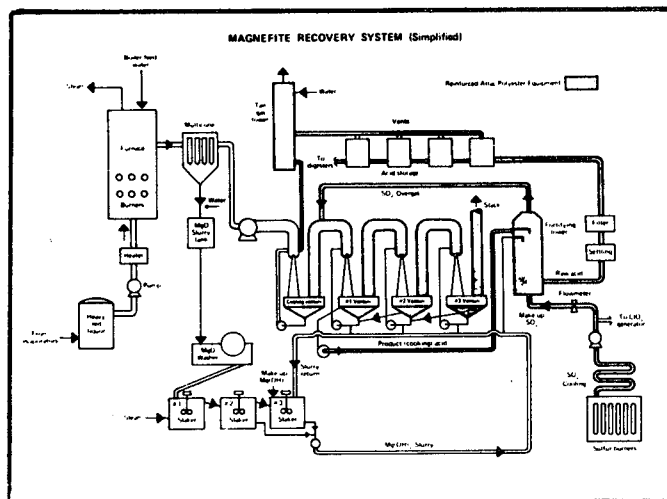


Fig. 3. Simplified sketch of Magnefite recovery system at Crown-Zellerbach mill at Camas, Wash.

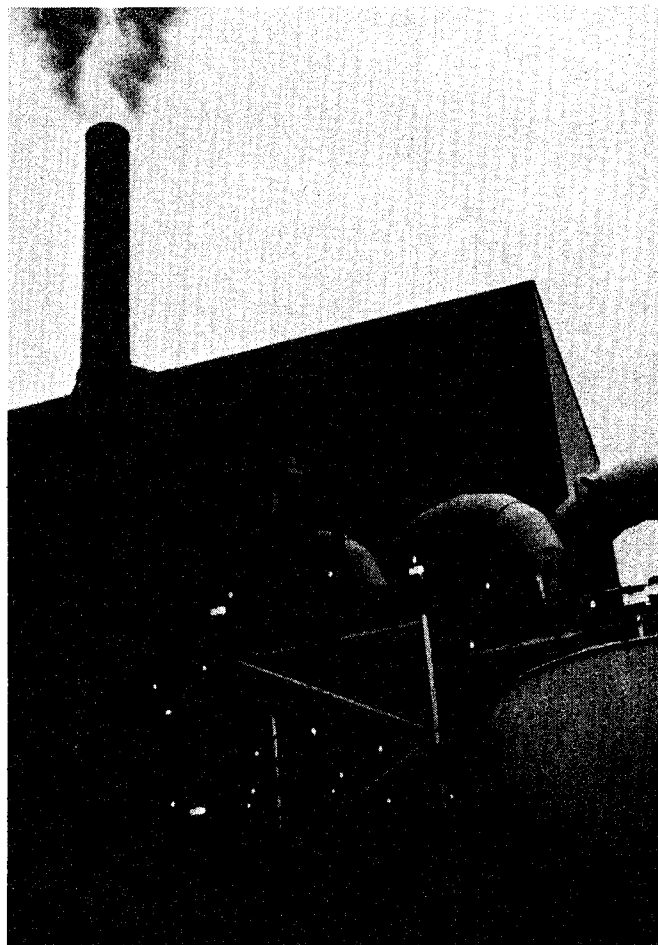


Fig. 4. Part of recovery system, showing FRP equipment including three venturis, stack, and fortification tower. Stack emission is mostly harmless water vapor.

WHAT THE CHEMICAL INDUSTRY NEEDS IN REINFORCED PLASTIC

by

JOHN H. MALLINSON*

ABSTRACT

This paper focuses on four areas in the use of reinforced plastics in the chemical industry where demonstrable improvement is needed. These areas are:

(1) The development of better resistance to slurry and gas stream abrasion. Some experimental work in this area is covered. Indications are that major improvements can be made. The end user can also materially improve his position through precautionary measures during installation. These are given.

(2) Better pipe joining systems at a reduced cost. The need for further improvement in RP pipe joining systems is suggested. Deficiencies of the present systems are explored and the requirements of a better system are established.

(3) An improvement in ductwork systems is desirable. While the industry has come a long way in developing high performance chemical resistant fire retardant ductwork systems smoke productivity from these systems is still considerable. Different types of ductwork systems are discussed—their advantages and disadvantages. The requirements for a high performance chemical resistant ductwork system with a low fire spread rating and a low smoke evolution rating is spelled out.

(4) The need for better training programs in reinforced plastics is demonstrated. Most present programs are rudimentary at best. The suggested training program involving all areas of need such as the engineer, the designer, the field supervisor and the craftsman are spelled out in detail.

BACKGROUND

The in depth end user of reinforced plastic material in the chemical industry in the areas of piping, ductwork, tanks and the different types of chemical process equipment speedily realizes the limitations which exist in the use of RP equipment. That is not only physical or chemical limitations inherent with the materials, but some of the methodology associated with the techniques and the industry.

All of us must realize that we are dealing with a relatively young industry. The steel industry is still evolving and it is relatively old. There is no reason to believe that the reinforced plastics industry will not similarly evolve and chances are it will at a much faster rate. The writer does not have the answers to the problems that he is going to pose. Some insights exist and the door has begun to open here and there—perhaps it will swing wide with advances in the next decade. We cannot believe that reinforced plastics are the answer to all things and all problems. Certainly limitations exist but if we can spread our avenues of knowledge a little wider the use of RP material will expand by several magnitudes. Certainly there are many areas that an individual could list as desired areas for improvement and what is listed here is only meant to be one man's opinion who has battled a cross section of problems facing the corrosion engineer and who has found that reinforced plastics today provide many of the answers and may provide still more as the technology evolves in the future.

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Some of the areas and targets which would be desirable for improvement are:

(1) ABRASION RESISTANCE

Failure By Abrasion

The use of reinforced plastic material, be it in the field of piping, ductwork, chutes, or agitated vessels, sometimes leads the engineer into a double barreled problem. That is, not only corrosion resistance but the ability to resist abrasion. One of the secrets of metallic resistance to a corrosive solution is that many times it forms a relatively impervious film or layer of material on the surface in contact with the corrosive solution. As long as this layer is stable no further attack occurs. But, occasionally a combination of corrosion and abrasion teams up to give a metallic surface a tough time. The corrosion resistant film is formed only to be abraded away. The action is repeated again and again and the metal finally fails through the corrosive-abrasive process. Now, in the field of reinforced plastics the mechanism may take on a completely different picture. Resistance to corrosion in RP is generally a "go—no go" proposition. There are no protective films to form. If the laminate is attacked chemically it will generally be found to be speedily unsuitable. Assuming that we have no disintegration or degradation of the laminate and where we are dealing with a combination of corrosive liquors carrying biting sharp crystals then we are faced with a potential failure from abrasion.

Case Histories—Good and Bad

Now, the RP material still gives a good account of itself even by conventional measures. For example, lead lines carrying crystals of Glaubers salt in a rayon spin bath solution have failed in three to six months while its reinforced plastics counterpart made of a polyester resin is still going strong after seven years. Magma slurries have been pumped continually through reinforced polyester piping for six years very successfully. The reinforced epoxies can also boast similar excellent case histories. We can generalize and conclude that FRP laminates provide good general abrasion resistance to slurries but don't perform well when we get into a sandblast type of action.¹

There are, however, a lot of unanswered questions in the field of abrasion resistance in the reinforced plastic area be it epoxy, furane or polyester. There is increasing evidence that at higher temperatures, in gas streams particularly when solid particles are being entrained, abrasion resistance of reinforced plastic material definitely suffers. This is particularly true in gas flows and where we are dealing with temperatures in the 250°F—270°F area. It is important to eliminate small areas of localized high velocity gases, particularly in direction changes if RP is to be successful in this area. For example,

(1) A 20" reinforced plastic elbow failed in 24 hours when subjected to an abrasive stream of Glaubers salt crystals being carried in a steam jet where the estimated velocity was 60,000' per minute. The remainder of the gas ducting carrying the same stream of crystals at an estimated velocity of 20,000' per minute showed no ill effects after 18 months of service. This successful ducting had long straight runs and sweeping ell.

(2) A control valve in slurry service throttled continuously and shot a jet of crystals against the 1/2" RP pipe wall which wore a hole in it in about fourteen months. Localized velocity was estimated at 20' per second. The area around it and downstream from it carrying the same crystal laden acid stream at much lower velocities such as 3—4' per second showed no ill effect whatever.

(3) A discharge in the apex from a cyclone carrying crystals in an acidic stream at an estimated velocity of 29' per second wore a hole through a 1/4" polyester pipe wall in several weeks.

(4) Modified evaporator flash chambers have shown evidence of

distress in 6—9 months where vapor velocities of 30,000' per minute are reached and right angled turns were involved.

(5) Condenser inspection plates receiving the direct impingement of the jet from a thermo compressor have failed in ninety days. The velocity profile on the cover plate was very evident. Carpenter 20 metallic blanks were placed over the cover plates to protect them from this abrasive force.

The Search For A Solution

Now, the history of abrasion in the RP field has caused sufficient concern under some conditions to have investigators attempting to find a better solution. To say that a cut and dried solution has been found to this problem would not be truthful. A number of investigators have reported methods of improvement in both wet and dry abrasive service but for some reason these have not been adopted generally in the industry.

The inclusion of organic veils in laminate construction such as mod acrylic, polyester, and polypropylene are reported as reducing losses due to abrasion.²

Incorporating in the laminate an abrasion barrier by saturating nylon cloth in a liquid adhesive and then impregnating the cloth with a silicon carbide. This has been reported to be helpful in assisting the abrasion resistance.³

One vendor makes a RP mortar sewer and waste water piping built up of an isophthalic polyester resin and silica sand reinforced with continuous roving glass fibers. Tests by the vendor show a minimal weight loss under abrasive conditions.⁴

The modified standard ASTM test in this area consists of a Taber abrader using calibrase wheels as an abrader which rubs against test specimen mounted on a turntable at given loads. The standard Taber abrader tests can only be considered as a preliminary test for screening of likely materials and samples after which extensive field testing must be undertaken to confirm the results obtained. Field tests must also ascertain whether any additives have changed the physical properties of the laminate structure along with its chemical resistance. In general, it has been said in the past that additives tend to leach out and lose their value in time. In preliminary testing using the standard Taber abrader some surprising observations were made:

(1) Laminates made from chemical resistant resins widely used by the fabricators today vary quite widely in abrasion resistance.

(2) In this test the Taber abrader was used on fiberglass reinforced plastic test samples fabricated according to SPI standards and containing different resins. The resulting Taber factor is expressed in milligrams lost per 1000 abrasion cycles using CS10 calibrase wheels at an operating counterweight loading of 1000 grams. Of course, the lower the number, the better the resistance to abrasion. The results of this test are:—

Resin A —	53
Resin B —	55
Resin C —	60
Resin D —	62
Resin E —	89
Resin F —	91
Resin G —	94
Resin H —	106
Resin I —	126
Resin J —	126
Resin K —	142

From the wide range of values, it could be concluded that the resin itself plays some role in establishing wear resistance of the laminate.

There are other factors which appear to have some influence on the abrasion properties of plastics. One is the type and completeness of cure. A recent test was made using resin 'B' in the fabrication of test samples, part of which were cured at room temperature for

four days and the other part were subjected to post curing at an elevated temperature of 200°F for four hours followed by ambient temperatures. After four days, abrasion tests were run. The room temperature cured samples had a Taber factor of 124 (Barcol 27) while the samples cured at 200°F had a factor of 55 (Barcol 38). The inference here is very strong. The first sample did not attain a complete cure and that the complete cure with a Barcol of 38 gave a measurable improvement in resistance to abrasion. This needs and requires further research and testing.

Various investigations are underway to improve the abrasion resistance of polyesters particularly, but may be equally applicable to the other thermoset resins. Some of these investigations involves proprietary additives which, in one case (Resin C), improves the abrasion resistance from a coefficient of 60 to 13, which is approximately 4.5 times better than the standard laminate. These tests have been expanded into the fabrication of chemical equipment, vapor piping, fly ash lines, and are in the midst of extensive field testing. Field tests extending over a year's time are encouraging in abrasion resistance, chemical resistance to rayon spin bath, and laminate physical strength and hardness.

Practical Methods of Improving Abrasion Performance

At this time the key to the best performance in abrasive service lies in:

- (a) Eliminating right angled turns—use long radius ells.
- (b) Keep the slurry flow parallel to the wall as much as possible.
- (c) Watch out for throttling valves or orifices that may accelerate the velocity tenfold in a localized area and impinge in an erratic manner against the pipe wall.
- (d) Where impingement does occur in small localized areas the area may be protected by imbedding in the laminate a 16 gauge metal sheet such as 316 stainless steel or Carpenter 20 or Hastelloy.
- (e) All laminated structures need to be cured completely if they are to be used in an abrasive service. The difference between a 27 Barcol and a 38 Barcol may double the life of the RP equipment. This may sound obvious but, unfortunately, we still receive fabricated equipment that has not developed a complete cure.
- (f) For a broad scale increase (450%) in abrasion resistance extending over the entire laminated structure resin modifications are necessary. At the present time our standard specification for laminates where an increase in abrasion resistance is required calls for an exact resin mix using an additive furnished by us and used in the fabrication at a prescribed thickness for the wear surface.

Present Abrasion Tests

Today there are a number of abrasive tests, several of which have been purposely developed to simulate field conditions—some of these are:—

(a) The ASTM standard D1044-56 (1961) covers the abrasion testing of transparent plastics with a Taber abrader. For opaque plastics, it is usual procedure to compare weight losses of materials tested rather than using the light transmission technique.

This is a dry test where calibrase wheels with known degree of abrasiveness and at given load, rub against a test specimen mounted on a turntable. The relative abrasion factor is normally expressed in milligrams lost per 1000 wear cycles.

(b) Another dry abrasion test is covered under ASTM standard D1242-56 (1961) where machines are used to abrade with either a loose abrasive or an abrasive tape. The relative resistance to abrasion is measured in these tests by volume loss.

(c) A favorite in slurry testing is to simulate long term abrasion conditions by rotating a section of pipe one-third filled with silt, sand and gravel for 3 million revolutions—then measuring the wall loss thickness in mils—a typical example of this kind of a test produced the following results:

(See next page)

Pipe material — wall thickness loss — mils	
Bare steel	— 1.1
Isophthalic polyester RPM	— 1.9
Mortar pipe	—
Cement lined steel	— 18.8
Epoxy coal tar and steel	— 20.5
Coal tar enamel lined steel	— 20.6

(d) Slurry Impingement⁵ Another very practical test seeks to identify the type of abrasion that occurs with the flow of solids and suspension against the surface. This is a very practical type of test. A stream of high velocity particles in suspension is directed against the sample of material to be tested. The volume reduction is measured under this exposure. A standard suspension of 3.5% Taconite solids (an iron ore) in water is pumped at a velocity of 30 ft./sec. through a 1/8 in. diameter orifice placed 1" from the specimen surface. After a standard time interval the volume of material removed is measured and a relative abrasion number assigned by comparing the results with standard polypropylene. The relative abrasion number then equals

$$\frac{\text{Volume \% Loss For Standard Polypropylene}}{\text{Volume \% Loss For Test Sample}} \times 10$$

It will be seen that the higher the abrasion number in this test the better the resistance to abrasion. This is an extremely practical test. A few of the abrasion numbers developed by this test are shown below:

Material	Relative Abrasion No.
Redwood	0.3
High density polyethylene	10-12
Mild steel	13
Natural rubber	14
Polyurethane	13-20
316 stainless steel	17-24
Ultra high molecular weight polyethylene	43-45
Ni-Hard	67

Recommended Further Work

Much work needs to be done in this area to:

- Provide resin additive formulations that will tailor make the equipment for high corrosion-abrasion performance. Many formulations may be necessary to solve different service conditions.
- A study of abrasion resistance as a function of temperature would be most helpful—there are some indications that at high temperatures (250°—270°F) abrasion resistance must not be as good as at temperatures 50°—100°F lower.
- Initiate a large broadening of abrasion resistance studies—In fact, work in this area has barely begun.
- We should recommend that the Society of the Plastics Industry should develop or adopt abrasion tests for both wet and dry service so that any proposed laminate system could be given a performance rating on the scale. This rating would, of course, have to be tied in with other SPI specs which have already been adopted. The advantages of a standard test in both wet and dry areas is obvious in establishing a reference of communication between fabricator and end user.

(2) BETTER PIPE JOINING SYSTEMS AT A REDUCED COST

It has been said by the uninitiated user of reinforced plastic piping systems that the biggest deterrent to their widespread use is the joining system. Most of the joining systems, taking one at a time, have their advantages and disadvantages. The writer would like to explore some of these with you.
(See Table 1.)

Now, a joint's satisfaction may encompass many things. An ideal objective would be to have a joint which was inexpensive to fabricate, such as the polyester butt and strap joint; one that is easy to take apart and reassemble, such as the O-ring coupling; and one which shows the ruggedness of a hand laid up flange joint. It should also be able to be assembled by a man with very little training and be assured of a foolproof connection. Obviously, we don't have all these things so that we are forced to compromise with either a butt and strap system or a flanged system or adhesive system or a combination of all three. Joints thus vary in cost from something that is relatively cheap to a joint which may be exceedingly expensive. The engineer then modifies his design and attempts to put systems together with a low cost joint of high reliability and adds enough flanged joints to permit him to install the system and to maintain it.

Because GRP is a late entry in the piping game it must dance to the tune of steel piping systems. For example, a GRP flange must make up to a 150# ASA flange. So we have a 30 million modulus metal (steel) on one side and a 3 million modulus plastic (FRP) on the other side. The contest isn't equal but we must still make do so the FRP flange must be given something extra such as raised face sealing rings to provide the same seal with the same bolt. Several different designs have been worked out with this thought in mind.⁶

This is the present "state-of-the-art", not completely satisfactory, but improving. The combination molded flange is an attempt to beat down the high cost of flanging. The adhesive flange system uses the same approach with perhaps better results but we are still looking for a low cost joint with high reliability, good corrosion resistance, and one which can be easily disassembled. This is the answer to an explosion in the use of GRP materials in many areas.

Unfortunately, the problem doesn't end there. A steel system can be drawn up to take care of misalignment. There is a danger in doing this on plastic systems. Molded flanges may be broken due to misalignment and pull up. Some plants take care of this through the frequent installation of bellows type expansion joints. In fact, some plants make it a standard practice to use a bellows type joint at any point they make up an RP system to a metal system, or to a pump, just to take care of misalignment. It is an exceedingly practical solution even though it adds to the total system installation cost.

(3) AN IMPROVEMENT IN DUCTWORK SYSTEMS^{7 8}

At the risk of sounding heretical, and knowing full well that there are many resins available in the marketplace which afford the purchaser the opportunity of buying duct systems with flame spread ratings of less than 25 and corrosion resistance which leaves little to be desired, what else can we wish for?

Basic Duct Systems Specifications

- Certainly any resin which is specified for duct systems should have a fire spread rating of 25 or less after the addition of a snuffing compound such as antimony trioxide. (ASTM E-84-61 Tunnel Test).
- The wise purchaser will make sure that sprinkler protection commensurate with the value of the duct system and the property to be protected is installed.
- The user will also make sure that periodical cleaning of the duct system both inside and out is done to prevent fire from combustible residues.
- Make sure beyond the shadow of a doubt that the resin specified will be completely satisfactory in the service conditions in which it will serve.

Now, we have said a lot here but have we said enough? Many resins systems available on the market today will fit the items mentioned above. The answer is that our suggestions above may represent the present "state-of-the-art" but they still leave something to be desired. Trace the history of fires involving GRP ductwork. The ones that caused the most serious losses came from smoke damage or ductwork decomposition and not from fire damage. Many

building codes require a flame spread rating of 25 and a smoke developed rating of 50 for air conditioning supply and exhaust ducts. Specifications such as this are fine for general office structures and buildings but cannot satisfactorily be met in special areas such as laboratory and process work. Here a supply may be handled by the conventional duct system to these buildings but fume exhaust is something else. Compromises must be made to meet the special corrosive conditions engendered by blistering chemicals travelling at high speed. It used to be that sound materials of duct construction in a fume exhaust system could be PVC, rubber lined metal, stainless steel, lead, brick lined concrete, plastisol lined systems. It is obvious, of course, that a stainless steel system or a brick lined concrete system are as nearly fire proof as can be obtained. They are, however, exceedingly expensive and costly to maintain. Rubber lined systems will burn and produce dense clouds of black smoke. No system is really fire proof as deposits in the system may burn and cripple the exhaust system by knocking out the fans.

Shortcomings of Present Materials

The present day generation of chemical resistance reinforced plastics to which additives have been blended will consistently produce fire spread ratings of less than 25 and sometimes 15. But the smoke developed ratings are less than desirable. Looking at the total span of polyesters, phenolics and epoxies, flame spread ratings may span from 15 up to several hundred, but smoke ratings may go from 400 to as high as 2400.

When we look at many alternate materials from which ductwork can be constructed, we still find a lot to be desired. Aluminum has very little corrosion resistance. While PVC may achieve a flame spread rating of 25 or less, a smoke rating of 2,000 goes with it. In addition, PVC decomposes by 300°F. If the fire gets real hot PVC will break down into hydrogen chloride plus other substances about 800°F. One plant which had an extensive PVC duct system suffered relatively little damage from the fire but major damage from the generated hydrogen chloride.

The olefin polymers break down about 400°F and, although generally satisfactory from a corrosion resistance standpoint, have very high flame spread ratings with heavy smoke development. Cement asbestos ductwork may explode about 1500°F. Plastisol systems may melt and let the fire drop down into the room.

Coated metal systems for ductwork leave a lot to be desired. If the coating is thin it may be porous. If it is thick we are back into the problem of a fire hazard again.

If we put an additive in the duct system material to lower the flame spread then we push up the smoke rating. For example, a material which may have a fire spread rating of 75 and a smoke rating of 600 may have a smoke rating of 1000 when an additive is used to lower the flame spread rating to 25.

When discussing this problem with a member of the SPI he readily conceded that difficulty exists in this area. It would appear that the GRP industry, while fully aware that such a problem exists, has not developed a satisfactory solution or compromise. To support this, one has simply to view the excellent film* on the T-341 Fire Test which simulates fire in ductwork conditions better than other tests now available. The production of smoke is very evident and alarming.

Recommended Targets

For your consideration, we need duct system resins and structures capable of achieving:

- (a) Fire spread ratings of less than 25.
- (b) A wide spectrum of chemical resistance compatible with the best resins available today.
- (c) A smoke developed rating of less than 50. Again, with this

achievement the industry would be able to expand its usefulness into areas that have heretofore been closed.

Certainly an approach of this type would receive a much more favorable attitude from the fire marshals and fire insurance companies and would be in a position to meet many of the building codes. A resin system meeting these specifications at a competitive price could speedily penetrate that section of the market concerned with fume handling and pollution reduction. If such a resin-additive system was equal to the best resins available today in chemical corrosion performance it would logically follow that such a system could move forward and become a standard for piping, tanks, and other chemical process requirements.

(4) BETTER TRAINING PROGRAMS IN REINFORCED PLASTICS⁷

The Reason Why

Although the use of reinforced plastics in the chemical industry can be traced back to the early 1950's its great in-depth use has largely been achieved in the past decade. Actually, material cost studies show that from 1961 to 1967 the cost of metallic systems rose by 34% but in the same period the cost of reinforced plastics went down by 23%. Since then, on the average, both types of systems have risen by 10-12%. Certain metallic systems have risen much more. It is also anticipated that the rise in cost of metallic systems will be at a much steeper rate.

The experience in tanks, ductwork and piping has proved to the chemical industry that these GRP materials have a definite place in our scheme of developing the optimum materials for the local function. But the use of this material does not grow full blown. It can only be achieved through a large amount of training at the levels of the field engineer, the designer, craft supervision, and the crafts themselves that finally make the ideas effective. The normal course of events in this field has proven that at the beginning labor performance was poor but this can be corrected through adequate training coupled with experience. To show the penetration that has been achieved in this field the experience of one chemical company showed virtually an insignificant usage in 1960 but by 1967 nearly one-third of the total cost of piping and fittings installed in the plant were spent in the RP area. Corrosion ductwork went from virtually zero in 1960 to 80% by 1967. Tanks and storage vessels zoomed from nothing to well over 60% by 1967. Today, in all these cases the figure is probably higher. By any standard, this new material merits serious consideration in the field of chemical process construction where the service conditions can be satisfactorily met.

Program Basis

Now, it has been suggested that a training program be put together strictly on the basis of manufacturers' literature. While we would be the first to agree that the manufacturers' literature is extremely helpful we believe that any training program should be of a much broader scope than this. Any program which is developed needs to provide training, not only in what to do but what not to do. It needs to be built up on a "need to know" basis tailored to fit the requirements of the people involved. There is, for example, little use in teaching the pipefitter many of the things that the engineer needs to know but at the same time there are certain fundamentals that need to be mentioned as some piping installations may be put up without drawings. Unless the craft is fully familiar with the do's and don't's we end up in trouble simply because the craft does not know what to do. It is not difficult to learn the few simple things that are required to install an FRP system and once learned it can be the end of costly corrosion and all of the efforts to maintain a metal system against corrosion. Briefly, we think that a training program in this field might consist of classroom training followed by field work.

*The Ceilcote Company, Berea, Ohio

Classroom Work

Each of these eleven proposed units would run one to three hours in length.

Unit 1 The Why of Reinforced Plastics

History, Reinforcing Material, Advantages, Scope, Relative Cost Trends.

Unit 2 Basic Application Principles

Resin Types, Laminate Systems, Service Application Guide, Product Standard.

Unit 3 Polyester Piping Systems

Laminates, Vacuum Service, Cost Information, Repair Techniques, Insulating Value, Light Stability, Advantages.

Unit 4 Epoxy Piping

Basic Construction, Installation Hints, Cost Information, Repair, Advantages.

Unit 5 A Reinforced Plastic Workshop in the Plant

Equipment, Use and Care of Jigs, Rollers, Saw, Grinder, Tapering Tools, Clean-up, Housekeeping, Storage of Resins, Accelerators, Catalysts.

Unit 6 Joining Reinforced Plastic Pipe

Methods, Costs, Bolting and Gasketing Specifications, Flanging Systems, Why Joints Fail.

Unit 7 Supporting and Anchoring Reinforced Plastic Pipe

Recommended Installation Practices for Epoxy and Polyester Pipe, Dealing with Pressure Surges, Design Check-points.

Unit 8 Reinforced Plastic and Industrial Sewer Drain Piping

Joining Methods, Excavation and Trenching, Costs, Installation Hints.

Unit 9 Personnel Labor Relations, Training and Safety

Safety and Hygiene Instructions, Resins, Catalysts, Adhesives, Reinforcing Materials, Building a Training Program.

Unit 10 Duct Systems

Costs, Wrapped Joints, Dealing with Expansion, Supporting, Repair, Prevention and Causes of Ductwork Fires, Cost Estimating, Product Standard.

Unit 11 Storage Tanks

Product Standard, Tank Construction, Filament Winding, Nozzles, Manholes, Accessories, Vents, Drains, Safety, Heating or Agitating in a Tank.

The above classroom training program could be tailored to fit the needs of the engineer, designer, or craftsman. For example, the **engineer and designer** would receive all eleven units with detailed emphasis on the reason why and many typical design problems. The **craft supervisor** would receive a similar program with less emphasis on the theoretical and more on the practical so that he would be aware of the needs of his particular craft. The **craftsman** himself needs to know the reason why in many cases but his instruction must be heavily practical. In a detailed workout, pipefitters could well benefit from Units 1-9 and 11. In many plants the painters are also used in RP installations, particularly on repairing tanks, piping, ductwork—so that their instruction would be in 1, 2, 5, 6, 9, 10 and 11. The sheetmetal trade, of course, is very active in ductwork installation and would be given Units 1, 2, 5, 9 and 10.

Field Training

Now, to get to the practical end, the field training program would consist of at least 3-4 months training in which the individual would have an opportunity to work on a variety of projects with direct instruction from his foreman. For example:—

Pipefitters — Training in wrapped joints, Cutting and fitting a nozzle to a tank, Making a tee, Safety, Encapsulating a line, Making a hot wrap, Making adhesive joints, Assembling piping sections, (both epoxy and polyester), Hanging a line, Anchoring, Tools, Jigs, Personal hygiene, Handling the resins, Adhesives, and Catalysts, Accelerated cure techniques.

Sheetmetal — Duct wrapped joint, Assembling a duct section, Hanging a duct section, Safety, Personal hygiene, Lay-out, Handling the resins, adhesives and catalysts, Accelerated cure techniques.

Painters — Wrapped joints, Encapsulating, Lining of vessels, Handling the resins, Safety, Adhesives and catalysts, Accelerated cure techniques.

Each supervisor should be provided with a field training check-off sheet to make sure that each individual has the opportunity to become well-rounded in the field.

Re-training in this area every 2-3 years, like every other area, is necessary. Craftsmen may begin practicing less than desirable techniques which they have developed themselves. New techniques and advances need to be taught.

In fact, at this time at least one company is thinking seriously of setting up a training program to certify FRP welders on a similar scale to that which is required for welders in the metal trades. It is believed that this would be a real advancement in the art.

Present Industrial Training

What I have said here is not meant to imply that training programs do not exist. They do. Some companies have done extensive work in this area while others have done relatively little. Most companies have been exposed to a cross section of fabricator know-how with some brief training on how to make a wrapped joint or how to make an adhesive joint and use a tapering tool. From this the program grew like Topsy and experience was the main teacher. This is hardly the best or most efficient way to learn as the mistakes are costly and the craft output low for a considerable period of time. A training program such as has been proposed here should definitely be a step forward.

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(Table No. 1)

METHODS OF JOINING PIPING SYSTEMS

Item	Type of Joining System	Advantages	Disadvantages	Comment
1	Butt Joints	a. Tremendously strong. b. Technique can be learned with little training. c. Equal in cost to adhesive joints in up to 6" in size and less expensive above that.	a. The joint cannot be taken apart for maintenance purposes. b. Is limited in use to polyester hand laid up pipe. c. To the "off again-on again" user of this equipment sufficient familiarity with the technique may become lost, producing unreliable joints. d. Should be made in temperatures above 50°F and under dry conditions.	The standard low cost joint with polyester hand laid up pipe.
2	Adhesive Joints	a. Very economical in sizes up to 6 inches. b. When properly made makes an extremely strong joint as contact area is considerable. c. Joint can be assembled with low manpower requirements	a. Above 6" in size the cost is more than a butt joint. b. Glue line cracks can be a problem. c. Mixing the adhesive per instructions is of great importance.	Commonly used with filament wound systems as a standard low cost coupling.
3	Flanged Joints (Adhesive-Epoxy)	a. A low cost flanged joint. b. Advances in technology have developed a tremendously strong adhesive. c. It is a tremendously strong flange.	a. Glue line problems in the adhesive can provide a real obstacle in system assembly under hammering and surging.	The use of flanged systems should be limited to that required for maintenance purposes and the replacement of metallic or lined flanged fittings.
4	Polyester Flanges: (A) Press Molded	a. Low cost, comparable in price to epoxy flanges.	a. Must be used with full faced gaskets. b. Cannot be over-torqued or failure at flange neck will result.	Can be used to make less expensive stub ends but must be handled with care on installation.
	(B) Hand Laid Up	a. Very strong joint. b. Although not recommended, joint can be used without a full faced gasket.	a. A most expensive joint and one which must only be used to provide system assembly and maintenance. b. Inherently a flange joint is weaker than a butt and strap joint. For example, on a 100# system flanges may begin to weep at 400 PSI but a butt and strap joint may go to 900-1100 PSI. Standard specifications are that they will be tight at twice the design pressure.	Unbelievably strong - in thousands of applications have only witnessed one or two failures.
5	O-Ring Type Joints: (A) Bell and Spigot (Flextran* as an example)	a. Commonly used in sewer service. Resists earth movement and tremors. b. Joints will pass a very tight specification on sewer service under 100 gal/in./mile/day at 50' head. c. Joint deflection of 20-50 permissable depending on size, reducing fitting costs.	a. Normally considered to be a sewer pipe and not recommended for pressure applications above ground.	An integral bell with a spigot end. Rubber ring makes a tight seal.
	(B) Quick connect Couplings (Kwikey**)	a. Satisfactory for moderate chemical service with 225# pressure rating for steady service and 150# for cyclic service. b. Eliminates need for adhesive and provides simple field assembly and disassembly. c. Good for temporary application and one where dismantling must be easy. d. Joint is re-usable. e. Good for long, straight piping lines and down-hole piping.	a. Temperature limitation of 150°F. b. In severe chemical service where a fitting is required an average of every five feet this joint would lose much of its advantage.	Quick connect coupling, using two O-rings and a double groove and key arrangement with each coupling to provide positive locking. Joint may ultimately be adapted to tough corrosive conditions.
6	Screwed Joint	a. Quick assembly. b. Easy disassembly. c. An inexpensive joint on small piping. d. Satisfactory for water and mildly corrosive systems.	a. Commonly disappears in larger size piping. b. Shows weakness in highly corrosive systems and premature failure.	A type of joint sometimes favored in the epoxy piping system or machine made systems.

*:-Trademark of Johns-Manville Corporation.

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PRESS MOLDED FLANGES FOR F.R.P. PIPE SYSTEMS

by

D. E. FIDDES* and J. LAZAROU**

ABSTRACT

The development and design of polyester premix molded flanges is documented. The advantages and disadvantages of press molded flange systems are discussed from both technical and economical aspects. Equipment and techniques used in production and assembly of flanges are detailed. Case histories are used to illustrate the various advantages.

GENERAL

It is generally accepted that connections in a pipe line system to valves, pumps, and in most cases tanks, will be achieved by the use of flanges. Flanges are also a desirable method of assembling piping systems inasmuch as they provide the following advantages:

1. The use of prespooled sections.
2. The ease of assembly and disassembly for cleaning purposes.
3. Partial replacement with minimum downtime.
4. Minor skills required of workmen to assemble or disassemble sections.
5. The joining together of pipes manufactured of different materials within one piping system.

The accepted system of joining together reinforced plastic piping is the butt and strap method. In fact, the use of flanges is recommended to be kept to a minimum¹. The primary reason for this recommendation appears to be due to the high cost of hand lay-up flanges². Because of these problems it is possible that many reinforced plastic piping systems have been designed without having the advantages which would accrue from the use of flanged connections. Furthermore, with the increasing costs of field labour the butt and strap joint is no longer as attractive to the end user or installing contractor who is faced with high labour costs in the field. (See Table I)³ The most obvious method of reducing the cost of flanges is to employ mass production methods and this leads to consideration of press molding with premix materials.

The use of press molded flanges goes back several years and various designs have been produced and marketed.

DEVELOPMENT AND DESIGN

Our approach was to collect as many of the existing press molded premix flanges as possible and to test each to destruction and examine the nature and method of failure. Parallel to this program various hand lay-up flanges were made to the recommended dimensions (See PS 15-69) and also tested to destruction. All the press molded samples tested were of the adhesive slip type connection and in most cases failure was observed in the hub section of the flange.

With economic considerations being foremost in the mind of the designer we first attempted to produce a press molded flange to the basic dimensions outlined in PS 15-69 for hand lay-up

flanges. Also, to provide a higher sealing pressure at the gasket face it was possible to incorporate grooves into the flange face surface at this time. (See Figs. 1 and 4).

The first trials were conducted on 2" diameter flanges and the second set of trials were conducted on 8" diameter flanges.

Flanges made in accordance with the dimensions outlined in Figure 1 proved to be reasonably satisfactory during the test program. However, ultimate failures did occur at the hub section. Theoretical analysis also shows that critical stresses are developed in this section. (See Fig. 2). It was then reasoned that by moving the neutral axis further away from the flange face and thus providing a more balanced design it may be possible to significantly increase the pressure rating of the flange. This was then done as shown in Figure 3.

The additional cost of this change is relatively small inasmuch as it only requires a few more cubic inches of relatively cheap premix material. The next phase of development work resulted from the fact that it was found impossible to retain flat faced gaskets at the higher pressures. This led to the trial of 'O' rings and ultimately resulted in the design of the molded in 'O' ring groove as shown in Figure 4.

With the molding of premix material we elected to drill the bolt holes after molding. (See Fig. 5). With molded holes the presence of "knit" lines requires additional material around the hole to provide adequate strength. Some available flanges achieve this by local sectional changes at the hole - a costly tooling consideration - or by oversizing the flange O/D⁴. This latter method while less costly for tooling, departs from sizes of flanges produced in metal and so results in mismatches at pump and valve connections, etc.

SPI PRODUCT STANDARD FOR COMPRESSION MOLDED FLANGES MADE FROM REINFORCED POLYESTER RESINS.⁴

Work on this standard has been carried out by a sub-committee for almost four years and the proposed standard is at Draft #7, as of August 4, 1971. This particular draft applies to press molded flanges connected to contact molded pipe (U.S. Department of Commerce Products Standard PS 15-69, 100 psi Service). There is on the part of some people some reticence to use press molded flanges made to this standard on filament wound pipe. However, we believe that if the filament wound pipe is manufactured to the recommended .1% design strain level, the application of press molded flanges to such a pipe will create less problems than could be experienced by putting these flanges on the 100 psi contact molded pipe. (see Appendix 1 for calculation showing this). The flange developed above can thus be shown as meeting or exceeding the requirements of this proposed product standard Draft #7.

CHEMICAL RESISTANCE

All of this development work was carried out using a polyester premix molding compound based on a bisphenol fumarate polyester resin. A paralleling development program was evaluating and testing the premix material in various corrosive environments. This testing program initially took the form of submersing premix molded sample along with the hand lay-up samples in various chemicals for periods in excess of twelve months. Examination was then carried out visually and by grinding or cutting the samples the depth of penetration (if any) was observed. It was found that in most cases the depth or penetration was less in the premix molded sample than in the hand lay-up sample.

It is suggested that this is possibly due to the fact that with short fibers of reinforcement material being used in the premix, together with complete and controlled cure of the resin system by virtue of hot press molding; the extent or penetration due to

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wicking action is minimized. Generally, it can be said that if a reinforced plastic piping system is suitable for a given environment; the use of press molded flanges based on a premix made from the same resin type as the pipe, will give equal performance.

This holds true for premixes based on vinylester resins for use with vinylester based piping and similarly for those based on hexachlorocyclopentadiene acid resins. After early development stages both the vinylester type and hexachlorocyclopentadiene acid base type premixes were incorporated into the test program for chemical resistance and other testing.

ADHESIVE SYSTEM

All of the original testing and early development was carried out using an epoxy based adhesive system.

However, it was realized early in the program that with significant amounts of piping being used for carrying of chlorine and chlorinated compounds the corrosion resistance of the adhesive could be a problem. We therefore initiated the development of polyester and vinylester based adhesive systems.

The requirements of a good adhesive system are quite complex but basically involve the ability to wet out the surface and provide a good chemical bond between mating surfaces. It's also should be capable of filling the space between the surfaces and doing this in a manner which provides high shear strength. With the low shrinkage factors involved in the epoxy curing systems these materials are the obvious choice for adhesives. The polyesters and vinylesters with relatively high shrink rates and shorter shelf life after mixing with fillers are far more difficult to produce as good adhesives. With proper mixing and surface preparation (See Fig. 6 and 7) and control of application it is possible to achieve a good polyester adhesive joint. A number of these systems are now available on the market.

PROBLEMS

With approximately 30,000 flanges of this design presently in use there have been remarkably few failures. Where there have been failures, careful investigation has in every known case shown that faulty techniques were applied during the application of the flange or installation of the system. These faulty techniques could be listed as follows:

1. Insufficient surface preparation of pipe or flange.
2. Uneven or insufficient application of adhesive.
3. Use of incorrect adhesive system, for example, epoxy in chlorine service.
4. Contamination of surfaces to be bonded.
5. Incorrect mixing of adhesive.
6. Joints carried out in unsuitable temperature and environment conditions.
7. Overstressing joints during installation due to:
 - a) Poor alignment of spooled sections.
 - b) Use of partial face gaskets.
 - c) Improper selections and/or positioning of expansion joints.
 - d) Over torque on bolts.

It should also be noted that failures of butt and strap joints could also be attributed to many of the reasons noted above. This was particularly true in the case of the early days of use of F.R.P. piping systems in the chemical process industry.

ECONOMICS

For the purposes of comparison See Table 2 and Figure 8 which are based on average labour rates paid in the Province of Ontario for reinforced plastic fiberglass work during 1961 and 1971 with a projection for 1981.

With the successes enjoyed by the use of press molded flanges we have also developed a line of press molded couplings. While it is not the subject of this paper to discuss in detail the couplings they are basically of similar design to the press molded flange. Table 3 and Figure 9 show a typical section of piping installed in 1969, in Ontario, Canada. For comparative purposes this has been costed out based on the use of press molded flanges, hand lay-up flanges, press molded couplings, and butt and strap joints.

Press molded flanges have worked successfully as tank nozzles. (See Figs. 10 and 11) An example here of economics would be in a case of a typical 24" diameter man-hole. The cost of a hand lay-up 24" man-hole flange is approximately 3 times that of a press molded unit.

DISADVANTAGES OF PRESS MOLDED FLANGES

1. Flanges are more susceptible to damage from over torquing.
2. With certain types of adhesive especially those based on polyester resin, control of the flange to pipe gap is needed for greatest strength.
3. Visual inspection of adhesive joint is not possible.
4. Higher skill requirement to assemble on pipe.

ADVANTAGES OF PRESS MOLDED FLANGES

The following list of advantages are considered to be significant factors in the recommendation to use press molded flanges for F.R.P. pipe systems.

1. Uniform resin to glass construction.
2. Better dimensional control.
3. Less expensive to produce
4. Controlled heat cure.
5. Better control of resin to catalyst ratio.
6. Better appearance.
7. Machine made, and therefore, capable of being duplicated with consistency.
8. With trained personnel, easier to install.
9. Controlled corrosion resistance.
10. Adequate strength for most F.R.P. piping application.
11. Capability of being manufactured with face grooves or 'O' ring grooves to assist in gasket sealing with low bolt torques.
12. Press molded flanges are in the process of being approved by S.P.I.

CONCLUSIONS

From the above we conclude that there are distinct technical and economical advantages to the use of press molded flanges.

It must be recognized that as with any other engineering material there are certain limitations which should be observed in their use. The butt and strap method of joining pipe is now accepted, but ten years ago this very method was regarded as being difficult, requiring special skills. With increased labour costs we submit that efforts should be made to train personnel in the application of press molded flanges as a means of controlling the costs of F.R.P. piping systems.

The authors wish to express their appreciation to Mr. R. Wills of Fibercast Company, Mr. R. Hayes of Dow Chemical Canada, and Mr. H. Thompson of C.I.L. Canada, for their valuable comments and information.

NOTES

1. NBS Voluntary Product Standard PS 15-69 Custom Contact Molded Reinforced Chemical Resistant Process Equipment. Para 3.5.7
2. Chemical Plant Design with Reinforced Plastics by John H. Mallinson, Page 65.
3. Table 1 is based on typical labour rates paid by both

fabricators and field contractors in the Province of Ontario, Canada, during 1971.

4. The 24th Annual Technical Conference, 1969, Section 4-C Proposed Product Standard for Compression Molded Flanges by Anton F. Fonda.

REFERENCES

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2. NBS Voluntary Products Standard PS 15-69 Custom Contact Molded Reinforced Polyester Chemical Resistant Process Equipment by U.S. Department of Commerce, Washington, D.C.
3. Chemical Plant Design with Reinforced Plastics by John H. Mallinson.
4. Proceedings from the S.P.I. Reinforced Plastics/Composites Division by the Society of Plastics Industry, years 1968,69,70.
5. Handbook of Reinforced Plastics of the Society of the Plastics Industry, Inc., by Samuel S. Oleesky and J. Gilbert Mohr.
6. Plastics Mold Engineering of the Society of Plastics Engineers, by J.H. DuBois and W. I. Pribble.
7. Handbook of Fiberglass and Advanced Plastics Composites by George Lubin.
8. Modern Flange Design Bulletin 502 by Taylor, Forge and Pipe Works.
9. Process Equipment Design - Vessel Design by Lloyd E. Brownell and Edwin H. Young.

JOSEPH LAZAROU

Born in Egypt. Graduated from the University of Alexandria, 1961. Worked for 4 years as a Design and Development Engineer for Home Appliances in Greece. Became involved in reinforced plastics in 1965, originally in boat making. Joined Protective Plastics in 1967, engaged in Design and Development of corrosion resistant products. Appointed Manager of Engineering Department in 1969.

APPENDIX NO 1

Consider a 12" diameter filament wound pipe, 100 psi compared to one of the same diameter and pressure, hand lay-up construction.

From PS 15-69 Wall thickness of hand lay-up pipe = 0.437"
Using Barlow's formula, average wall stress = 1373 psi
(Assuming modulus of elasticity of 1×10^6 psi)

Then Strain = 0.1373%

This exceeds the recommended 0.1% strain level for filament wound pipe.

The above strain will be partially transmitted to the flange hub area thereby applying a hoop stress in the hub of the flange. With premix material of modulus of elasticity of 1.5×10^6 psi is to be expected. Thus, the maximum hoop stress = $E \times e$ for the hub section of the flange will be:

Hand lay-up pipe to press molded flange $E \times e$ = 2059 psi

Filament wound pipe to press molded flange $E \times e$ = 1500 psi

Thus properly designed filament wound pipe exerts less stress into the hub area of the press molded flange.

DEREK E. FIDDES

Born in England. Entered plastics industry in 1949 and after serving a 5 year apprenticeship in tool making and mold designing returned to college on a Plastics Institute Bursary award. Graduated from Borough Polytechnic, London, in 1956, and after a period with Bristol Aircraft emigrated to Canada in 1957. Joined Naugatuck Chemicals engaged in Development and Technical Service, polyester resins and premix molding compounds. Joined Protective Plastics in 1961, specializing in corrosion resistant applications. Appointed General Sales Manager in 1969.

TABLE I³

	BUTT/STRAP	HAND LAY-UP FLG.	PRESS MOLDED FLG.
DIAMETER	A	B	C
4"	\$24.00	\$64.00	\$22.00
6"	\$32.00	\$74.00	\$31.00
10"	\$52.00	\$136.00	\$62.00

BUTT/STRAP

A - COST OF BUTT & STRAP JOINT - FIELD LABOUR + MATERIAL.

HAND LAY-UP

B - COST OF HAND LAY-UP FLANGES, SHOP FABRICATED & ATTACHED + FIELD BOLTING (LABOUR + MILD STEEL CADMIUM PLATED BOLTS + RED RUBBER GASKET).

PRESSMOLDED

C - AS FOR B BUT WITH PRESSMOLDED FLANGE.

TABLE II

6" FIELD PIPE JOINING

	1961	1971	1981?
BUTT & STRAP IN THE FIELD	\$19.00	\$32.00	\$52.00
HAND LAY-UP FLANGES IN THE FIELD	\$48.00	\$74.00	\$112.00
PRESS MOLDED FLANGES IN THE FIELD	\$20.00 *	\$31.00	\$43.00

* EXTRAPOLATED FIGURE IF PRESS MOLDED FLANGE HAD EXISTED IN 1961

1961 - MATERIAL COST SLIGHTLY HIGHER THAN 1971

1981 - MATERIAL ASSUMED AS EQUAL TO 1971

LABOUR COSTS AT 6% INCREASE/YEAR

TABLE III (See also FIG. 9)

METHOD OF ASSEMBLY	\$ TOTAL COST INSTALLED
PRESS MOLDED FLANGES	
Shop Fabricated and Attached	\$ 3,070.00
Field Bolting	
HAND LAY-UP FLANGES	
As Above	\$ 5,560.00
BUTT & STRAP- Field Joints	\$ 3,190.00
COUPLINGS - Field Joints	\$ 2,680.00

NOTE:

The above figures are for comparative purposes only and are based on typical published list prices. No allowance for lay-out or supports has been included

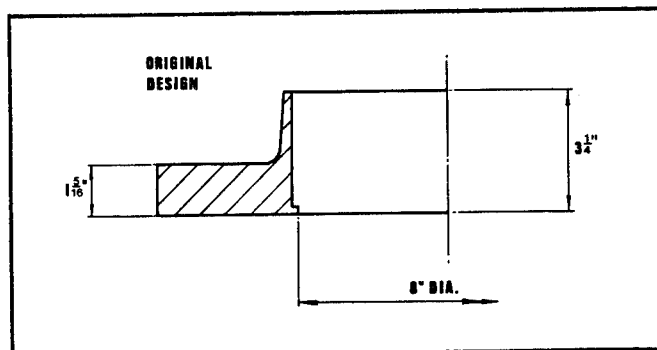


Fig. 1.

WELDING NECK FLANGE DESIGN

SHEET A

DESIGN CONDITIONS				GASKET and BOLTING CALCULATIONS				(From Design Tables 2 and 3)			
Design Pressure, P		150 PSI		Gasket Details		Facing Details		N = 2.750			
Design Temperature		AMBIENT		8" ID - 13 1/2" OD		FULL FACE		b = 0.585			
Flange Material		ATLAC-382-05		1/8" THK. NEOPRENE				y = 0			
Bolting Material		A 307 B		60 DIAMETER.				m = 0.5			
Corrosion Allowance		—		W _{m2} = bπGy = 0		A _m = greater of W _{m2} /S _a or W _{m1} /S _b = 2.36 sq in					
Allowable Stress	Flange	Design Temp., S _{f0}	2,000	H _p = 2bπGmP =	2,970 #	A _b = 2.42 sq in					
		Atm. Temp., S _{f0}	2,000	H = G ² πP/4 =	13,600 #	W = .5(A _m + A _b)S _a =	16,700				
	Bolting	Design Temp., S _b	7,000	W _{m1} = H _p + H =	16,570 #	W _{m1} =	16,570				
		Atm. Temp., S _b	7,000	Gasket Width Check (Raised Face ONLY): N _{min} = A _b S _a /2yπG = —							
CONDITION		LOAD		X		LEVER ARM		= MOMENT			
Operating	H _D = πB ² P/4 =		7600 #	h _D = R + .5g ₁ =		1.56"		M _D = H _D h _D =		11,900 lb in	
	H _G = H _p =		2970 #	h _G = .5(C - G) =		0.50"		M _G = H _G h _G =		1480 lb in	
	H _T = H - H _D =		6,000 #	h _T = .5(R + g ₁ + h _G) =		1.19"		M _T = H _T h _T =		7140 lb in	
								M ₀ =		20,520 lb in	
Gasket Seating	H _G = W =		16,700 #	h _G = .5(C - G) =		0.50"		M ₀ =		8,350	
Allowable Stress	STRESS CALCULATION—Operating Conditions (use M)				SHAPE CONSTANTS (From Design Table 4 and Design Charts 1, 2 and 3)						
	1.5 S _{f0}	Long. Hub, S _H = fM/λg ₁ ²	4377	2152	K = A/B =		1.69	h/h ₀ =		1.38	
	S _{f0}	Radial Flg., S _R = βM/λt ²	1826	496	T =		1.63	F =		0.67	
	S _{f0}	Tang. Flg., S _T = (MY/t ²) - ZS _R	1986	1450	Z =		2.08	V =		0.885	
	S _{f0}	greater of .5(S _H + S _R) or .5(S _H + S _T)	3181	1801	Y =		3.87	f =		1.0	
Allowable Stress	STRESS CALCULATION—Gasket Seating (use M)				OTHER STRESS FORMULA FACTORS						
	1.5 S _{f0}	Long. Hub, S _H = fM/λg ₁ ²			U =		4.26	e = F/h ₀ =		0.475	
	S _{f0}	Radial Flg., S _R = βM/λt ²			g ₁ /g ₀ =		2.5	d = U/V h ₀ g ₀ ² =		4.41	
	S _{f0}	Tang. Flg., S _T = (MY/t ²) - ZS _R			h ₀ = √B g ₀ =		1.41				
	S _{f0}	greater of .5(S _H + S _R) or .5(S _H + S _T)									
				t (assumed)		1.31	2.0				
				α = t ₀ + 1		1.62	2.02				
				β = 4/3 t ₀ + 1		1.83	2.36				
				γ = α/T		0.99	1.24				
				δ = t ³ /d		0.51	1.81				
				λ = γ + δ		1.50	3.05				
				M = M _D /B		2565	2565				
				M = M ₀ /B		1043	1043				
				If bolt spacing exceeds 2a + t, multiply M ₀ and M ₀ in above equations by: √ Bolt spacing / (2a + t)							
TAYLOR FORGE & PIPE WORKS											
P.O. Box 485, Chicago 90, Ill.											
District Sales Offices											
Atlanta					Philadelphia						
Chicago					Pittsburgh						
Houston					San Francisco						
Los Angeles					Tulsa						
Newark											
Computed <i>[Signature]</i>				Date		March 78/68					
Checked				Number		68/103					

① BASED ON h = 1 1/4", h/h₀ = 0.885

Fig. 2.

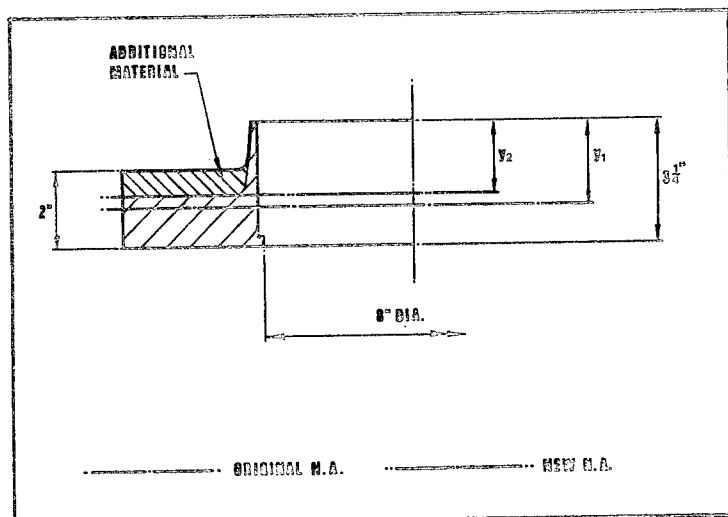


Fig. 3.

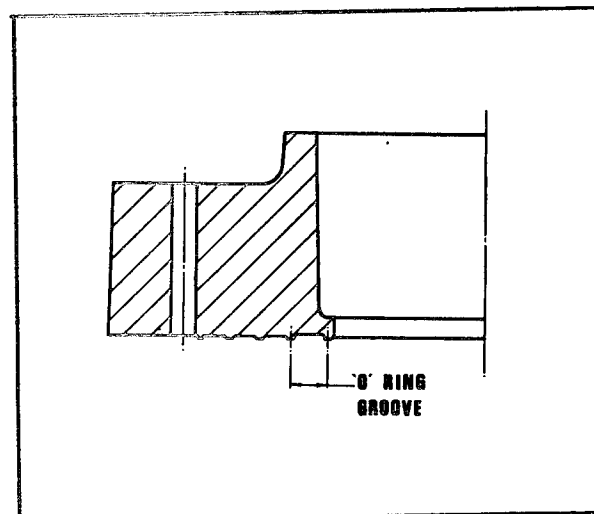


Fig. 4.

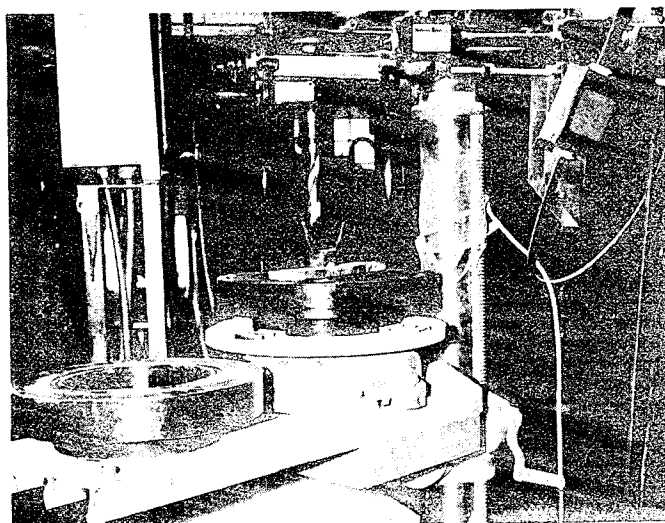


Fig. 5. Drilling of Bolt Holes

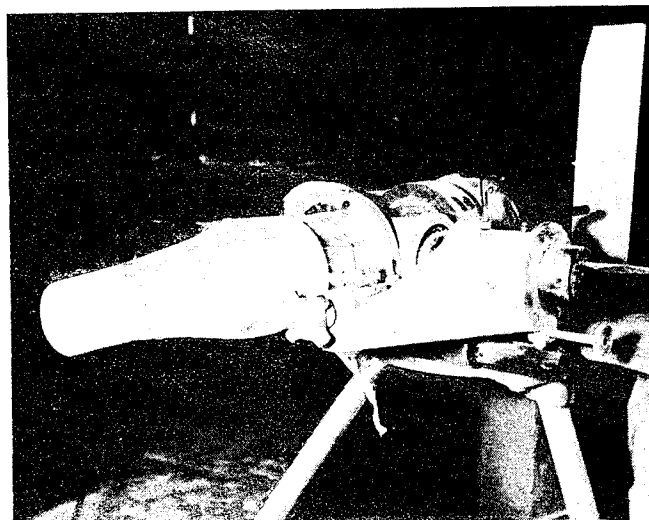


Fig. 6. Pipe Surface Preparation

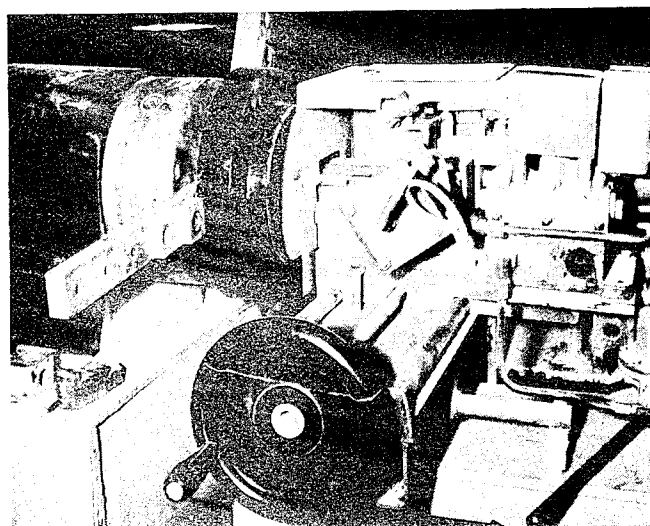


Fig. 7. Flange I.D. Preparation

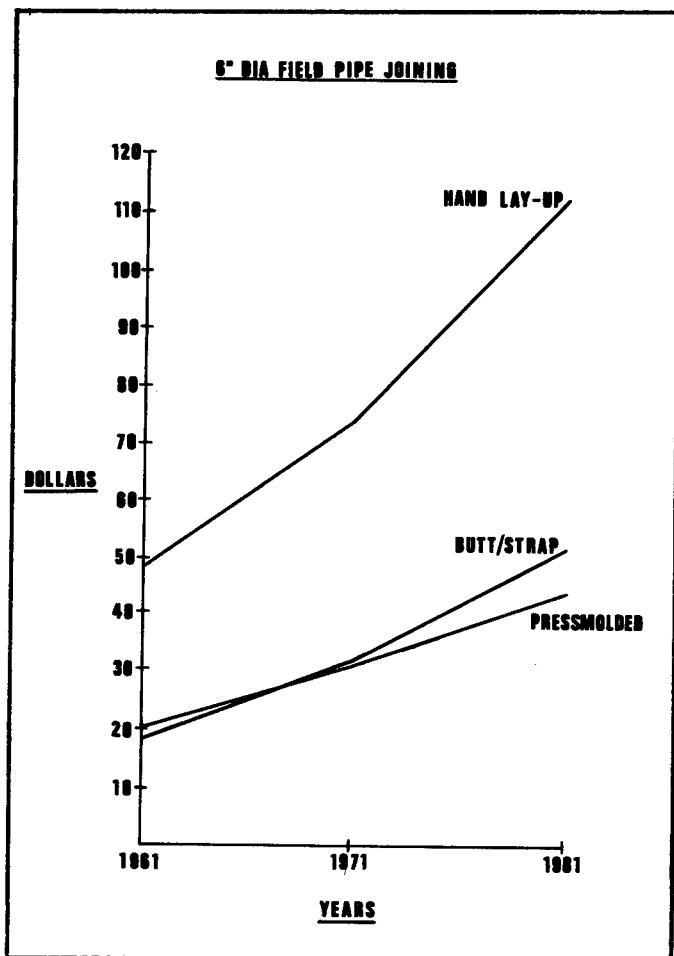


Fig. 8.

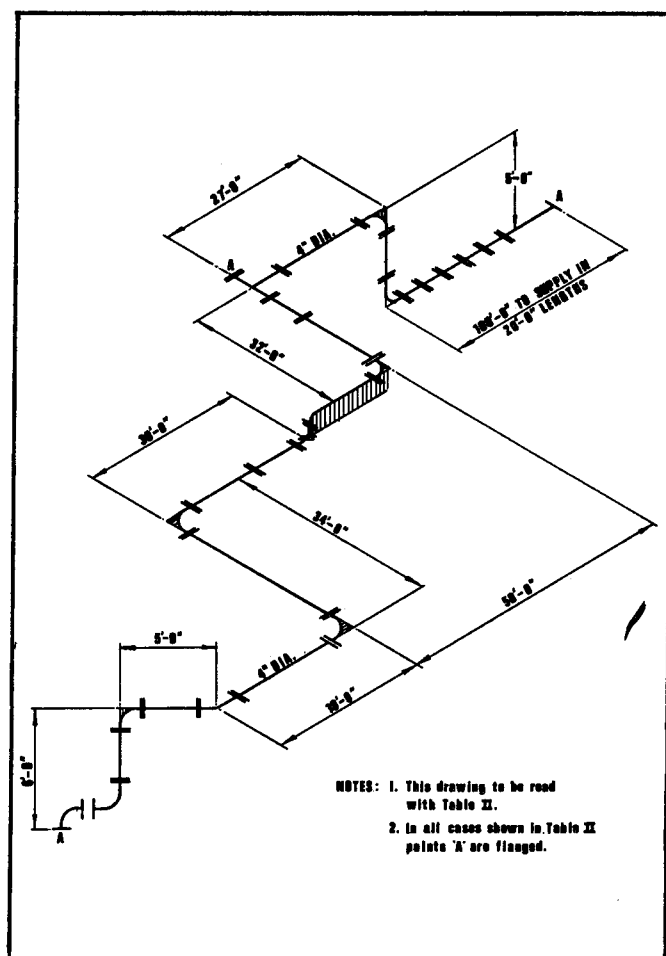


Fig. 9.

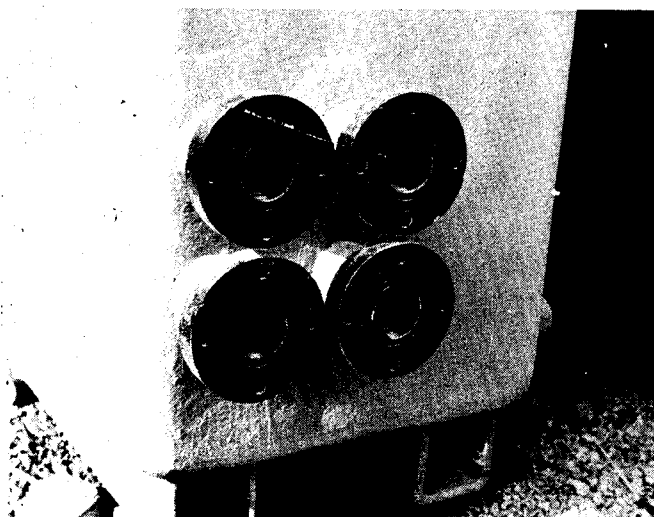


Fig. 10. Typical Application of Press Molded Flanges as Tank Nozzles.



Fig. 11. Press Molded Flange on Conical Tank Drain and as Bases for Support Legs.

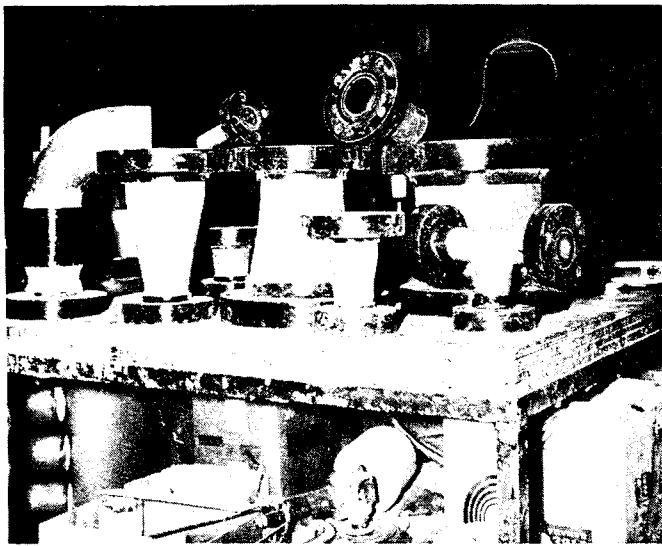


Fig. 12. Typical Fittings in Process of Assembly.

SECTION TWO

MATERIALS

A NEW APPROACH TO CORROSION CONTROL OF THE CHEMICAL PROCESS AND RELATED INDUSTRIES

by

ANDREW A. DUKERT* and ALKIS CHRISTOFAS*

ABSTRACT

Corrosion has always been a serious problem to man. From time to time new materials or new adaption of old materials have been developed to assist in overcoming corrosion problems. Each new development has still presented limitations.

A considerable effort by a special staff group at Pennwalt Corporation has resulted in the upgrading of KYNAR® dispersion corrosion control system. Although KYNAR® dispersion and similar coatings service life beyond 212°F (100°C) and especially where temperatures are cycled from high to low has been limited because of three factors (high shrinkage, high thermal coefficient of expansion and permeation), it has now been overcome by a KYNAR® laminate development. Other fluorocarbons and other chemical resistant base polymers reflect similar problems.

Basically a liquid carrier, the polymer in dispersion form is combined with a fabric to produce a laminate having qualities which enable the finished construction to realize the maximum physical and thermo-chemical benefits under most adverse conditions.

Development of the laminate program originated in 1960. Actual installations in the C.P.I. and elsewhere are limited however to about four years at this time. Extensive laboratory testing has shown that maximum continuous use temperatures in most liquid environments can be increased from 212°F (100°C) (maximum limit for KYNAR® dispersion coating and other polymeric systems) to 300°F (150°C) for the Kynar® laminate system. The KYNAR® laminate system guarantees greater strength, wider useful temperature range, impermeability, practically no shrinkage and greatly reduced thermal coefficient of expansion.

The laminate can be applied using specific adhesives or by self-bonding specially formulated dispersions.

Both self-bonded and adhesive bonded systems have withstood numerous temperature cycles between tap water temperature (approximately 50°F [10°C]) and 320°F (160°C) without blistering or becoming loosened in any way. In fact additionally subjecting the exposed plates and piping facilities protected with the laminate systems to 28 inches (71mm) of mercury vacuum at the elevated temperature point of the cycle had no adverse affect.

Chemical resistance tests have been run and are continuing. Whereas application of base polymer by way of dispersion coatings or otherwise bonded or applied melt processed polymer has limited safe operating temperatures, the laminate construction has provided the

means by which the maximum temperature/chemical resistance of the polymer can be realized.

Constant improvement in development and processing in the overall chemical industry has brought about a demand for structural and corrosion resistant materials which must withstand these newly created environments. Although structurally sound to begin with steel, stainless steel, nickel, titanium, special metal alloys and many polymeric materials soon give way to chemical attack in many services, especially at elevated or widely fluctuating temperatures.

In some cases precious or semiprecious metals including alloys can be used successfully but often present an economic or other disadvantage. This is true to an even greater extent when process equipment, tooling or accessories are of complicated design.

To some extent relatively inexpensive structural materials such as carbon steel have been protected by coating, overlaying, lining or in some way combining with other materials which afford greater protection against corrosion.

Although certain organic materials provide some protection against chemical attack in corrosion environments, the fluorocarbons are most outstanding in this respect. Unfortunately some of these same fluorocarbon materials present overriding disadvantages such as gross permeability, excessive shrinkage, high thermal coefficient of expansion, brittleness, high cold flow characteristics, low abrasion resistance, difficulty in processing or other commonly known poor features.

Comparing all of the advantages and disadvantages one readily observes that KYNAR®, Pennwalt's polyvinylidene fluoride, possesses the best "across the board" qualities. This means that while it does not excel in any particular property, relatively high rating in all areas single it out as an exceptional polymer.

KYNAR® has long been noted for its excellence in tough coatings for decorative outdoor exposure and highly corrosive chemical exposures. KYNAR® melt processed pipe fittings, pumps, valves in addition to an array of other equipment and products are long time standards for use in the chemical process industry. Similar applications are found in petrochemicals, food processing, automotive, nuclear, general transportation and other specialized fields.

Based on these convictions a logical development to minimize the several critical deficiencies was undertaken. The most glaring faults common to the vinylidene fluoride polymer in any form were obviously high shrinkage and high thermal coefficient of expansion. Photograph #1 shows four inch KYNAR® homopolymer tubing before and after exposure to 500°F (260°C) for 20 minutes compared with an equal thickness of the laminate exposed at the same time. The laminate tubing made by cold bending around a wooden mandrel then fusing another strip of the laminate to the butt joint. While the laminate tubing could have been reshaped (with pressure) to some degree at the 500°F (200°C) temperature, it was only slightly deformed as opposed to the homopolymer tubing which melted and completely lost its original shape. Since the crystalline melting point of the KYNAR® homopolymer is 340°F (170°C), it is readily understandable how the laminate construction has provided the means by which the maximum temperature/chemical resistance of the polymer can be realized.

First attempts to incorporate inert fillers with the polymer revealed that only limited loading was possible and certain filler materials containing silica and copper promoted decomposition within the range of processing conditions. While this is primarily true of the melt processed fills, especially when the compound is under pressure at elevated temperatures, the potential problem still exists to a lesser degree with liquid formulations. Even though shrinkage and thermal coefficient of expansion were lowered in filled formulations, the degree of change was limited. Furthermore lower tensile, impact and elongation properties became evident.

The use of reinforcing fibrous fillers in any form (woven, non-woven, knitted, etc.) to alter specific properties or qualities of any

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KYNAR is a registered trademark of Pennwalt Corporation for its polyvinylidene fluoride resin.

polymer has been practiced for quite a few years. However, resolving this detail for a polymer whose monomer is a gas and whose flow characteristics in the melt state are relatively poor creates quite a challenge. This triggered the development which has resulted in a patented process for realizing a polyvinylidene fluoride (or other) polymer reinforced with woven, non-woven, knitted or otherwise embodied impregnated fibers to form a singular or multiple layer laminated structure.

In order to best understand the need for KYNAR® laminates, one must recognize some of the shortcomings of corrosion control coatings using organosol types similar to the KYNAR® dispersions. Sheet linings with many polymers and even composites have also presented problems. It was evident quite a number of years ago that field failures were being experienced where KYNAR dispersions coated over metal objects suffered from blistering and general loss of adhesion when subjected to various environments. It was noted for instance that in boiling water KYNAR®, which is a very chemically resistant product, when applied in the form of a dispersion and coalesced into a solid continuous film suffered from gross blistering and ultimate total delamination. TFE, FEP, KYNAR®, KEL-F, polypropylene and penton sheet linings presented similar problems. At first the total picture was not readily understood. In time, however, it was recognized that an initial very tenacious bond could be realized by modifying the basic dispersion with additives to encourage adhesion and remain intact after as many as 11,000 hours in continuously boiling water. However, when objects coated with KYNAR® build up dispersion systems were subjected to higher than boiling water temperatures and especially when temperatures were cycled between boiling water (or higher steam temperature) and tap water temperature, in relatively short order the coating would become blistered and disengaged from the substrate. Water accumulated between the substrate and the coating. The obviously loose and wrinkled liner became vulnerable to physical damage.

Undesirable characteristics of high initial shrinkage, gross thermal coefficient of expansion and permeability of KYNAR® were singled out as the main reason for failure. Recognized differences in thermal coefficient of expansion between the coating and the substrate led first to filling the dispersions with compatible inert fillers to help minimize both shrinkage and the differences (compared to steel) in thermal coefficient of expansion. Even in spite of this the differences were still sufficiently evident that the interaction between the coating and the substrata at the interface when cycled between high and low temperatures in the presence of moisture always caused a failure in shorter time than one would term acceptable. The two 1/4" (6.35mm) thick 8" x 8" (203.200 mm x 203.200 mm) panels shown in photograph #2 show the tremendous significance and benefit provided by the laminate construction over straight homopolymer protection. Permeability (water vapor transmission) for the KYNAR® laminate is not quite as good as for homopolymer sheet of equal thickness. The considerable difference in initial shrinkage and thermal coefficient of expansion shows how this combination of qualities provides such markedly different high temperature behavior. The dispersion coated panel which originally exhibited tenacious adhesion was simply exposed to 280°F (138°C) in a 35 psi steam environment for 48 hours. The net result a complete loss of adhesion, blistered coating, and finally a broken blister. The panel covered with KYNAR® laminate was exposed to the same conditions. Nothing happened. The same laminate covered panel was then exposed to 320°F (160°C) in 75 psi steam for 24 hours. Before cooling 28 inches (71.12 cm) of mercury vacuum was drawn for one hour; then the temperature cooled to 50°F (10°C) for one hour. This cycle was repeated 35 times without failure.

It is rather obvious at this point that not only does KYNAR® suffer from the problems of high shrinkage and high thermal coefficient of expansion, but other polymers as well fall in this category. Photograph #5 shows comparison of steel vs. KYNAR® laminates and conventional fluoroplastics. Many materials are

chemically resistant themselves, but because of combination of factors they are at best a risk when used as a coating or lining combined with steel or other metals to control corrosion in chemical processes. In photograph #3 we see equal thickness panels of FEP¹ HALAR² KYNAR® and KYNAR® laminate (reading from bottom left in clockwise direction). Photograph #4 shows same panels after exposure to 300°F (149°C). Notice how the unsupported polymers deformed at this temperature. It is quite evident that the thermal expansivity of KYNAR® reinforced laminates is the most significant factor in its superior behavior over the homopolymer and other chemical resistant polymers used in corrosion control applications when compared to steel.

During early stages of the development of the KYNAR® laminates, even though potential rewards promised to be appealing this attitude was not shared by all. Preliminary results were extremely promising, but few people could be convinced that this was a desirable approach to overcoming problems of KYNAR® dispersion coatings and linings while it was in fact creating a new sound concept for corrosion control.

Once understood, the program progressed rather rapidly, took on new meaning and importance both in-house and with interested customers and end users. These laminates now promise to be an outstanding step in the direction of chemical corrosion control. Photograph #6 shows a single test cell used for evaluating KYNAR® dispersion coated or laminate protected steel plates. Steel cells of the same general design were used for testing similar panels at elevated temperatures and pressures. Similar device was described in a paper presented under the title of "Development of an Improved Method for Evaluating Tank Lining Systems" at the 18th Annual Conference, National Association of Corrosion Engineers, Kansas City, Missouri on March 19-23, 1962. Photograph #7 exhibits several chemical resistance test cells in which KYNAR® homopolymer dispersion coating and KYNAR® reinforced laminates were compared directly. Exposures indicate the laminates applied to metal substrates afford safe chemical resistance to chemicals without disbonding at temperatures up to 300°F (150°C). KYNAR® dispersion coated substrates are not recommended for any service above 212°F (100°C)

Basically while KYNAR® laminates are generally the combination of polyvinylidene fluoride resin and a woven or non-woven fabric, a multiplicity of materials can be used as the reinforcement media. For instance, felt materials, knitted materials, mats of various types can provide the reinforcing detail. Even pre-pregs can be made using conventional FRP fiber-resin spray techniques.

For the most part, there are two basic approaches to the KYNAR® laminate lining of process or storage vessels or equipment where chemical resistance or corrosion control is needed. These will be referred to as "wet lay-up" and "continuous free laminate".

Wet lay-up is the building of a laminated assembly of reinforcing media directly bonded to the substrate using a primer KYNAR® dispersion. Once the primer has been fused, successive layers of impregnated reinforcing media are applied to the desired thickness. An intricately shaped ball float and linkage assembly, photograph #8 for liquid level control, protected with KYNAR® (wet lay-up) laminate has stood up longer than any previously used materials in system which transforms anhydrous HF to 70% HF. It is obvious how corrosive this environment can be.

The continuous laminate is generally described as the impregnation of any number of individual layers of fabric, felt or knitted construction, solvent evaporated, resin fused, and then at one time heat bonded together in nip rolls. An alternate method can be continuously impregnating and fusing as a single web. Subsequently continuous or precut single plies are bonded together in the desired number of layers in a secondary operation. Heated rolls or flat bed molding pressure are used for such lamination.

Generally speaking woven fabrics (glass, synthetics, metallics, carbon fibers, etc.) or dense felt-like structures can be used in either of the systems to produce a sound construction which provides a

¹FEP is a registered trademark of E.I. du Pont de Nemours & Co.

²HALAR is a registered trademark of Allied Chemicals Corp.

chemical resistant barrier with the application of little or no pressure. Porous felts or spray-up of fibers and resins whether in pre-preg form or otherwise must always be predried (solvents evaporated) and then densified to shape and size using heat and pressure.

In the case of wet lay-up it is always necessary to prime the properly prepared metal (or other material) surfaces to be protected with a specially formulated dispersion. It provides the most tenacious bond when the total construction is exposed to severe chemical and temperature conditions.

The KYNAR® laminate system consists preferably of three layers of woven or non-woven fabric impregnated with from 50-60% of resin based on total solids weight. There have been deviations in both directions; that is, a fewer number of plies (layers) and a greater number of plies (layers). Number of plies (layers), types of reinforcing media, etc. are predicated upon the severity of the end use environment. One must always be attentive to just what is so important to overcome, "the interaction which takes place between the substrate and the protective construction during any temperature cycling", to fully appreciate the need to accurately control for optimum resin to reinforcing media ratio.

Use of the KYNAR® laminates provides the remedies to realize KYNAR's® maximum chemical resistance under the most critical temperature cycling conditions. It is by "building in" the shrink resistance, low thermal coefficient of expansion and additional reinforcing detail which limits or minimizes the interaction between the corrosion controlling laminate and the substrate, that one can appreciate the maximum temperature limitations of the base polymer (see photograph #2). Starved laminate constructions will naturally suffer by gross permeation and attack by active chemicals. On the other hand resin rich constructions also suffer because of higher shrinkage and the greater difference in thermal coefficient of expansion. To repeat, it was these inherent faults which originally prompted the laminate development.

Based on a number of service applications in successful commercial use and laboratory testing over the past several years, it is readily apparent that the two most objectionable factors (high shrinkage and gross coefficient of thermal expansion) have been for the most part overcome by the combination of the reinforcing materials with the polyvinylidene fluoride resin dispersion.

It is a prerequisite when dealing with KYNAR® laminate of either the wet lay-up or bonded types that substrate surface preparation be the foundation for a quality corrosion protective barrier. While it is absolutely imperative that the metal preparation be extremely carefully controlled, especially for the wet lay-up, it is also good practice to have the same treatment of welds, porosity in metal, etc. for the bondable type construction. In addition to good basic engineering design features such as generous fillets and radii, uniform cross-sectional thicknesses, identical or at least similar metals being combined, minimal number of components, etc; it is also necessary that cast, wrought, or otherwise processed metals be carefully inspected.

Both new and old metal constructions must be prebaked at a temperature of approximately 700-750°F (371-399°C) for a sufficient time to insure the decomposition of grease, wax, oil or other contaminant type products which may be imbedded or impregnated into the metal surfaces. Impurities such as rolling compounds and mill scale have been known to cause problems subsequent to coating with corrosion control finishes. They too must be removed. The time at temperature detail will vary for the simple reason that light structures can normally be baked out in a matter of a few hours as opposed to large, heavy vessels and heavy wall constructions which should be treated over night. Used vessels, especially if heavily impregnated with oily substances usually cannot possibly be made sufficiently clean and must be abandoned for new metal.

As mentioned before, the best basic engineering design principles for metal structures must be used so that the welding of plates or

sectional components are located at the most accessible locations. The welding must be completely sound; that is, free from blow holes and porosity. Any weld spatter or other extraneous material must also be removed prior to sandblasting operations. Welding should be completed first followed by grinding of the weld areas flush, smooth and free from holes and spatter. Sandblasting should be done with Ottawa type sand (or equivalent) so that the metal surface profile is approximately .005-.006" deep (0.127-0.178 mm) (never in excess of .008" deep [0.203mm]). If minimal welding and grinding are required after sandblasting to rehabilitate a vessel (either a new one or old one) it will not be necessary to sandblast again. On the other hand if an area of welding and regrinding is required, then welded and ground areas should be made free of weld spatter and resandblasted. Exact care must always be observed to make sure that the sand or abrasive media used is dry and free of contaminants. In fact sand or blasting media should only be used once and then disposed. Where old metal is being protected with the laminate, in the event that after sandblasting and initial coating with the dispersion primer any signs of leaching, bleeding, or other imperfect detail appear, it is best that all the faulty areas of metal be cut out and replaced. If the faulty condition is gross, replace the entire structure rather than try to protect the faulty metal with KYNAR® laminates. If KYNAR® laminates (in fact any corrosion control materials) are applied over the faulty or inadequately prepared metal, the useful service life will be considerably shortened.

On the wet lay-up system the metal surfaces after having been pre-treated should be primed using an appropriate KYNAR® dispersion and fused. The dry film thickness of the primer should be in the neighborhood of .004-.005" (0.102-0.127 mm). This is the main link between the substrate and the total corrosion resistant laminate system. Using specially formulated dispersions and processing technology, an appropriate number of plies (layers) of impregnated reinforcing media are applied and fused in place.

The KYNAR® laminate liner shown in photograph #9 is made to protect the interior surfaces of a butterfly valve. This unit still developmental boasts lifetime endurance because of ability to replace liner when worn or damaged.

The 10" (3048.01 mm) diameter (300 psi rated) KYNAR® lined tee in photograph #10 has been cycled from tap water temperature for two hours to 300°F (150°C) for twenty hours, evacuated at 27 inches (68.58 cm) of mercury while still at the elevated temperature for 15 minutes and is still intact after more than 200 cycles. The 10" (3048.01 mm) diameter end flanges (also 300 psi rated) shown in photograph #11 have withstood the same service conditions.

Large complex shaped agitator covered with KYNAR laminate has withstood extremely abrasive as well as corrosive environment for more than three years (see photograph #12).

Photograph #13 shows a 36" (91.44 cm) diameter x 4 foot (1.219 meter) flanged end vessel having multiple spool openings of various sizes. Lined with KYNAR® laminate this unit has been exposed to solutions ranging in pH from 3 to 8 at 200°F (93°C) plus for approximately two years without failure.

Photograph #14 shows how close details of domed head with many openings can be neatly covered with KYNAR® laminate.

Photograph #15 shows a Saunders type valve body which has been lined with the laminate. Parts such as this which require extremely close tolerances can be coined to dimensions as a secondary operation as shown in photograph #16.

Because of the resistance of KYNAR® to radiation, the glove box assembly shown in photograph #17 was lined with the laminate. Units of this type and other accessory equipment now command KYNAR® laminate as standard for protection against hot acids, nuclear wastes, and at the same time withstand mechanical abuse associated with this environment.

Continuous KYNAR® laminate whether for self-supporting construction or for a type which is adhesive bonded to a substrate or as the base of FRP construction is also made using specially formulated dispersions.

For self-supporting construction a single ply (layer) of reinforcing media is impregnated to between 50% and 60% dry resins solids based on total dry weight of construction. Single web impregnating and fusing equipment entails subsequent lamination into the desired number of plies (layers). Multiple web treating equipment affords in-line processing and avoids multiple handling.

Continuous (otherwise unsupported) KYNAR® laminate can be used instead of molding or otherwise assembled structures which require extreme chemical resistance over a wide range of temperatures. Such parts are easily constructed by cutting out in patterns which when assembled provide the desired geometry. The individual components are invariably butt joined and reinforced with a cap strip (also made of the base laminate) on one or both sides. Additional reinforcement can easily be incorporated to the required degree.

Evidence of the ease with which self-supporting structures KYNAR® laminate can be fabricated is born out in photograph #18 a 4-1/2" (114.30 mm) diameter stand pipe and photograph #19 showing a 24" (60.96 cm) diameter x 26" (66.04 cm) long scrubber vessel. The latter unit is in good service condition after more than three years at elevated and cycled temperatures. Photograph #20 shows a precut KYNAR® laminate in its flat and ultimately formed shape. This tower packing support grid is the only one of many materials used which has withstood an apparently extremely severe corrosive service. The chemical environment has not been identified but temperature in the service fluctuates from tap water to 250°F (121°C).

Composite products such as the honeycomb structure in photograph #21 are essential where weight is an important factor along with corrosion and abrasion resistance at elevated or cycled temperatures. Balsa wood, urethane foam as well as many low density core structural materials can be more than adequately protected against critical chemical environments with KYNAR® laminates.

KYNAR® laminates are teamed up with less costly polyester or epoxy resins reinforced and glass mat or other reinforcing media using conventional FRP technologies (see photograph #24). Stepwise build-up of total cross-section of KYNAR® laminate and FRP construction is shown in photograph #25. A similar construction is displayed in photograph #26 where the vessel is being tested under steam pressure. This same vessel has withstood in excess of one year exposure in bromine processing plant. Subsequently additional vessels were made embodying only minor design changes which attest to the desirability of this construction in such highly corrosive environment. KYNAR® homopolymer has been used successfully in bromine operations at lower than 212°F (100°C) temperatures for more than six years.

When the KYNAR® laminate is to be used for adhesive bonding to a substrate then one of the surface layers must be totally free of resin since polyvinylidene fluoride resin has exceptional release characteristics and is not readily bondable over massive areas. Here again specially formulated dispersions are selected for this operation.

Photograph #27 shows an operator welding a reinforcing cap strip in a highly stressed area.

When continuous adhesive bondable laminates are to be applied to vessels or other objects, metal preparation can be only slightly relaxed compared with metal treatment for wet lay-up. There must not be oily or waxlike substances either on the surface or imbedded in the metal since this will detract from the bond strength of the laminate to metal surface. This will be exaggerated at high temperatures, especially after cycling, and ultimately result in a delamination at the interface. The need for complete elimination of pinholes and deep pits in weld areas or heavily porous areas is not particularly critical. The epoxy adhesive will seek its own level and usually fill the porosity areas. Since there is no solvent to evaporate, voids or pinholes will not become evident during curing.

In the event facilities are not available for continuous laminating, then individual ply sections cut to the desirable total area can be laid

up in a press and press laminated. It is extremely important that only a minimal pressure be applied (5-10 psi) since excessive pressures will cause breaking of glass fibers at the cross-overs in a woven construction.

It has been most common to date to use glass fabric as a reinforcing media for economic reasons. It should also be understood that metal mesh (whether woven or knitted), carbon fabrics, knitted stretchables, and non-woven felts or matts of various compositions can be employed to make KYNAR® laminates. In each instance the dispersions used will remain essentially the same. Various combinations of reinforcing media within a given structure also provide economic benefits. As an example, one would not consider using glass either in HF applications or in strong caustic applications—carbon is preferred. However, surface plies (layers) could be carbon fabric and base plies (layers) non-woven glass fabric (felt).

Since the continuous laminate does not require exposure to successive fusing cycles, one may build as many plies needed only observing that the one face of the outside layer shall not be impregnated to effect the bonding to a substrate.

Continuous KYNAR® laminates are easily applied to simple curvature surfaces by first cutting patterns which when heat formed and assembled, will provide a continuous cover and then bonding in place with a suitable adhesive. Epoxies are most commonly employed for this type assembly. Butt joints are carefully cleaned and a cap strip, also made of laminate, is fused in place centered over seam. Photograph 22 shows a mechanical method of clamping sections to be bonded in place. Photograph 23 depicts the "vacuum bag" technique.

Combination of wet lay-up and adhesive bonded KYNAR® laminates are also encouraged. Several recommended applications would be:

- 1) In the event oven equipment is not available to accommodate a given size structure.
- 2) When "field" installations are required.
- 3) Lined (flanged) pipe and piping products (including pumps, valves, etc.).
- 4) Plates or sections which will be field (or subsequently) assembled.
- 5) Parts of large buildings, roof, siding, large ducts, or other large structures.
- 6) Existing rail cars (both box cars and tank cars).
- 7) Barges or other transport submersibles.
- 8) Dock and bulkhead areas.

Photograph #28 shows a 30" (76.20 cm) diameter x four foot (1.219 meters) long flanged (both) ends vessel showing multiple openings and typical support system which makes both ends readily accessible. This is a combination of KYNAR® wet lay-up and continuous laminate.

Even though there are several schools of thought on whether spark testing or electrical testing of any sort is a desirable approach, there are many who insist on specifications which require this detail. In no case, however, should one guarantee to pass more than 10,000 volts regardless of the type of laminate being tested whether it be wet lay-up or the continuous adhesive bonded laminate. The basic reason for this limitation, of course, is because conductive fillers are sometimes used in the dispersions for the build coats of the KYNAR® laminate system. Therefore, one could easily destroy an otherwise satisfactory useful part by the application of a high voltage spark testing inspection.

Physical properties in general improve considerably for the KYNAR® laminate over the homopolymer as shown in table #1. Tensile, impact, elongation and other properties can vary even beyond values shown (for KYNAR®/glass fabric) depending on type and material used as reinforcing media. Values shown are representative of 7628 and 7520 types woven glass fabric laminates having three or four plies (layers) and between 50% and 60% resin based on total dry solids.

Continued progress is being made to provide even better quality laminate structures and to make them more affordable.

ACKNOWLEDGEMENTS

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ALKIS CHRISTOFAS

Alkis Christofas graduated from Praktikon Likion School in Athens, Greece in 1930. He majored in math and chemistry. He also studied chemistry at the University of Athens until 1933.

In Greece he worked as a chemist and production supervisor in the soap industry and vegetable oil extraction and refining industry.

Mr. Christofas came to this country in 1948 and worked initially in the ceramics industry. He attended LaSalle College and the Philadelphia Institute taking a number of associated courses in plastics technology.

He joined Pennwalt in 1953 working mostly in application research of new products. He joined the polymer group in 1958 in charge of application research and in 1960 was transferred to The Technical Service Laboratory of the Plastics Department where he is presently working as a Project Leader on application research and process development.

During this period he has authored or co-authored several patents for plastics, finishes and related equipment.

ANDREW A. DUKERT

Andrew A. Dukert, Pennwalt Corporation studied engineering at Baltimore Polytechnic Institute and Johns Hopkins University. He is a graduate of Maryland Institute in aircraft design. He studied air navigation under Commander P. V. H. Weems (USNR). He has been associated with the Martin Company, American Viscose Corporation, and was Vice President in charge of Engineering and Manufacturing at Penn Plastics Corporation before joining Pennwalt in July of 1960. He is well-known throughout the industry for his contributions to plastic engineering and for his work in S.P.E., S.P.I., and ASTM. He is author and co-author of a number of papers and patents on plastics and related subjects. Some of his inventions include fluorocarbon products, tooling, and equipment. He is presently Manager of Technical Service for Pennwalt's plastics materials.

TABLE I

TYPICAL PROPERTIES OF KYNAR GLASS FABRIC LAMINATES VS. HOMOPOLYMER

Property	Unit/Method	KYNAR Laminate	KYNAR Homopolymer
Thickness	Inches	0.045 - 0.060	0.045 - 0.060
	Millimeters	1.143 - 1.524	1.143 - 1.524
KYNAR/Glass Cloth	% By Weight	50/50 - 60/40	100
Shrinkage	Inches(in./in.)	0.030 - 0.090	0.0003 - 0.0005
	Millimeters	0.762 - 2.286	0.008 - 0.013
Plies		4 - Style 7628 Cloth	Not Applicable
		3 - Style 7520 Cloth (Or Equivalent)	
Coefficient of Thermal Expansion	In./In./°F	7.2×10^{-6}	9.7×10^{-5}
	ASTM D-696	(77 - 230°F)	(77 - 230°F)
Water Vapor Transmission	G/100 sq. in./24 Hrs (100°F)	0.025 - 0.123	0.026
	ASTM D-696	(.060" thick)	(.060" thick)
Tensile Strength	PSI	10,000 - 13,000	5200 - 7500
	ASTM D-1708		
Elongation	Percent	10 - 14	100 +
	ASTM D-1708		
Impact Strength	Ft. Lbs./In.	10 - 15	3.4 - 3.8
	ASTM D-256		

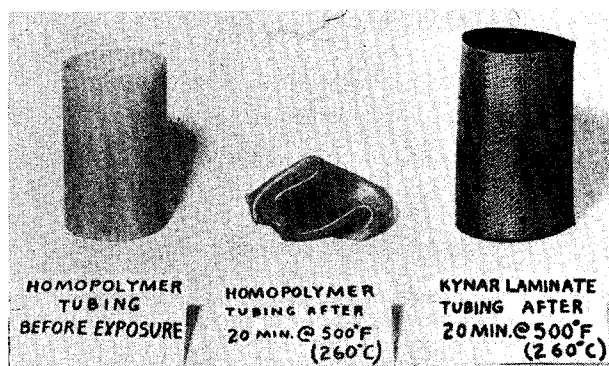


Photo. 1. Comparison of KYNAR homopolymer and laminate tubing exposed to elevated temperature.

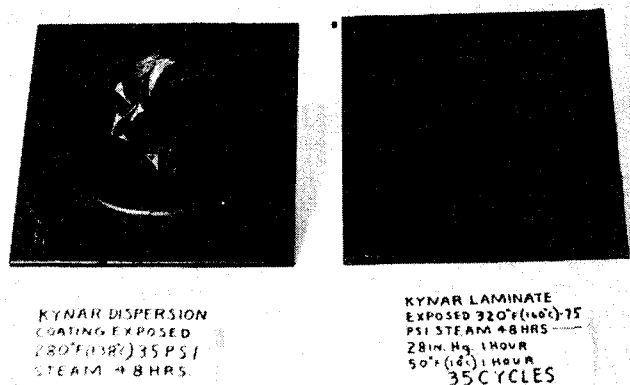


Photo. 2. Comparison of KYNAR dispersion coating and KYNAR laminate on steel plates.

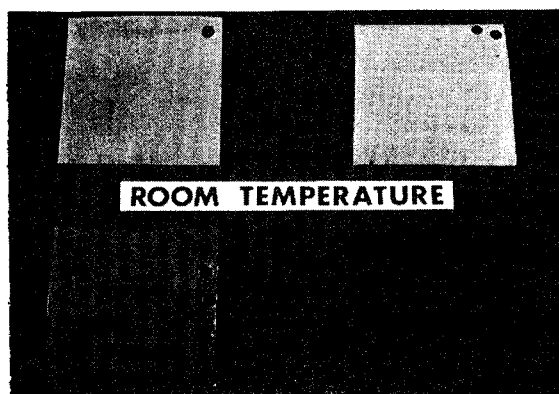


Photo. 3. 8" x 8" panels of FEP - HALAR - KYNAR and KYNAR laminate before exposure [read clockwise from lower left hand corner].

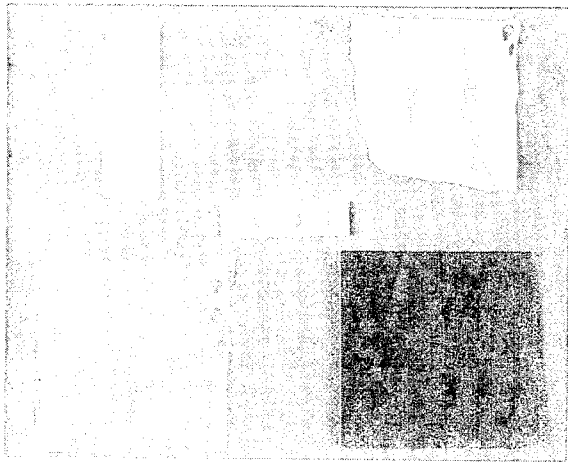


Photo. 4. 8" x 8" panels of FEP - HALAR - KYNAR and KYNAR laminate after exposure to 300°F. [read clockwise from lower left hand corner].

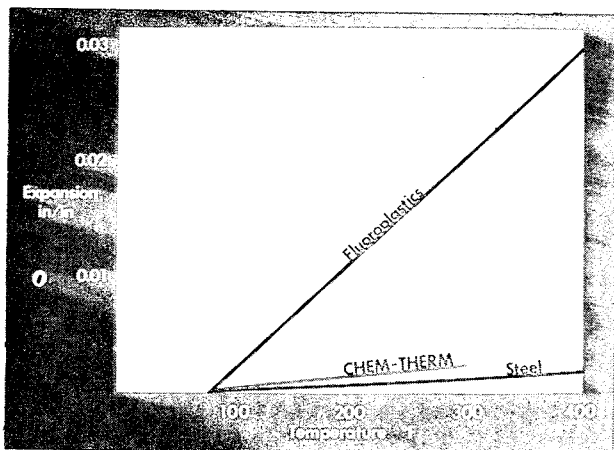


Photo. 5. Shows comparison of thermal expansion of steel vs. KYNAR laminates and conventional fluoroplastics.

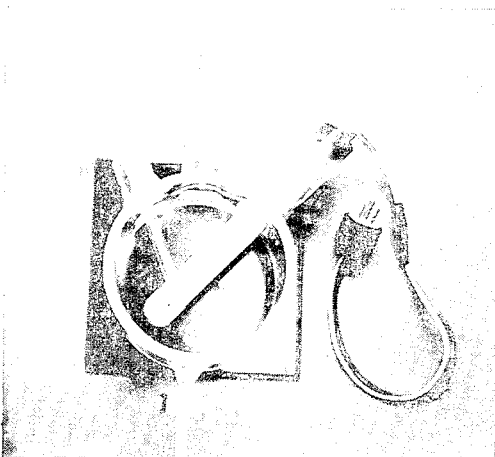


Photo. 6. Typical Pyrex test cell used for chemical testing of protective coverings over stand and 8" x 8" size plates.

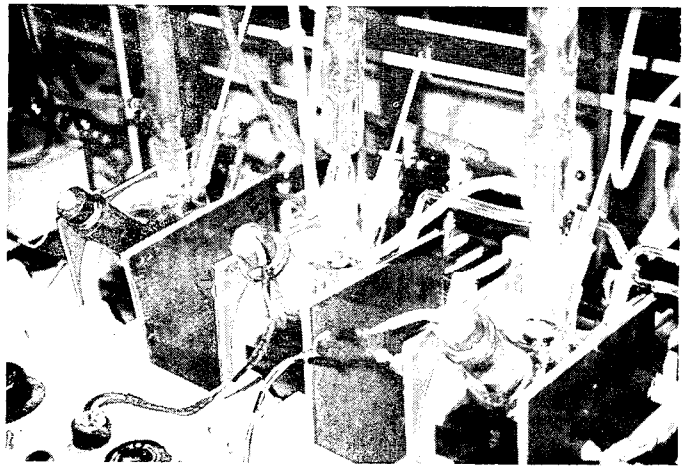


Photo. 7. General view of several chemical resistance test cells.

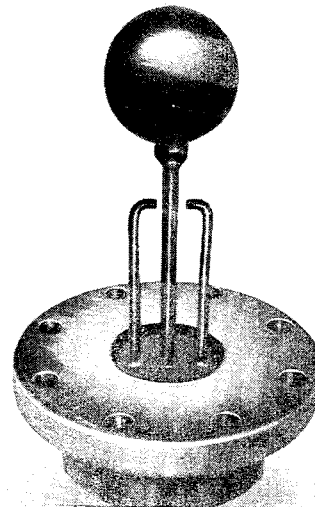


Photo. 8. Wet lay-up construction on liquid level device for H.F. service.



Photo. 9. KYNAR/Glass cloth laminate liner shown only partially completed using wet lay-up.

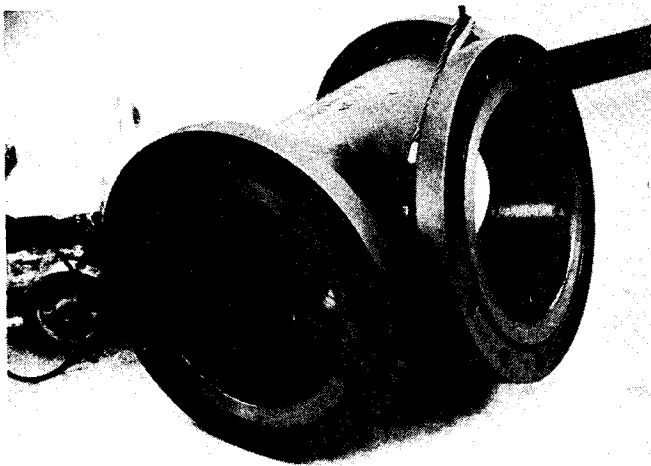


Photo. 10. 10" diameter KYNAR laminated lined pipe tee.

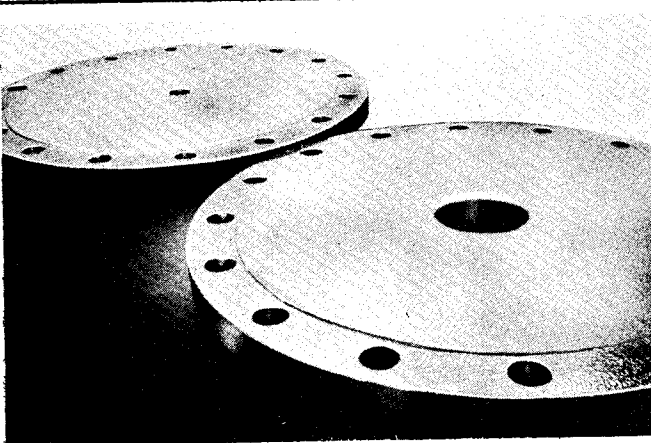


Photo. 11. Wet lay-up on 10" diameter flanged end covers [300 p.s.i. rated].

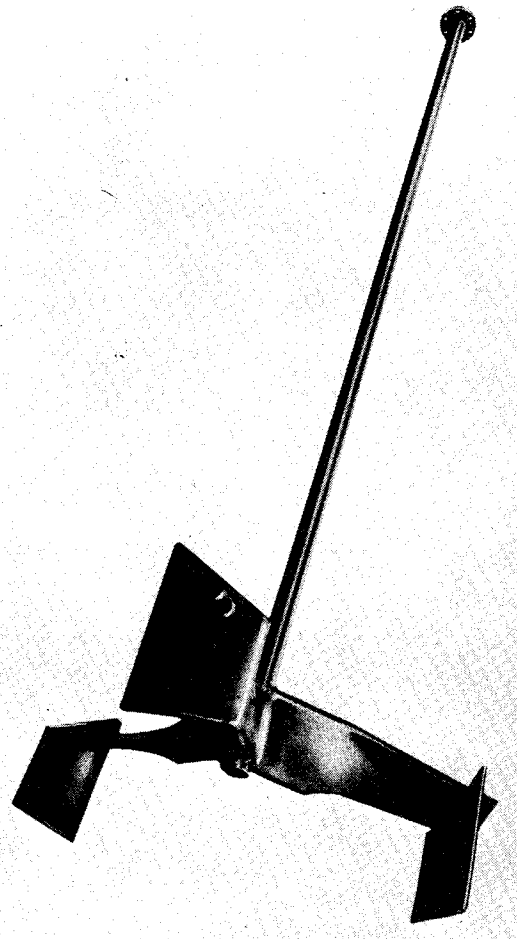


Photo. 12. Wet lay-up over intricately shaped large diameter agitator.

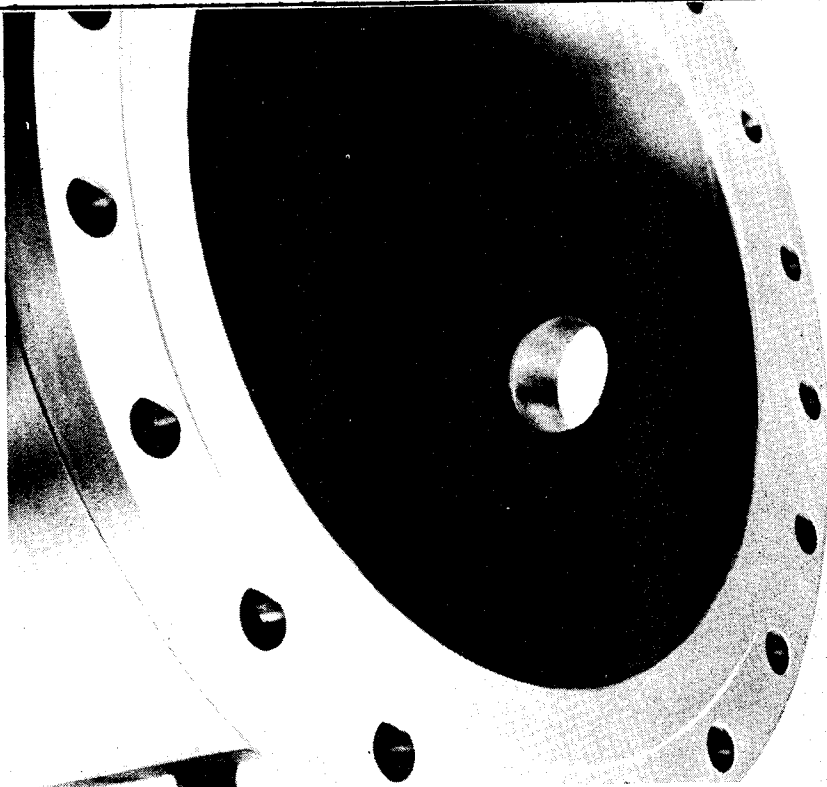


Photo. 13. Flanged end of wet lay-up laminate protected 36 inch diameter steel vessel.

Photo 14. ERYNNE laminate stand pipe before being laminated.



Photo 17. Large glove box assembly for handling nuclear materials. Laminate applied by wet lay-up.

Photo 18. Wet lay-up of ERYNNE laminate on the body of a glove box.

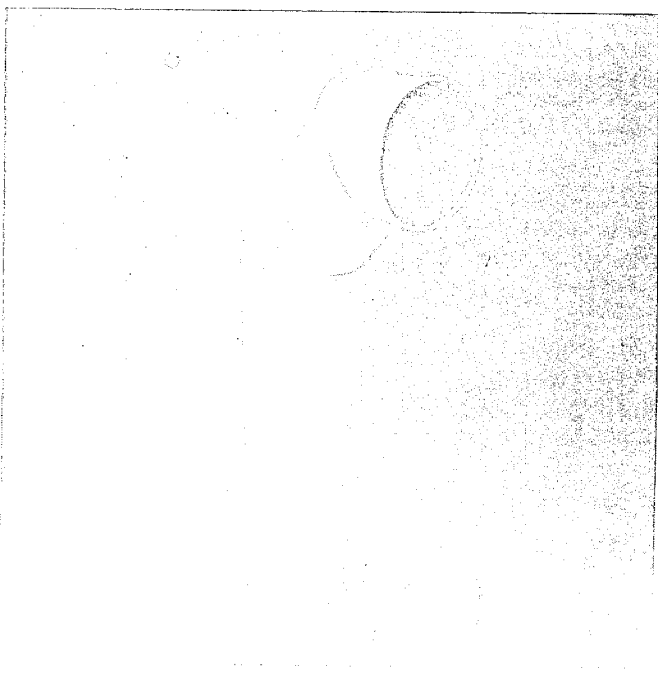


Photo 19. ERYNNE laminate stand pipe before being laminated.

Photo 20. 1/2" diameter ERYNNE laminate stand pipe before being laminated.

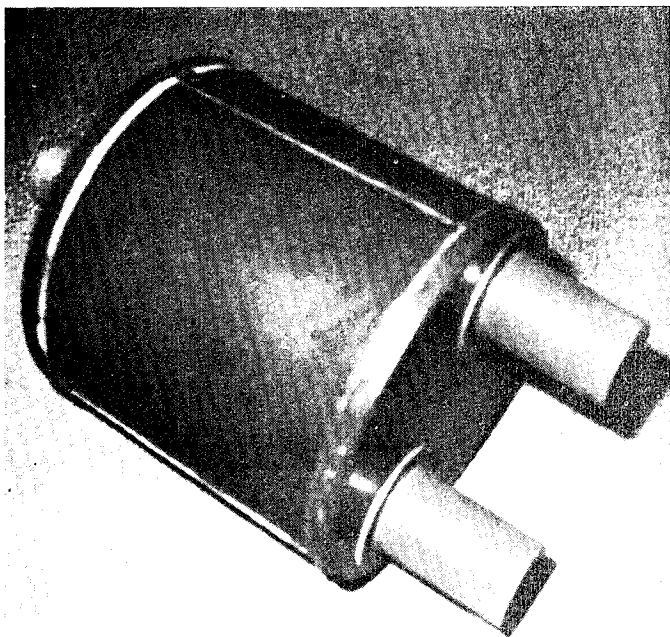


Photo. 19. 24" diameter x 26" long unsupported KYNAR laminate scrubber vessel.

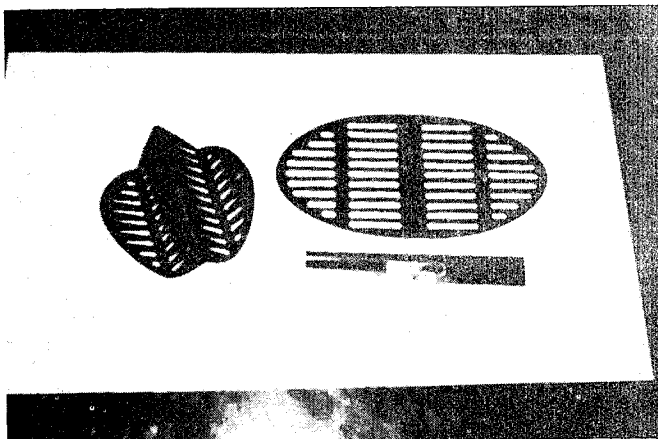


Photo. 20. 15" diameter die cut and framed support for scrubbing tower packing.

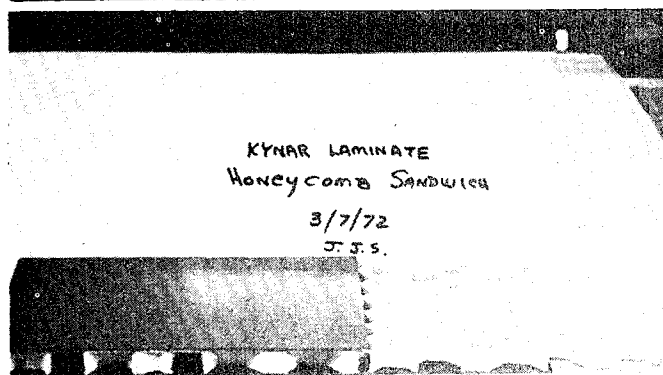
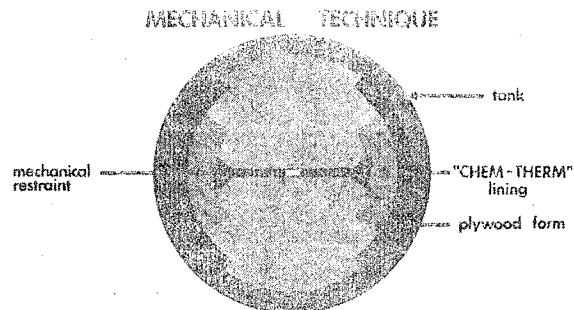


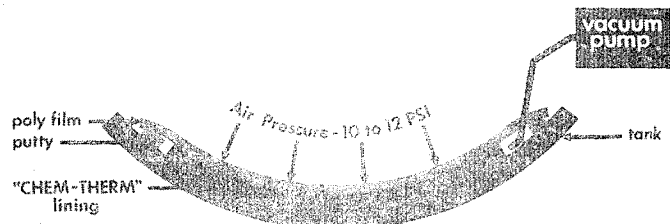
Photo. 21. KYNAR laminate in a typical honeycomb construction.



- 1) MUST CUT PLYWOOD TO FIT TANK WALLS.
- 2) APPLIES PRESSURE IN A LARGER AREA.
- 3) UNEVEN PRESSURE AND POSSIBLE VOIDS IN THE BOND LINE.
- 4) RESTRICTS WORK IN THE TANK.

Photo. 22. Typical application of KYNAR continuous laminate using mechanical clamping technique.

VACUUM BAG TECHNIQUE



- 1) FAST AND EASY.
- 2) APPLIES EVEN PRESSURE OVER THE ENTIRE SURFACE TO ALLOW COMPLETE CONTACT.
- 3) DRAWS OUT AIR POCKETS IN THE ADHESIVE BOND LINE.
- 4) DOES NOT INTERFERE WITH WORK IN OTHER PARTS OF THE TANK.

Photo. 23. Application of continuous laminate construction using vacuum bag technique.

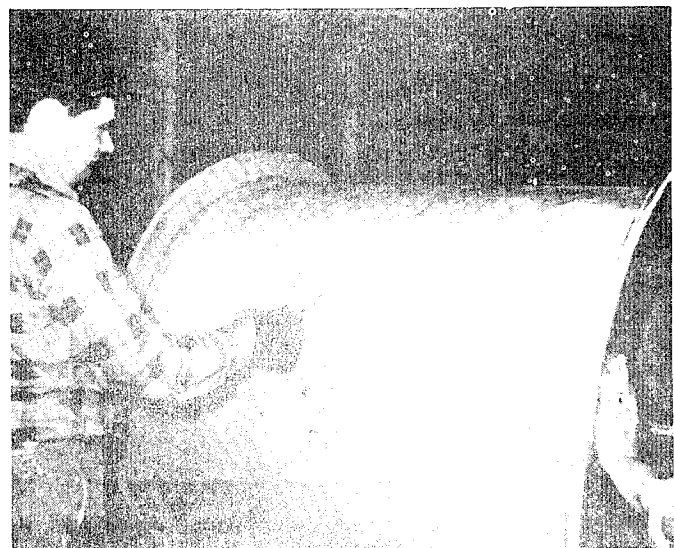


Photo. 24. "Laying up" E.P.R. over KYNAR laminate inner face on large diameter pipe section.

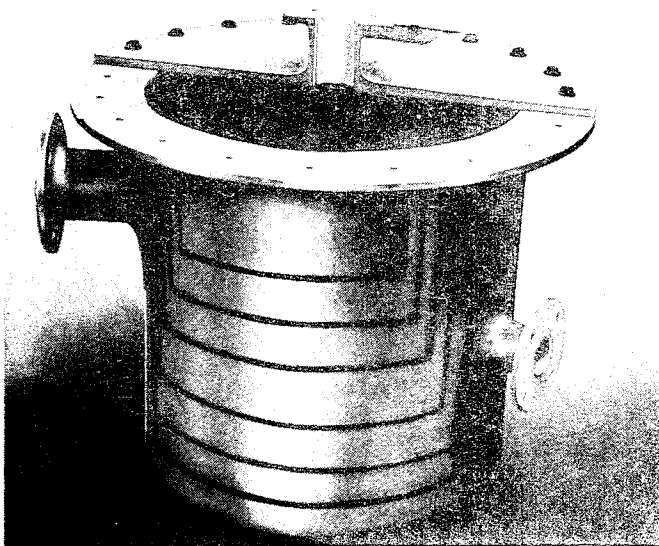


Photo. 25. KYNAR flanged vessel 21 1/2" diameter by 21" deep showing typical KYNAR laminate F.R.P. composite construction

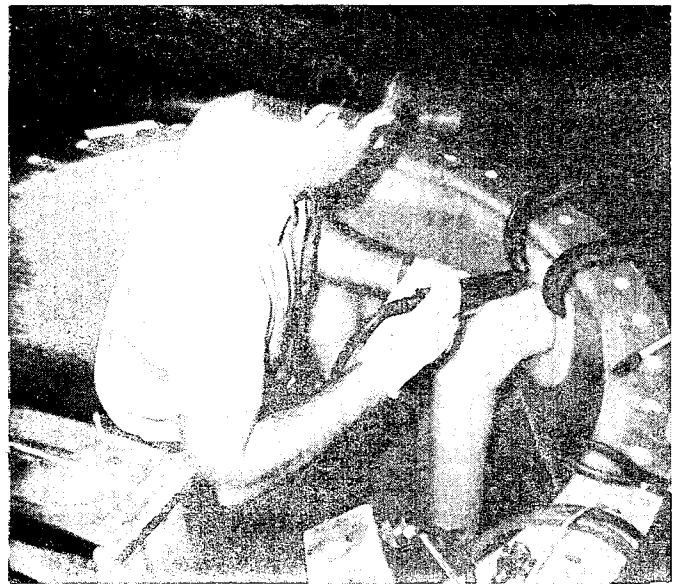


Photo. 27. Welding KYNAR laminate flanged pipe inside large vessel.

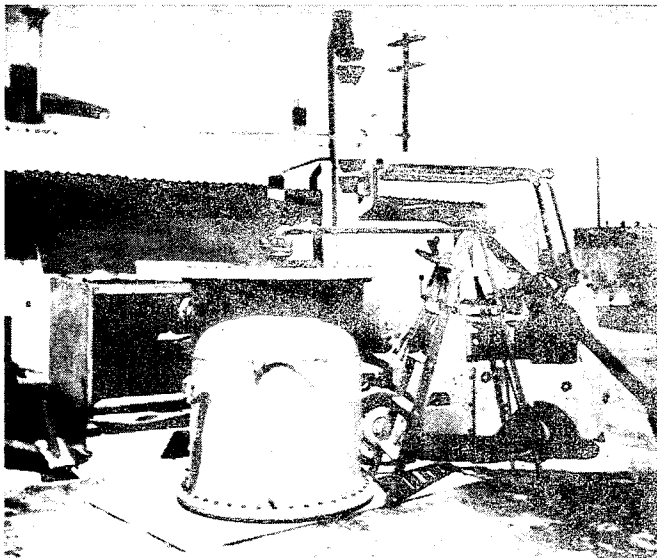


Photo. 26. KYNAR laminate-epoxy glass reinforced vessel under going steam pressure test.

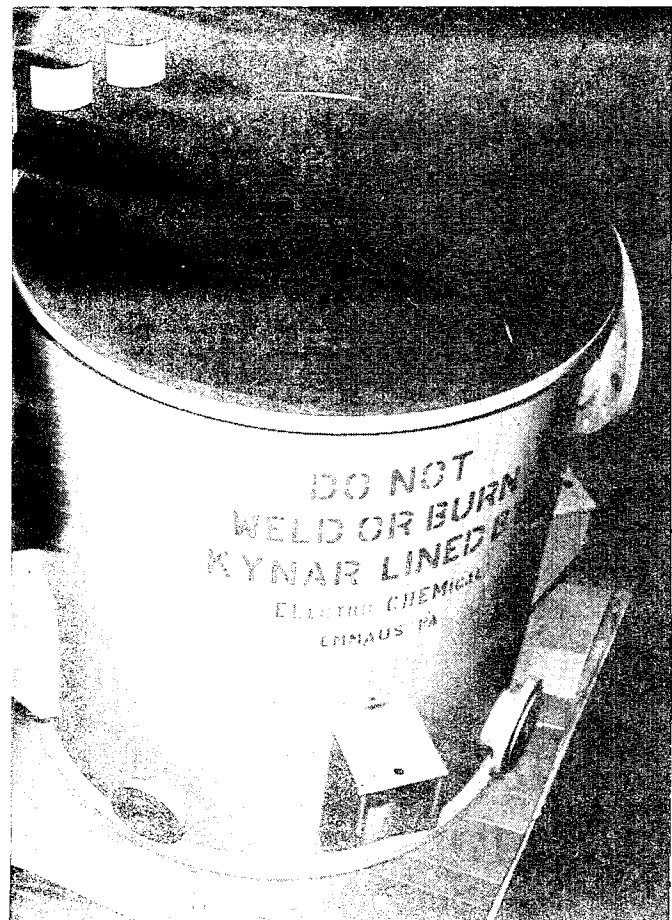


Photo. 28. 30" diameter x 4' long flanged ends vessel showing multiple spool openings and typical support system which makes both ends readily accessible. This is a combination of KYNAR wet lay-up and continuous laminate.

Sec 6-A (pg. 1-7)

SOLVENT RESISTANCE OF FIBER REINFORCED PLASTICS

by

WILLIAM W. McCLELLAN, THOMAS F. ANDERSON and
RAYBURN F. STAVINOHAN*

ABSTRACT

The results of exposing SPI reinforced plastics coupons made from four different types of corrosion resistant thermosetting resins in a large number of organic compounds for one year is presented. Predictable behavior of the corrosion resistant plastics is shown for different compounds in the same class. An epoxy novolac vinyl ester type resin was found to have dramatically better resistance than any of the other resins to a majority of the organic compounds used in the test program.

INTRODUCTION

In treating waste liquids in pollution clean-up, industry and government groups are many times faced with handling large volumes of water which contain small amounts of acids, alkalis, oxidizing chemicals, and organic solvents and plasticizers. The metals used to handle the organics in the processing operation are often unsuitable in the waste treatment operation from the standpoint of cost or corrosion resistance or a combination of both. Materials are needed that will withstand these combined corrosive environments and that are readily available in the required fabricated form at reasonable cost.

Corrosion resistant reinforced plastics have offered many solutions to materials problems in the pollution control field. However, relatively little information has been publicly available on how these materials behaved in environments containing various organic compounds. Because of this need for information, a program was initiated to determine the highest temperature at which representative corrosion resistant reinforced plastics could be expected to satisfactorily handle different organic chemicals and their commercially important mixtures with each other and inorganic chemicals and water.

This paper reports on the first phase of that program in which laminates of representative corrosion resistant resins were totally immersed, for the most part, in full strength commercial organic compounds. This full strength approach was taken since it was found that the organic contaminants in waste waters, in most instances, tend to form a separate phase. These separate phases invariably collect on the surfaces of the tanks and piping in which the waste water is being handled to give essentially concentrated exposure to the chemical involved. This first phase is primarily a screening to classify the organic chemicals into three groups: (1) those that cause a serious attack on all of the reinforced plastics, even at room temperature; (2) those that do not cause any change in the reinforced plastics at the test temperature; and (3) those that fall in between. Additional testing is in process, both in plants and in the laboratory on the third group. This work will be reported on later.

EXPERIMENTAL

Laminates of polyester and vinyl ester resins used by the chemical process industry for CR applications were chosen for this organic chemical exposure study. Over 150 different environments were used to represent a broad scope of organic chemicals. The testing was done by immersing fiberglass reinforced coupons in the organic liquids or mixed chemicals at 120°F for up to one year. Periodically, measurements were taken to determine percent weight change, thickness change and 934 Barcol hardness. In chemicals where serious degradation of the laminates occurred, testing was started at lower temperatures. In some chemicals where no change was observed in the laminates after six months, testing was started at higher temperatures.

Facilities

The facility and equipment used for this corrosion testing were designed around the parameter of safety. Because hazards of fire, toxicity and reactivity are greater for organic chemicals at elevated temperatures, extra precautions are needed.

A testing room isolated from other work areas was insulated and heated to 120°F with a steam space heater while an adjacent room was kept at 80°F. A thermocouple temperature probe in the 120°F room was connected to a temperature control switch outside the room. This switch was set to activate a solenoid steam control valve that feeds the steam heater. This gave a safe control of heat. Inside the test room, wide mouth glass bottles were used to hold each organic test chemical. The lids were equipped with safety seals which keep in vapor but vent on excessive pressure build up. This kept the vapor of flammable liquids to a minimum. The electrical fan motor of the steam heater and all lights inside and around the test room conform to explosion-proof standards of the National Fire Protection Association (Electrical Classification: Class I, Group D, Div. 1).

Test Samples

The four resin types chosen for testing were a bisphenol-A fumarate polyester (Bis-A Resin), a chlorendic acid polyester (HET-A Resin), an epoxy based vinyl ester (DERAKANE® 411), and an epoxy novolac vinyl ester (DERAKANE® 470). Laminates of each resin were hand layed-up to a fiberglass composition of C-veil 1 1/2 oz. mat 1 1/2 oz. mat C-veil, approximately 0.125 inches thick. Covered with Mylar film to prevent air inhibition, the laminates were cured at room temperature using catalyst systems, as recommended by each respective resin manufacturer, to give 30 minute gel times. After curing at room temperature for one day, they were then post-cured for 2 hours at 200°F.

Each resin laminate was tested for Barcol hardness (934.1) and for residual styrene by infrared spectroscopy to insure that each resin laminate being tested was properly cured. All laminates were found to have excellent cure. Data verifying degree of cure is shown in Table XVII.

The laminates were then cut into 1 x 3 inch test coupons. To observe any effect of edge attack, the edges were left uncoated allowing the exposed edges of the laminate to come in contact with the test liquids. The test coupons were measured before being immersed, taken out after a designated period of time, wiped dry, measured, and again immersed if the coupon showed no gross deterioration.

Chemicals Tested

For this corrosion resistance study, the organic chemicals were limited to those that are liquid and safe for testing at 120°F or 80°F. The chemicals used in testing were selected to be representative of the more important classes of organic compounds.

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Each liquid organic chemical was examined as to potential safety hazards before being used in the test. Material Safety Data Sheets plus other pertinent information were collected on each chemical and related to the testing conditions. This information and precautions related to testing were transcribed on a special form that could be easily used by testing personnel. The form was also the authorization sheet for chemicals to be tested.

Measurements

Measurements of weight, thickness, and hardness were taken of the test coupons to determine the degree of corrosion resistance offered by each resin laminate in organic chemicals. For ease of analysis, the measurements are represented as percent weight change from the original weight, thickness change in mils from the original thickness (≈ 0.125 mils) and 934 Barcol hardness meter reading of the surface. Measurements were taken before immersion and after 10 days, 1, 2, 3, 6 and 12 months. Besides the measurements, appearance changes were noted, and if a test coupon delaminated or swelled beyond practical limits, or the surface broke open, it would be considered a failure at that time.

RESULTS

The interpretation of the results of this Phase I total immersion testing was clear cut in those chemicals where no significant change in the measured properties of the laminates occurred in one year at the test temperature. It was felt that good field service could be expected.

Interpretation of testing where the coupons disintegrated or were severely mechanically damaged by the chemical used was equally clear cut. These environments could not be recommended.

Interpretation of the results in environments where intermediate changes occurred was much more difficult. Below are the general guidelines used in judging these environments.

1. Very little change which levels off. Can be recommended for field service.
2. Moderate swelling which levels off. No rupture of the resin fiberglass bond. Recommended for limited field service.
3. Moderate swelling that is slowing down but has not leveled off in one year. No rupture of resin fiberglass bond. Continue test. One Side Testing and Non-Critical Field Service.
4. Major swelling which levels off. No rupture, or limited rupture of the resin fiberglass bond. Same as in 3 above.

These guidelines are used in reviewing the results of testing in the several classes of organic compounds considered below.

Chlorinated Aliphatics

In Table I and Figure I, we see the results of immersion of the standard test coupon series in chloroform at 80°F and carbon tetrachloride at 120°F. Not shown are the results of exposure of the laminates to methylene chloride (dichloromethane) which swelled all laminates to failure in 10 days or less at 80°F. Note how all coupons except the one of DERAKANE® 470 laminate swelled badly and failed in 10 days (the first inspection period) in chloroform (trichloromethane) at 80°F. The DERAKANE® 470 coupon swelled badly and failed at the 1 month inspection. However, only the Bis-A resin shows any serious attack in carbon tetrachloride (tetrachloromethane) after six months at 120°F. A piping system of DERAKANE® 470 resin handling carbon tetrachloride at 50 psi and 177°F has been in service over two years.

Tables II and III and Figures 2 and 3 show the results of the immersion testing in various degrees of chlorination of ethane and ethylene. Note that the DERAKANE® 470 laminate which showed the best performance in each environment showed severe attack by the 1,2 dichloroethylene at 80°F with successively less action at 120°F by 1,2 dichloroethane, 1,1,2 trichloroethylene, perchloroethylene (1,1,2,2 tetrachloroethylene) and 1,1,1 trichloroethane.

Table IV and Figure 4 show the results of testing in dichloropropane at 80°F and 120°F and dichloropropene at 120°F. Note how the addition of another carbon atom to the chain reduced the solvent action as compared with dichloroethane and dichloroethylene shown in Table II. As was shown also in Tables II and III, the carbon double bond is much more aggressive.

In Tables V and VI and Figures 5 and 6, we see the very rough solvent action of pyridene and phenol dramatically reduced by halogen substitutions. In the case of pyridine, solvent action caused all of the laminates to fail in 10 days to 1 month at 120°F. The substitution of 4 hydrogens by chlorine changes the solvent action and causes all laminates to give satisfactory performance in tetrachloropyridine after 1 year's exposure at 120°F. Where all laminates are severely attacked by 88% phenol in 1 month at 120°F, the dibromo substituted phenol has not destroyed either the DERAKANE® 470 resin or HET-acid resin laminate after 1 year's exposure at 120°F, although the HET-acid laminate has been badly swelled.

Benzene and Chlorinated Benzenes

Table VII and Figure 7 show the dramatic difference in solvent effect shown on the laminates by benzene and its mono and di substituted chlorine numbers at 120°F. Most striking is the behavior of the DERAKANE® 470 laminate. Note the slow increase in weight in benzene up to 8.6% in 12 months while in the monochlorobenzene, the 8.6% weight increase is gained in 6 months. Contrast this with the extremely small gain of only 0.8% in 12 months in O-dichlorobenzene. Note the sharp contrast in appearance of the different laminates.

Benzene and Methyl Substituted Benzenes

In Table VIII and Figure 8, note the successively lower rate of attack on DERAKANE® 470 when one and then two methyl groups are substituted for hydrogen on the benzene ring.

Benzene and Ethyl Substituted Benzenes

In Table IX and Figure 9 see how the substitution of one ethyl group on the benzene ring has about the same effect on reducing the solvent swelling of the laminates as the two methyl groups in the previous example. As would be expected, the substitution of the second ethyl group reduced in a major fashion the attack on all of the laminates, so that any of them could be expected to give good service at 120°F with perhaps some questions existing on the performance of the Bis-A resin.

Benzene and Vinyl Substituted Benzenes

In Tables X and XI and Figures 10 and 11, note how the vinyl substituted benzene (styrene) is as aggressive at 80°F as the ethyl benzene was at 120°F in the previous group. The same aggressive behavior is shown by the vinyl toluene at 80°F while the divinyl benzene at 80°F is very much less active than either one.

Aliphatic Acids

Table XII and Figure 12 show the combination solvent swelling-chemical action of glacial acetic and acetic anhydride versus the greatly reduced activity of the four carbon atom butyric acid. Note especially the difference in the appearance of the coupons.

Ketones

In Table XIII and Figure 13, note how acetone at 80°F causes about the same swelling as methyl ethyl ketone at 120°F.

Acetate Versus Chloride

Note in Table XIV and Figure 14 the difference in behavior of the laminates in amyl acetate versus amyl chloride. While the DERAKANE® 470 resin laminate performs best in both chemicals, observe that DERAKANE® 411 resin is the poorest in the acetate

but second best in the chloride. Notice the green coloration in some of the coupons in the chloride which is typical of coupons in hydrochloric acid and acid chloride salt solutions.

Morpholine

Note in Table XV and Figure 15, the reduction in severity of attack when 2 methyl groups are substituted on the morpholine ring.

Glycol Versus Oxide

Table XVI and Figure 16 show the very inert character of butylene glycol at 120°F versus the very aggressive attack of butylene oxide at 80°F.

CONCLUSIONS

As a result of this first testing phase, the behavior of laminates made of the most widely used corrosion resistant thermosetting resins was determined in over 150 organic chemical environments. Examination of the results shows the following:

1. The epoxy novolac vinyl ester resin is very superior to the conventional CR resins in almost all of the test environments and opens up many new applications for corrosion resistant RP equipment.
2. The base has been established to predict the corrosion behavior of members of organic compound classes on thermosetting reinforced laminated equipment from known activity of other members of the class.
3. Increasing halogenation of both aliphatic and aromatic organics reduced their attack on all of the corrosion resistant thermoset resin laminates.
4. Organics with carbon to carbon unsaturated double bonds showed greater solvent swelling action than their saturated counterparts.
5. Increasing substitution of aliphatic groups on the benzene ring gave decreased solvent swelling.
6. Solvent swelling was correlatable within classes of organics with activity decreasing in the higher members of a series.
7. Many waste water clean-up projects can solve their materials problems with the information generated thus far in the program.

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He has publications on "Plastic Materials in Structural Applications" and "Polyester Fiber Glass Equipment for Corrosion Applications".

He holds patents on polyester stabilization, polyester molding compounds, plastic tank trucks, methods of extracting glass fibers, insulated nestable containers and methods of making same.

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TABLE I

CHLOROFORM	80°F				1 MONTH				3 MONTHS				6 MONTHS			
	ORG.	HT	THK	BH	HT	THK	BH	HT	THK	BH	HT	THK	BH	HT	THK	BH
CHCl ₃	934	934	934	934	934	934	934	934	934	934	934	934	934	934	934	934
DERAKANE®411	42	199	533	F	FAIL	IN TEN DAYS										
DERAKANE®470	48	14	16	4	49	90	F	FAIL	IN ONE MONTH							
BIS-A RESIN	43	211	402	F	FAIL	IN TEN DAYS										
HET-A RESIN	48	88	182	F	FAIL	IN TEN DAYS										
CARBON TETRACHLORIDE 120°F																
CCl ₄																
DERAKANE®411	42	0	2	39	0	2	40	0.1	3	38	0.5	7	38			
DERAKANE®470	48	0	2	48	0	0	48	0	0	46	0	3	46			
BIS-A RESIN	43	0.1	0	40	2.1	1	31	6.9	7	16	11	11	5			
HET-A RESIN	48	0	0	46	0.2	0	46	0.4	1	45	0.5	3	45			

FIG. 1

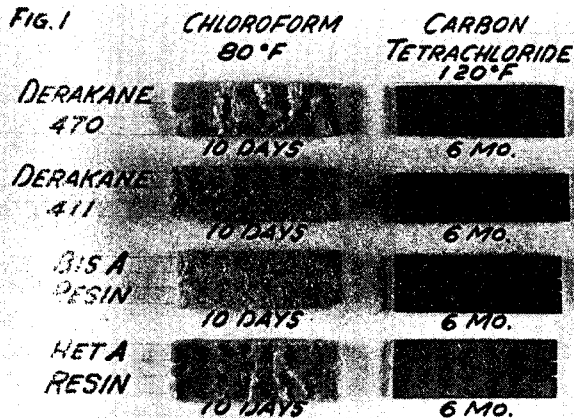


TABLE II

DICHLOROETHANE		120°F				10 DAYS				1 MONTH				3 MONTHS				6 MONTHS			
CICH ₂ CH ₂ Cl		ORG.	WT	THK	BH	WT	THK	BH	WT	THK	BH	WT	THK	BH	WT	THK	BH				
		934	5	MILS	934	5	MILS	934	5	MILS	934	5	MILS	934	5	MILS	934				
RESIN																					
DERAKANE 411	42	16	24	0	45	53	0	FAIL	IN ONE MONTH												
DERAKANE 470	48	4.6	5	22	21	22	0/65	26	37	0/60	26	39	0/50								
BIS-A RESIN	43	40	17	0	FAIL	IN TEN DAYS															
HET-A RESIN	48	13	15	0	30	42	0/50	FAIL	IN TWO MONTHS												

DICHLOROETHYLENE		80°F																			
CICH=CH ₂ Cl		ORG.	WT	THK	BH	WT	THK	BH	WT	THK	BH	WT	THK	BH	WT	THK	BH				
		934	5	MILS	934	5	MILS	934	5	MILS	934	5	MILS	934	5	MILS	934				
RESIN																					
DERAKANE 411	42	42	52	0	35	50	0	FAIL	IN ONE MONTH												
DERAKANE 470	48	22	24	0	27	35	0/60	28	35	0/50	28	39	0								
BIS-A RESIN	43	FAIL	IN TEN DAYS																		
HET-A RESIN	43	36	48	0	32	47	0/35	FAIL	IN ONE MONTH												

TABLE III

TRICHLOROETHANE 120°F		1 MONTH				3 MONTHS				6 MONTHS				12 MONTHS			
Cl ₃ CCH ₃		ORG.	WT	THK	BH	WT	THK	BH	WT	THK	BH	WT	THK	BH	WT	THK	BH
RESIN		934	5	MILS	934	5	MILS	934	5	MILS	934	5	MILS	934	5	MILS	934
DERAKANE 411	42	0.1	3	36	2.1	5	38	12	13	15							
DERAKANE 470	48	0	2	45	0.5	3	43	0.9	3	41							
BIS-A RESIN	43	2.4	4	27	6.9	10	20	13	17	3							
HET-A RESIN	48	0.3	3	42	1.4	4	40	2.9	5	38							

TRICHLOROETHYLENE 120°F																								
Cl ₃ C=CHCl		ORG.	WT	THK	BH	WT	THK	BH	WT	THK	BH	WT	THK	BH	WT	THK	BH							
RESIN		934	5	MILS	934	5	MILS	934	5	MILS	934	5	MILS	934	5	MILS	934							
DERAKANE 411	42	35	47	0/0	42	48	0/3	42	50	0														
DERAKANE 470	48	18	20	5	26	29	0/65	27	30	2														
BIS-A RESIN	43	55	75	0	FAIL	IN TEN DAYS																		
HET-A RESIN	48	35	49	0	FAIL	IN TWO MONTHS																		

PERCHLOROETHYLENE 120°F																	
Cl ₂ C=CCl ₂		ORG.	WT	THK	BH	WT	THK	BH	WT	THK	BH	WT	THK	BH	WT	THK	BH
RESIN		934	5	MILS	934	5	MILS	934	5	MILS	934	5	MILS	934	5	MILS	934
DERAKANE 411	42	1.5	0	34	4.8	4	30	9.2	6	25	11	10	19				
DERAKANE 470	48	0.3	0	38	0.9	0	40	1.1	2	38	1.5	3	37				
BIS-A RESIN	43	13	11	0	26	20	0	29	28	0	31	33	0				
HET-A RESIN	48	3.0	2	28	7.5	6	8	12	9	6	14	15	3				

TABLE IV

DICHLOROPROPANE		80°F		1 MONTH				3 MONTHS				9 MONTHS				12 MONTHS			
CH ₃ CHClCH ₂ Cl		ORG. BH		WT	THK	BH		WT	THK	BH		WT	THK	BH		WT	THK	BH	
		934		5	MILS	934		5	MILS	934		5	MILS	934		5	MILS	934	
RESIN		934		5	MILS	934		5	MILS	934		5	MILS	934		5	MILS	934	
DERAKANE 411		42		2.4	3	28		12	5	32		26	0						
DERAKANE 470		48		0.5	0	42		0.7	2	43		3.5	6	34					
BIS-A RESIN		43		4.1	4	20		7.4	9	15		16	14	10					
HET-A RESIN		48		1.4	1	40		4.8	7	20		22	21	0					

DICHLOROPROPANE		120°F		1 MONTH				3 MONTHS				6 MONTHS				12 MONTHS			
CH ₃ CHClCH ₂ Cl		ORG. BH		WT	THK	BH		WT	THK	BH		WT	THK	BH		WT	THK	BH	
		934		5	MILS	934		5	MILS	934		5	MILS	934		5	MILS	934	
RESIN		934		5	MILS	934		5	MILS	934		5	MILS	934		5	MILS	934	
DERAKANE 411		42		34	49	0/8		34	49	0/10		34	60	0		FAIL	IN SIX MOS		
DERAKANE 470		48		3.3	3	26		5	7	20		6.7	11	16		12	18	5	
BIS-A RESIN		43		25	27	FAIL	IN ONE MONTH												
HET-A RESIN		48		12	16	0/60		21	29	0/60		22	33	0		25	34	0	

DICHLOROPROPENE		120°F																				
CHCl=CHCH ₂ Cl		ORG. BH		WT	THK	BH		WT	THK	BH		WT	THK	BH		WT	THK	BH				
		934		5	MILS	934		5	MILS	934		5	MILS	934		5	MILS	934				
RESIN		934		5	MILS	934		5	MILS	934		5	MILS	934		5	MILS	934				
DERAKANE 411		42		59	86	0		FAIL	IN ONE MONTH													
DERAKANE 470		48		25	29	0/60		30	29	0/55		31	36	0		30	39	0				
BIS-A RESIN		43		67	198	-		FAIL	IN ONE MONTH													
HET-A RESIN		48		47	78	-		FAIL	IN ONE MONTH													

TABLE V

PYRIDINE 120°F		1 MONTH			3 MONTHS			6 MONTHS			12 MONTHS		
⊙N	ORG. BH	WT	THK	BH	WT	THK	BH	WT	THK	BH	WT	THK	BH
RESIN	934	5	MILS	934	5	MILS	934	5	MILS	934	5	MILS	934
DERAKANE-411	42	FAIL IN TEN DAYS											
DERAKANE-470	48	158	479	F	FAIL IN ONE MONTH								
BIS-A RESIN	43	FAIL IN TEN DAYS											
HET-A RESIN	48	200	228	F	FAIL IN ONE MONTH								
TETRA CHLOROPYRIDINE 120°F													
⊙ ₄ ⊙N													
DERAKANE-411	42	0.5	1	40	0.7	3	40	0.9	3	35	1.6	6	35
DERAKANE-470	48	-0.1	1	44	-0.2	3	42	-0.3	4	40	0	4	41
BIS-A RESIN	43	0.3	0	38	0.6	3	36	0.5	4	35	1.1	6	36
HET-A RESIN	48	-0.3	1	44	0.3	2	41	0.1	2	43	0.3	3	43

FIG. 2

	DICHLOROETHANE 120°F	DICHLOROETHYLENE 80°F
DERAKANE 470	8 Mo.	8 Mo.
DERAKANE 411	1 Mo.	1 Mo.
BIS A RESIN	10 DAYS	10 DAYS
HET A RESIN	2 Mo.	1 Mo.

FIG. 3

	TRICHLOROETHANE 120°F	TRICHLOROETHYLENE 120°F	PERCHLOROETHYLENE 120°F
DERAKANE 470	6 Mo.	8 Mo.	1 YR.
DERAKANE 411	6 Mo.	8 Mo.	1 YR.
BIS A RESIN	6 Mo.	10 DAYS	1 YR.
HET A RESIN	6 Mo.	2 Mo.	1 YR.

FIG. 4

	DICHLOROPROPANE 80°F	DICHLOROPROPANE 120°F
DERAKANE 470	9 Mo.	1 YR.
DERAKANE 411	9 Mo.	6 Mo.
BIS A RESIN	9 Mo.	1 Mo.
HET A RESIN	9 Mo.	1 YR.

FIG. 5

	PYRIDINE 120°F	TETRACHLORO PYRIDINE 120°F
DERAKANE 470	1 Mo.	1 YR.
DERAKANE 411	LOST	1 YR.
BIS A RESIN	10 DAYS	1 YR.
HET A RESIN	1 Mo.	1 YR.

PHENOL 88%		120°F		1 MONTH		3 MONTHS		6 MONTHS		12 MONTHS	
DERAKANE	470	ORG. BH	WT	THK	BH	WT	THK	BH	WT	THK	BH
RESIN		934	WT	THK	BH	WT	THK	BH	WT	THK	BH
DERAKANE-411	42	150	15	F	934	150	15	F	934	150	15
DERAKANE-470	48	92	-	-	934	92	-	-	934	92	-
BIS-A RESIN	43	100	191	F	934	100	191	F	934	100	191
HET-A RESIN	48	20	15	0/55	934	20	15	0/55	934	20	15

DERAKANE	470	ORG. BH	WT	THK	BH	WT	THK	BH	WT	THK	BH
RESIN		934	WT	THK	BH	WT	THK	BH	WT	THK	BH
DERAKANE-411	42	24	16	0	934	24	16	0	934	24	16
DERAKANE-470	48	6.4	6	27	934	6.4	6	27	934	6.4	6
BIS-A RESIN	43	12.4	11	22	934	12.4	11	22	934	12.4	11
HET-A RESIN	48	4.6	6	35	934	4.6	6	35	934	4.6	6

TABLE VII

BENZENE		120°F		1 MONTH			3 MONTHS			6 MONTHS			12 MONTHS		
DERAKANE	470	ORG. BH	WT	THK	BH	WT	THK	BH	WT	THK	BH	WT	THK	BH	
RESIN		934	WT	THK	BH	934	WT	THK	BH	934	WT	THK	934	WT	
DERAKANE-411	42	19	50	0/26	934	19	50	0/35	934	19	50	0/35	934	19	
DERAKANE-470	48	2.3	15	38	934	2.3	15	38	934	2.3	15	38	934	2.3	
BIS-A RESIN	43	FAIL IN TEN DAYS			934	FAIL IN TEN DAYS			934	FAIL IN TEN DAYS			934	FAIL IN TEN DAYS	
HET-A RESIN	48	11.8	22	0/65	934	11.8	22	0/65	934	11.8	22	0/65	934	11.8	

MONOCHLOROBENZENE 120°F

DERAKANE	470	ORG. BH	WT	THK	BH	WT	THK	BH	WT	THK	BH
RESIN		934	WT	THK	BH	934	WT	THK	BH	934	WT
DERAKANE-411	42	36	49	0/4	934	36	49	0/4	934	36	49
DERAKANE-470	48	3.1	4	32	934	3.1	4	32	934	3.1	4
BIS-A RESIN	43	35	F	F	934	35	F	F	934	35	F
HET-A RESIN	48	19	20	0/62	934	19	20	0/62	934	19	20

o-DICHLOROBENZENE 120°F

DERAKANE	470	ORG. BH	WT	THK	BH	WT	THK	BH	WT	THK	BH
RESIN		934	WT	THK	BH	934	WT	THK	BH	934	WT
DERAKANE-411	42	13	21	0/42	934	13	21	0/42	934	13	21
DERAKANE-470	48	0.1	1	40	934	0.1	1	40	934	0.1	1
BIS-A RESIN	43	9.8	12	2	934	9.8	12	2	934	9.8	12
HET-A RESIN	48	1.2	3	35	934	1.2	3	35	934	1.2	3

BENZENE		120°F		1 MONTH			3 MONTHS			6 MONTHS			12 MONTHS		
⊙	ORG. BH	WT	THK	BH	WT	THK	BH	WT	THK	BH	WT	THK	BH		
	934	WT	THK	BH	WT	THK	BH	WT	THK	BH	WT	THK	BH		
RESIN	934	WT	THK	BH	WT	THK	BH	WT	THK	BH	WT	THK	BH		
DERAKANE#411	42	19	50	0/26	19	50	0/35	19	51	0/	20	51	0/		
DERAKANE#470	48	2.3	15	38	4.2	19	30	5.8	24	17	8.6	27	12		
BIS-A RESIN	43	FAIL IN TEN DAYS													
HET-A RESIN	48	11.8	22	0/65	16.7	34	0/60	17.5	53	0/	18	56	0/		
TOLUENE 120°F															
⊙CH ₃															
DERAKANE#411	42	17	25	0/65	21	45	0/40	23	46	0/	FAIL IN SIX MOS				
DERAKANE#470	48	0.6	4	36	1.3	4	30	2.1	9	26	5.5	16	12		
BIS-A RESIN	43	19	36	0/50	FAIL IN TWO MONTHS										
HET-A RESIN	48	7.3	15	0/65	14	0/57	14	28	0/	14	32	0/			
XYLENE 120°F															
⊙(CH ₃) ₂															
DERAKANE#411	42	2	8	30	8.4	14	7	17	28	0	20	32	0		
DERAKANE#470	48	0.01	3	43	0.0	2	41	0.0	5	40	1.4	80	34		
BIS-A RESIN	43	5.6	9	8	11	20	0/55	16	33	0	17	35	0		
HET-A RESIN	48	0.6	3	44	1.6	5	34	3.1	9	18	9.0	27	1		

TABLE IX

BENZENE		120°F		1 MONTH		3 MONTHS		6 MONTHS		12 MONTHS			
ORG. BH	WT	THK	BH	WT	THK	BH	WT	THK	BH	WT	THK	BH	
934			934			934			934			934	
			935			935			935			935	
RESIN													
DERAKANE-411	42	19	50	0/26	19	50	0/35	19	51	0/	20	51	0/
DERAKANE-470	48	2.3	15	38	4.2	19	30	5.8	24	17	8.6	27	12
BIS-A RESIN	43	FAIL IN TEN DAYS											
HET-A RESIN	48	11.8	22	0/65	16.7	34	0/65	17.5	53	0/	18	56	0/

ETHYL BENZENE		120°F											
ORG. BH	WT	THK	BH										
934			934										
			935										
RESIN													
DERAKANE-411	42	8.4	15	0/50	20	44	0/40	20	45	0	23	50	0
DERAKANE-470	48	0.4	1	40	0.5	3	40	0.6	5	40	1.5	9	34
BIS-A RESIN	43	9.5	18	0/56	17	34	0/50	17	37	0	19	40	0
HET-A RESIN	48	1.1	6	28	7.8	14	2	10	19	0	15	22	0

DIETHYL BENZENE		120°F											
ORG. BH	WT	THK	BH										
934			934										
			935										
RESIN													
DERAKANE-411	42	0	3	36	0	6	36	0.3	8	33	1.9	10	25
DERAKANE-470	48	0	0	49	0	1	45	0	3	45	0.6	4	40
BIS-A RESIN	43	0.6	0	37	1.1	3	31	2.2	6	25	5.4	12	10
HET-A RESIN	48	0.1	0	49	0.2	1	40	0.5	3	43	1.5	6	32

DERAKANE	470	DERAKANE	411	BIS A RESIN	HET A RESIN
1 MO.	1 YR.	1 MO.	1 YR.	1 MO.	1 YR.
1 MO.	1 YR.	1 MO.	1 YR.	1 MO.	1 YR.
1 MO.	1 YR.	1 MO.	1 YR.	1 MO.	1 YR.
1 MO.	1 YR.	1 MO.	1 YR.	1 MO.	1 YR.
1 MO.	1 YR.	1 MO.	1 YR.	1 MO.	1 YR.

DERAKANE	470	DERAKANE	411	BIS A RESIN	HET A RESIN
1 YR.	1 YR.	1 YR.	1 YR.	1 YR.	1 YR.
1 YR.	1 YR.	1 YR.	1 YR.	1 YR.	1 YR.
1 YR.	1 YR.	1 YR.	1 YR.	1 YR.	1 YR.
1 YR.	1 YR.	1 YR.	1 YR.	1 YR.	1 YR.
1 YR.	1 YR.	1 YR.	1 YR.	1 YR.	1 YR.

DERAKANE	470	DERAKANE	411	BIS A RESIN	HET A RESIN
1 YR.	1 YR.	1 YR.	1 YR.	1 YR.	1 YR.
1 YR.	1 YR.	1 YR.	1 YR.	1 YR.	1 YR.
1 YR.	1 YR.	1 YR.	1 YR.	1 YR.	1 YR.
1 YR.	1 YR.	1 YR.	1 YR.	1 YR.	1 YR.
1 YR.	1 YR.	1 YR.	1 YR.	1 YR.	1 YR.

DERAKANE	470	DERAKANE	411	BIS A RESIN	HET A RESIN
1 YR.	1 YR.	1 YR.	1 YR.	1 YR.	1 YR.
1 YR.	1 YR.	1 YR.	1 YR.	1 YR.	1 YR.
1 YR.	1 YR.	1 YR.	1 YR.	1 YR.	1 YR.
1 YR.	1 YR.	1 YR.	1 YR.	1 YR.	1 YR.
1 YR.	1 YR.	1 YR.	1 YR.	1 YR.	1 YR.

TABLE X

BENZENE 120°F	ORIG. BH	1 MONTH			3 MONTHS			6 MONTHS			12 MONTHS		
		HT	THK	BH	HT	THK	BH	HT	THK	BH	HT	THK	BH
DERAKANE 470	934	19	50	0/26	19	50	0/35	19	51	0/	20	51	0/
DERAKANE 470	934	48	2.3	15	38	4.2	19	30	5.8	24	17	8.6	27
BIS-A RESIN	934	43	FAIL IN TEN DAYS										
HET-A RESIN	934	48	11.8	22	0/65	16.7	34	0/60	17.5	53	0/	18	56
STYRENE 80°F													
DERAKANE 470	934	42	2.3	7	34	13	13	20	20	51	0	19	50
DERAKANE 470	934	48	0.1	1	45	0.5	1	40	0.8	4	38	2.0	8
BIS-A RESIN	934	43	6.8	8	10	14	15	0/45	17	24	0	21	28
HET-A RESIN	934	48	1.3	1	40	1.8	2	-	2.5	6	30	9.8	15
VINYL TOLUENE 80°F													
DERAKANE 470	934	42	0.3	3	40	0.6	3	33	0.6	8	36	2.0	13
DERAKANE 470	934	48	0.6	1	48	0.1	1	47	0	2	47	0.2	2
BIS-A RESIN	934	43	0.5	-1	43	1.5	1	38	1.7	4	33	7.4	8
HET-A RESIN	934	48	0.2	-1	40	0.2	-2	42	0.4	1	43	0.9	3

TABLE XI

BENZENE 120°F	ORIG. BH	1 MONTH			3 MONTHS			6 MONTHS			12 MONTHS		
		HT	THK	BH	HT	THK	BH	HT	THK	BH	HT	THK	BH
DERAKANE 470	934	42	19	50	0/26	19	50	0/35	19	51	0/	20	51
DERAKANE 470	934	48	2.3	15	38	4.2	19	30	5.8	24	17	8.6	27
BIS-A RESIN	934	43	FAIL IN TEN DAYS										
HET-A RESIN	934	48	11.8	22	0/65	16.7	34	0/60	17.5	53	0/	18	56
α-METHYLSTYRENE 120°F													
DERAKANE 470	934	42	9	12	0/45	20	30	0/14	22	42	0	33	44
DERAKANE 470	934	48	0	1	48	0	2	40	0.3	3	39	1.3	4
BIS-A RESIN	934	43	5.6	9	8	14	18	0/50	18	28	0	FAIL IN SIX MOS.	
HET-A RESIN	934	48	0.3	1	42	1.6	2	30	2.7	4	27	8.5	12
DIVINYLBENZENE 80°F													
DERAKANE 470	934	42	0.1	1	42	0.1	2	40	0	7	36	0.4	9
DERAKANE 470	934	48	0.1	-1	48	0	-1	45	0	1	43	0.1	2
BIS-A RESIN	934	43	0.2	0	40	0.7	1	32	0.8	2	33	2.4	4
HET-A RESIN	934	48	0.2	0	49	0.3	0	44	0.3	2	44	0.5	2

TABLE XII

ACETIC ACID 120°F	ORIG. BH	1 MONTH			3 MONTHS			6 MONTHS			12 MONTHS		
		HT	THK	BH	HT	THK	BH	HT	THK	BH	HT	THK	BH
DERAKANE 470	934	42	12	34	0/40	22	40	0/30	17	45	0/40	19	44
DERAKANE 470	934	48	4.5	8	15	7.7	12	10	9.1	19	7	12	23
BIS-A RESIN	934	43	6.7	14	0/60	12	17	0/60	13	26	0	13	28
HET-A RESIN	934	48	7.5	12	2	42	16	0/65	13	24	0	12	25
ACETIC ANHYDRIDE 120°F													
DERAKANE 470	934	42	21	24	0/32	24	44	0/10	25	55	0	FAIL IN SIX MOS.	
DERAKANE 470	934	48	2.3	3	30	14.6	7	22	5.7	14	12	12	19
BIS-A RESIN	934	43	9	15	0/52	16	22	0/52	16	26	0	FAIL IN SIX MOS.	
HET-A RESIN	934	48	9.3	13	0/58	15	21	0/56	16	28	0	17	26
BUTYRIC ACID 120°F													
DERAKANE 470	934	42	1.5	0	25	3.8	4	20	11	10	0	FAIL IN SIX MOS.	
DERAKANE 470	934	48	0.5	2	30	0.7	2	26	1.3	4	25	3.3	6
BIS-A RESIN	934	43	1.5	2	23	3.8	7	8	6.0	10	0	11.2	15
HET-A RESIN	934	48	1.1	2	33	2.3	4	21	4.0	8	10	9.0	13

TABLE XIII

ACETONE 80°F	ORIG. BH	1 MONTH			3 MONTHS			6 MONTHS		
		HT	THK	BH	HT	THK	BH	HT	THK	BH
DERAKANE 470	934	42	17	87	0	13	51	0/0	17	51
DERAKANE 470	934	48	5.5	7	4	11	23	0/60	15	31
BIS-A RESIN	934	43	12	5	0	17	47	0/40	14	41
HET-A RESIN	934	48	13	6	0	15	39	0/37	15	30
METHYL ETHYL KETONE 120°F										
DERAKANE 470	934	42	18	29	0	28	51	0	FAIL IN TWO MONTHS	
DERAKANE 470	934	48	0.5	8	14	13	26	0/58	13	26
BIS-A RESIN	934	43	7.2	19	0	10	40	0/35	18	44
HET-A RESIN	934	48	9.7	16	0	15	35	0/42	16	37

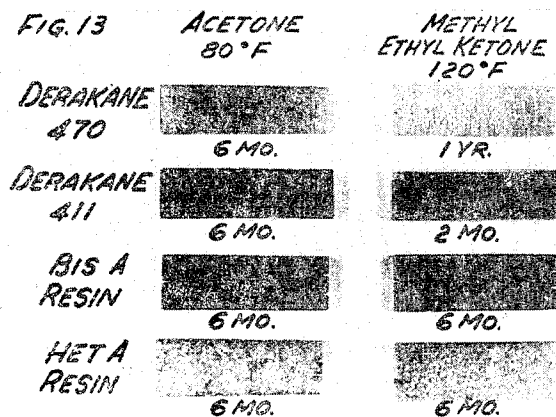
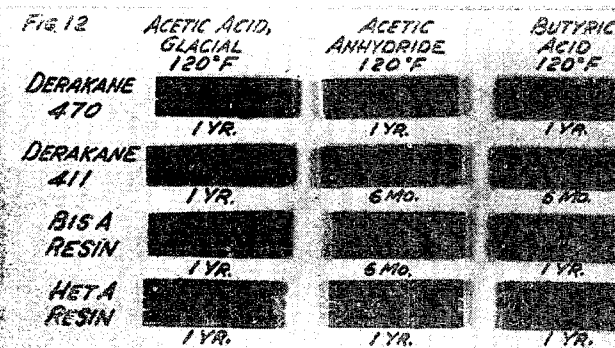
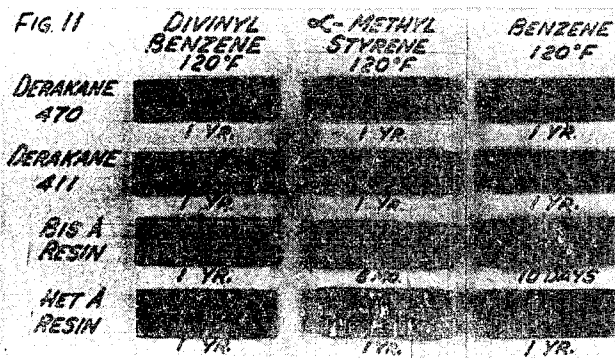
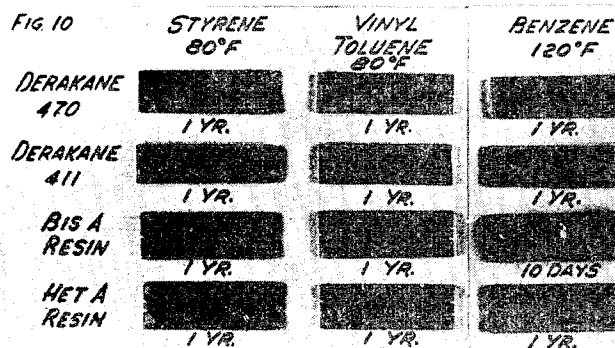


TABLE XIV

AMYL ACETATE 120°F		1 MONTH				3 MONTHS				6 MONTHS				12 MONTHS			
CH ₃ COOC ₅ H ₁₁	ORG. BH	WT	THK	BH	934 935	WT	THK	BH	934 935	WT	THK	BH	934 935	WT	THK	BH	934 935
DERAKANE®411	42	6.4	10	0/41	934 935	16	14	0/32	20	40	0	22	40	0			
DERAKANE®470	48	0.3	2	40	0.5	2	36	0.8	4	32	2.1	6	26				
BIS-A RESIN	43	2.1	3	30	5.6	8	0/50	8.5	12	0	14	18	0				
HET-A RESIN	48	1.1	1	38	3.1	5	18	5.4	10	10	13	16	0				

AMYL CHLORIDE 120°F		1 MONTH				3 MONTHS				6 MONTHS				12 MONTHS			
C ₅ H ₁₁ Cl	ORG. BH	WT	THK	BH	934 935	WT	THK	BH	934 935	WT	THK	BH	934 935	WT	THK	BH	934 935
DERAKANE®411	42	0.2	2	42	0.3	3	40	0.7	4	38	4.8	6	25				
DERAKANE®470	48	0	0	49	0	0	42	0.3	2	42	1.2	2	37				
BIS-A RESIN	43	3.5	5	15	8.5	11	0/57	12.0	20	0	14	26	0				
HET-A RESIN	48	1.0	1	35	2.4	5	22	4.6	8	10	11	12	2				

FIG 14

	AMYL ACETATE 120°F	AMYL CHLORIDE 120°F
DERAKANE 470	1 YR.	1 YR.
DERAKANE 411	1 YR.	1 YR.
BIS A RESIN	1 YR.	1 YR.
HET A RESIN	1 YR.	1 YR.

TABLE XV

MORPHOLINE 120°F		1 MONTH				3 MONTHS				6 MONTHS				12 MONTHS			
OCH ₂ CH ₂ NHCH ₂ CH ₂	ORG. BH	WT	THK	BH	934 935	WT	THK	BH	934 935	WT	THK	BH	934 935	WT	THK	BH	934 935
DERAKANE®411	42	FAIL	IN TEN DAYS														
DERAKANE®470	48	4.8	7	22	6.5	12	13	23	44	0	FAIL	IN SIX MOS.					
BIS-A RESIN	43	29	18	FAIL	IN ONE MONTH												
HET-A RESIN	48	7.2	12	14	FAIL	IN TWO MONTHS											

DIMETHYL MORPHOLINE 120°F		1 MONTH				3 MONTHS				6 MONTHS				12 MONTHS			
OCH(CH ₃)CH ₂ NHCH ₂ CH(CH ₃)	ORG. BH	WT	THK	BH	934 935	WT	THK	BH	934 935	WT	THK	BH	934 935	WT	THK	BH	934 935
DERAKANE®411	42	48	84	0	FAIL	IN ONE MONTH											
DERAKANE®470	48	0.1	-5	45	0.2	0	43	1.2	3	35	3.3	6	35				
BIS-A RESIN	43	1.3	4	32	2.7	6	20	7.6	11	0	FAIL	IN SIX MOS.					
HET-A RESIN	48	0.8	2	49	2.4	5	32	4.4	10	10	15	18	0				

FIG 15

	MORPHOLINE 120°F	DIMETHYL MORPHOLINE 120°F
DERAKANE 470	6 MO.	1 YR.
DERAKANE 411	1 MO.	1 MO.
BIS A RESIN	1 MO.	6 MO.
HETA RESIN	3 MO.	1 YR.

TABLE XVI

BUTYLENE GLYCOL 120°F		1 MONTH				3 MONTHS				6 MONTHS				12 MONTHS			
HOCH ₂ CH ₂ CH ₂ CH ₂ OH	ORG. BH	WT	THK	BH	934 935	WT	THK	BH	934 935	WT	THK	BH	934 935	WT	THK	BH	934 935
DERAKANE®411	42	0	1	40	0	1	40	0	2	36	0	2	38				
DERAKANE®470	48	0	1	46	0	2	45	0	3	45	0	3	42				
BIS-A RESIN	43	0	1	38	0	1	38	0	4	40	0	3	40				
HET-A RESIN	48	0	1	46	0	1	46	0	2	44	0	4	45				

BUTYLENE OXIDE 80°F		1 MONTH				3 MONTHS				6 MONTHS				12 MONTHS			
CH ₃ HCOCHCH ₃	ORG. BH	WT	THK	BH	934 935	WT	THK	BH	934 935	WT	THK	BH	934 935	WT	THK	BH	934 935
DERAKANE®411	42	21	51	0	FAIL	IN TWO MONTHS											
DERAKANE®470	48	13	14	0/60	17	34	0/60	18	38	0	18	36	0				
BIS-A RESIN	43	22	54	0/36	FAIL	IN TWO MONTHS											
HET-A RESIN	48	21	63	0/15	FAIL	IN TWO MONTHS											

FIG 16

	BUTYLENE GLYCOL 120°F	BUTYLENE OXIDE 80°F
DERAKANE 470	1 YR.	1 YR.
DERAKANE 411	1 YR.	2 MO.
BIS A RESIN	1 YR.	2 MO.
HET A RESIN	1 YR.	2 MO.

TABLE XVII

BARCOL HARDNESS AND RESIDUAL STYRENE

LAMINATE	WT. % RESIDUAL STYRENE MONOMER*	BARCOL HARDNESS
BIS A RESIN	< 0.2	43
HET-ACID RESIN	0.4	48
DERAKANE® 470 RESIN	< 0.2	48
DERAKANE® 411 RESIN	0.4	42

* THE DERAKANE COUPONS WERE CUT INTO APPROXIMATELY 0.5" SQUARES, WEIGHED, AND EXTRACTED WITH A KNOWN AMOUNT OF CHLOROFORM. THE STYRENE BAND AT 990 CM⁻¹ IN THE INFRARED SPECTRUM WAS THEN MEASURED TO OBTAIN THE PERCENT RESIDUAL STYRENE.

NEW HIGH PERFORMANCE CORROSION RESISTANT RESIN

by
R. J. LEWANDOWSKI, E. C. FORD, JR., D. M.
LONGENECKER, A. J. RESTAINO and J. P. BURNS*

ABSTRACT

The first member of a new series of versatile corrosion-resistant polyester resin is described. It is identified as ATLAC 580-05** polyester resin. This new resin combines both internal and terminal unsaturation. Urethane connecting groups are included to improve wet-out and bonding. Corrosion resistance properties and elevated temperature strength retentions of ATLAC 580-05 resin are superior to those of conventional "vinyl-ester" resins. Application areas include contact molding, filament winding, linings, and thick sheet fabrications.

INTRODUCTION AND BACKGROUND

A number of unsaturated polyester resins are currently available for use in manufacturing reinforced plastic structures. ATLAC 382, a condensation bisphenol-A fumarate polyester, is recognized in the industry as having the broadest range of corrosion resistance and is considered the industry standard for corrosion resistant performance.

Recently, we have seen the advent of the "vinyl-ester" resins which generally contain only terminal unsaturation. One of the earlier composition of matter disclosures was made in 1962 by Rafael L. Bowen in U.S. patent 3,066,112 (Reference 1). Subsequent disclosures were made in 1967 and 1968 by Mr. F. Fekete in two patents (Reference 2 & 3) assigned to H. H. Robertson Co. Shell Chemical Company introduced a series of resins based on this technology, tradenamed EPOCRYL® in 1965-1966. More recently, Dow Chemical introduced a series of bisphenol-A "vinyl-ester" resins tradenamed DERAKANE®.

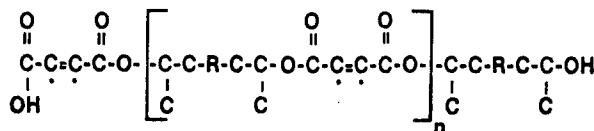
As a family, these resins have shown good handling characteristics in cure, reasonably good corrosion resistance, and improved resiliency. They typically suffer from poor strength retentions at elevated temperatures. Attempts to formulate for this property have generally resulted in increased rigidity and low viscosities which introduce poor handling characteristics and make fabrication difficult. Also, the family as a whole has suffered from poor corrosion resistance to caustic and chlorine as shown by D. Evans, et al., of Diamond Shamrock at the 29th SPI Conference (Reference 5). There have also been shelf stability problems.

This paper describes the first member of a potential series of bisphenol-A chemically resistant resins which combine the best properties of polymers containing both internal and terminal unsaturation. The new resin is named ATLAC 580-05 and provides improved chemical resistance over existing flexible "vinyl-ester" resins. It also has the desirable handling and resiliency characteristics of the "vinyl-ester" resins with superior elevated temperature resistance. As with all the ATLAC polyesters, it has a six month shelf stability.

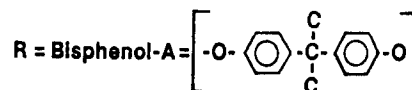
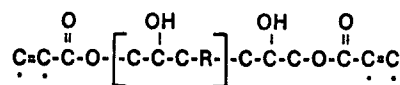
CHEMISTRY

The chemistry of both the chemically resistant polyester resins based on bisphenol-A (ATLAC 382) and the terminally unsaturated "vinyl-ester" resins, have been discussed widely in the literature. Their structures have been idealized as follows:

Bisphenol-A-Fumaric Acid Condensation Polyester



Vinyl Ester Addition Resin

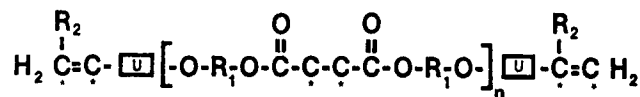


* Denotes reactive sites

The bisphenol-A fumaric acid condensate polyester (ATLAC 382) is typified by the reactive sites being in ester groups within the polymer chain. The ester groups are theoretically subject to attack by hydrolysis but are protected by their proximity to bulky bisphenol-A groups. This is easily demonstrated by an unquestioned 20-year proven history in handling a broader spectrum of corrosive environments than any polyester known.

The "vinyl-ester" type resin was defined by Vetter (Reference 4) as "a polymerizable resin in which the terminal positions of the resin are "vinyl-ester" groups and in which the main polymeric chain between the terminal portions comprises the residue of a polyepoxide resin." Basically, this is accomplished by reacting acrylic or methacrylic acid with an epoxy resin which places the reactive unsaturation groups in the terminal position. These reactive sites in either resin eventually react with styrene or other monomer to form a cross-linked thermoset resin. The vinyl ester type resins generally result in single unit molecular structures and highly ordered cross-linked resins when copolymerized with styrene. Various claims (Reference 4) have been made for these structures. They include better reactivity and resiliency because of the terminal nature of the reactive sites, and better wet-out on fibers because of the acrylate. Time has shown these claims to be valid, but the resiliency has been gained at the expense of property retention values at elevated temperature. Claims relating to anticipated excellent resistance to caustic and oxidizing environments have not been proven. This may be related to the hydroxyl content of these resins (Reference 5). This will be discussed later in this paper.

ATLAC 580-05 represents a unique new chemistry designed to take advantage of the good points of both the above molecular structures. The potential family of molecules resulting from this new chemistry can be idealized as follows:



R₁ - Bisphenol group

R₂ - Alkyl group or hydrogen

U - Urethane Connecting Group

* - Reactive sites

The molecular nucleus is similar to the BPA fumarate polyester and has internal unsaturation. This portion of the molecule contributes improvements in viscosity, high temperature strength, and corrosion resistance to the vinyl structures. In addition, the benefits of better reactivity, re-

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siliency, and wet-out associated with the terminal vinyl groups are maintained.

In order to improve the molecule even further, the urethane groups just prior to the terminal vinyl unsaturation were added. These groups are known to produce superior wet-out and adhesion properties.

As can be seen, ATLAC 580-05 represents a unique new chemical approach to the manufacture of versatile corrosion resistant unsaturated polyester resins.

SOLUTION PROPERTIES

The solution properties of ATLAC 580-05 are contained in Table I. The solution viscosity is in the range of 350-550 centipoise which is generally recognized as that needed in most operations. The six-month shelf life is indicated along with the ability to be thixotroped. As can be seen, "the vinyl-ester" material did not respond to the thixotrope. This, of course, results in the ATLAC 580-05 being easier to handle on vertical surfaces such as those encountered when lining steel or concrete tanks as well as secondary joints and bonds.

CURING AND FABRICATING

ATLAC 580-05 can be cured with the typical cobalt naphthanate/methyl ethyl ketone peroxide curing systems at room temperature. Relatively low exotherms result which prove useful in fabricating thick structures. Specific systems for curing at various room temperatures as well as elevated temperatures are available in our literature or from our laboratory.

It was noted during fabrication of the samples described later that the resin has excellent wet-out characteristics with various glass fiber products. Thick laminates were produced without fiber prominence due to high exotherms. It was further noted the resin cures "dry-to-the-touch" immediately after cool down of the exotherms.

The excellent air drying capability of ATLAC 580-05 is further enhanced by the fact that relatively low concentrations of paraffin are needed to produce non-air inhibited surfaces. Only 0.2% paraffin by weight of resin is recommended which should make topcoating and secondary bonding simpler.

CHEMICAL RESISTANCE

ASTM C-581 is the recognized corrosion test for comparing the resistance of unsaturated polyester resins in composites. It was, therefore, selected to determine the corrosion resistance of ATLAC 580-05 as compared to the most commonly used commercial resilient "vinyl-ester" resin.

Laminates of both resins were prepared per C-581. They consisted of 25 $\pm$ 2% glass using two plies of 1½ oz. chopped strand mat surface on both sides with a ply of 10 mil C-glass surfacing veil. Cobalt/DMA/MEKP curing systems having a 30-40 minute gel time were used for both resins. Both laminates were also postcured for 4 hours at 100°C to insure complete cure. Barcol hardnesses of the resulting laminates were in the 40-45 range.

4" x 5" test coupons cut from the above laminates were exposed for 1 year at 203° $\pm$ 5°F in the selected environments indicated in Figures 2 and 3. Specimens were removed from each environment and tested after 1, 3, 6, and 12 months' exposure. To simplify this mass of data, bar graphs depict the relative one year retentions of flexural strengths and modulus in Figures 1 & 2. Included on these charts for reference are statistical ranges of retention for ATLAC 382 representing some 20 years of testing on that particular resin.

As anticipated, ATLAC 580-05 matched the overall resistance of the resilient "vinyl-ester" resin in acid and acidic salts, (H₂SO₄, HNO₃, HCl, CH₃COOH, and Alum). In non-acid environments, (NaOH, NaOCl, and H₂O), it performs closer to ATLAC 382-05A and is superior to the "vinyl-ester" product. The caustic data shows both the ATLAC 580-05 and the "vinyl-ester" failed at the one year test interval in this extremely difficult environment. However, ATLAC 580-05 resisted the environment for a longer period of time than the "vinyl-ester" resin since at the 6 month test interval the "vinyl-ester" was barely testable with a flexural strength retention of 12% while the ATLAC 580-05 had a better

appearance with a 25% retention. Our laboratories have reproduced this poor performance in caustics of the "vinyl-ester" resin on a number of occasions and our data are in agreement with that presented by Mr. Evans of Diamond Shamrock at the 29th SPI Conference (Reference 5).

In conclusion, it can be seen that the ATLAC 580-05 offers an extra measure of safety in handling environments in the higher pH range and is, at minimum, equivalent to the "vinyl-ester" resins in acidic environments. We recommend that when highly caustic environments are involved, caution be exercised and our laboratories be contacted for suggestions for the resin system of choice.

MECHANICAL PROPERTIES

To demonstrate the expected mechanical properties of the ATLAC 580-05 resin, two types of glass reinforced composites common to the corrosion resistant FRP industry were prepared.

One was the same ½" composite used for corrosion testing composed of two plies of contact molded 1½ oz. chopped strand mat with a ply of 10 mil C-glass surfacing veil on either side. This laminate is nominally 110 mils thick, but described in the literature as ½". Data comparing the ATLAC 580-05 with the "vinyl-ester" polyester are contained in Table II. The data presented are representative only of the specific composites listed. Value ranges for ATLAC 580-05 are available in our product literature.

As can be seen from the data, ATLAC 580-05 will offer at least equal, and often higher, strengths and moduli than the "vinyl-ester." Impact resistance is equivalent. This property will prove of value in relatively thin molded structures such as found in filament wound pipe and ducts.

Another laminate common to the FRP corrosion industry is similar to the one described above, but extended in thickness by adding alternate plies of 24 oz. woven roving and 1½ oz. chopped strand mat. Laminates of each resin system were made by contact molding in the following sequence: veil/mat/mat/woven roving/mat/woven roving/mat/woven roving/mat. Nominal thicknesses were 5/16" and the glass contents were controlled to 36 $\pm$ 2%. The laminates were postcured 2 hours at 100°C to insure complete cure of both systems. Curing systems used were cobalt naphthanate/DMA/MEKP adjusted to give 40-50 minute gel times at 75°F. Comparative data resulting from these laminates were contained in Table III.

Table III shows the same improvement in properties obtained in the thinner laminates.

Because the ATLAC 580-05 structure combines unsaturation within the molecule as well as at the terminal groups, it was theorized that the ATLAC 580-05 should present higher temperature resistance at equivalent resiliencies to a straight "vinyl-ester" resin having only terminal unsaturated groups. To put this to the test, identically prepared 5/16" laminates were fabricated as described above. Each was postcured for 2 hours at 100°C and then tested at temperatures up to 250°F where ATLAC 382 structures are now in service. Appropriate samples of each laminate were prepared, placed at the desired temperature for ½ hour, then tested at that temperature. The resulting data are plotted in Figures 3, 4, 5 and 6.

As can be seen from the figures, the superior strength and good temperature resistance of ATLAC 580-05 gives a margin of extra strength throughout the spectrum of elevated temperature exposure. At 200°F ATLAC 580-05 provided a margin of 4000 psi tensile strength, 2900 psi flex strength and 180,000-320,000 psi modulus over the "vinyl-ester."

This testing is intended to illustrate the relative temperature resistance of the resins and since similar tests with ½" and ¾" laminates have shown the same trend, we feel it is real. There is no basis, however, to translate the numerical data on the lab samples directly to design numbers, as laminate preparation has been closely controlled under laboratory conditions and the testing is done with a full temperature soak; whereas, field exposure is normally one-sided only.

CONCLUSIONS AND APPLICATIONS

As can be seen from the data present, the unique structure of ATLAC 580-05 fills an industry need by overcoming many of the deficiencies found in the "vinyl-ester" type resin. It provides the wet-out, curing, and

resiliency properties necessary for the filament winding or contact molding of corrosion-resistant structures. As an added bonus, it offers better retention of strength at high temperatures and better overall corrosion resistance. The new resins will provide manufacturers with minimal warpage in thick laminates and because of its structure should be an excellent candidate for lining systems. Work is progressing at this time to obtain bond strength data for various substrates and to develop corrosion testing data of actual linings, using the ATLAB® Tank Tester.

The ATLAC 580-05 resin represents a unique new chemical synthesis method for producing unsaturated polyester resins. Our Research and Development Laboratories are already working on expanding this new chemistry with anticipated significant improvements over existing products.

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4. C. M. Veters, "Derakane® Vinyl Ester Resins Show Improved Chemical Resistance for Corrosion Control," Proc. 25th Annual Technical and Management Conference on Reinforced Plastics, Society of Plastics Industry, 1970.
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Joseph P. Burns is a Development Associate in the New Product Development Section of ICI United States Inc. His responsibilities encompass resin, polymer and composite development. He holds a B.Sc. in Chemistry from the Philadelphia College of Pharmacy & Science and an M.S. from the University of Louisville in 1951. He is a member of the American Chemical Society, SPE, ASTM and Sigma XI. He was previously employed with Devoe & Reynolds Co. and U.S. Plywood Corp. He is author or co-author of several patents in the applied polymer field.

Table 1.
ATLAC® 580-05
SOLUTION PROPERTIES

	<u>ATLAC 580-05</u>	<u>"VINYL-ESTER" Resilient</u>
Solids (%)	50	55
Viscosity⁽¹⁾ (c p s)	350-550	400-600
Stability	6 mos.	—
Thixotropic Index⁽²⁾ (1% Cab-o-sil)⁽³⁾	2.27	1

- (1) Brookfield — #3 spindle 50 rpm
(2) Brookfield — #3 spindle 10 rpm (cps)
100 rpm (cps)
(3) Registered trademark of Cabot Corp.

Table II.
ATLAC® 580-05
MECHANICAL PROPERTIES
1/8" LAMINATES ⁽³⁾

	ATLAC 580-05	"VINYL-ESTER" Resilient
Flex. Str. (psi) (1)	17,100	14,500
Flex. Mod. (psi x 10 ⁻⁶) (1)	0.85	0.63
Tensile Str. (psi) (2)	15,600	12,400
Tensile Mod. (psi x 10 ⁻⁶) (2)	1.03	0.90
Tensile Elongation (%) (2)	1.77	1.78
Falling Ball Impact (g-M/in ²)	196	194
Barcol Hardness	37-42	28-33
% Glass	25	25

- (1) ASTM D 790-71
- (2) ASTM D 638-72
- (3) Note: Laminate construction: C-veil/mat/mat/C-veil

Table III.
ATLAC[®] 580-05
MECHANICAL PROPERTIES
5/16" LAMINATES⁽³⁾

	ATLAC 580-05	"VINYL-ESTER" Resilient
Flex. Str. (psi) (1)	24,700	21,300
Flex. Mod. (psi x 10 ⁻⁴) (1)	1.07	0.98
Tensile Str. (psi) (2)	17,700	15,400
Tensile Mod. (psi x 10 ⁻⁴) (2)	1.37	1.26
Tensile Elongation (%) (2)	2.15	1.89
Barcol Hardness	43-47	41-45
% Glass	36	37.4

- (1) ASTM D 790-71
- (2) ASTM D 638-72
- (3) Note: Laminate construction C-veil/mat/mat/woven roving/mat/woven roving/mat/woven roving/mat

FIG. I
ATLAC[®] 580-05 vs. VINYL-ESTER POLYESTER
ONE YEAR CORROSION - 200 °F⁽¹⁾
LAMINATES
PERCENT FLEX RETENTION

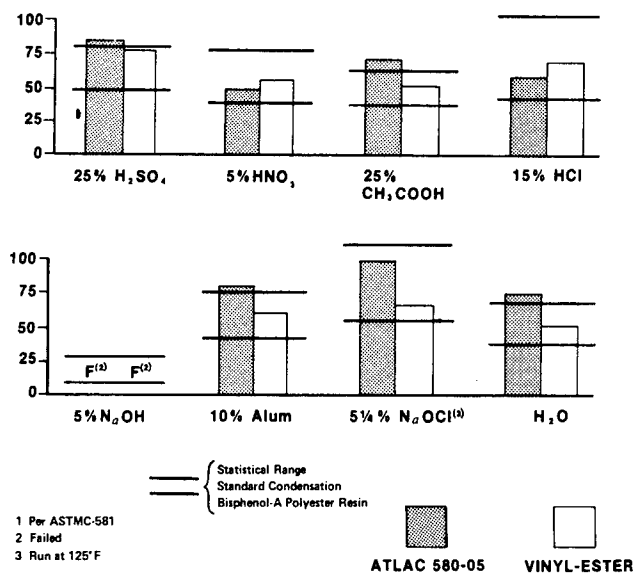


FIG. II
ATLAC[®] 580-05 vs. VINYL-ESTER POLYESTER
ONE YEAR CORROSION - 200 °F⁽¹⁾
LAMINATES
PERCENT FLEX MOD. RETENTION

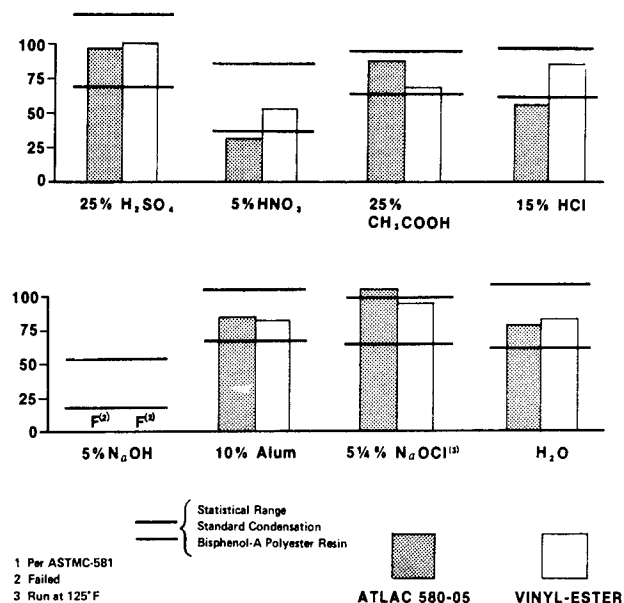


FIG 3
ELEVATED TEMPERATURE FLEXURAL
PROPERTIES 5/16" MAT-WOVEN ROVING LAM.

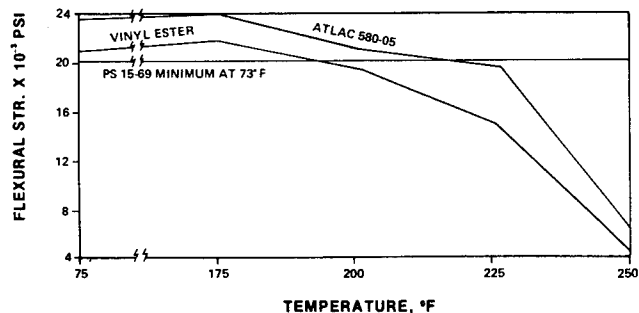


FIG 4
ELEVATED TEMPERATURE FLEXURAL
PROPERTIES 5/16" MAT-WOVEN ROVING LAM.

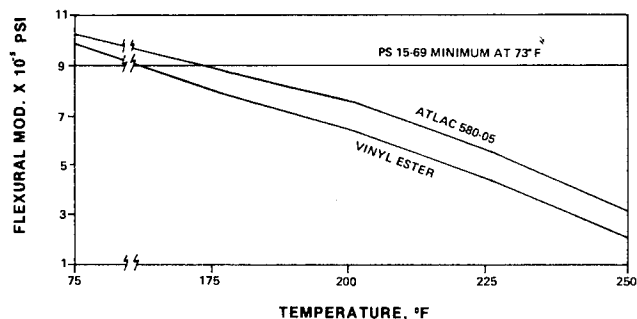


FIG 5
ELEVATED TEMPERATURE TENSILE
PROPERTIES 5/16" MAT-WOVEN ROVING LAM.

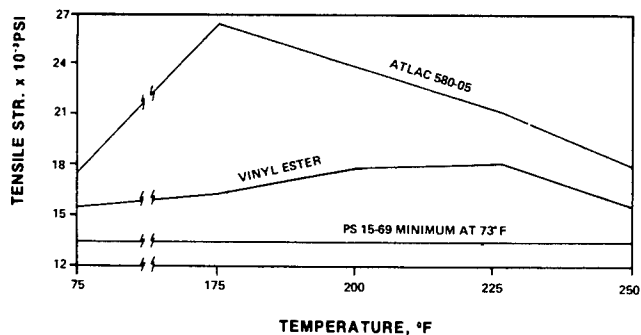
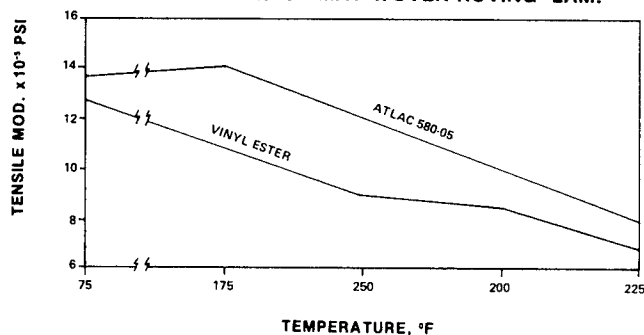


FIG 6
ELEVATED TEMPERATURE TENSILE
PROPERTIES 5/16" MAT-WOVEN ROVING LAM.



SECTION THREE

PIPE AND PIPING SYSTEMS

QUALITY CONTROL FOR CORROSION RESISTANT EQUIPMENT

by

ROLLIN C. BERNHOFT*, ROBERT E. BARNETT**,
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ABSTRACT

Reinforced plastic equipment has demonstrated and recorded many advantages in corrosion service, proving that high standards, properly maintained, insure the purchaser maximum performance.

The objective is to obtain a higher degree of quality among all companies fabricating industrial equipment to be used in corrosive environments. After lines of responsibility have been established, the objectives can be reached through well planned quality control programs. These programs require qualified personnel, equipped with proper methods and tools. The investment in such programs can generate greater profits. Management is charged with the responsibility of setting and meeting high goals of quality.

INTRODUCTION

Reinforced plastics are continuing to play a large part in overcoming increasing corrosion problems in industry. The task becomes greater and more difficult with increased demands on equipment as higher production volumes generally cause more severe conditions and new products create even more applications for the material.

Manufacturers of chemical resistant reinforced plastic equipment must take exceptional care to insure that the quality of products produced provide the best possible resistance to chemical attack and required physical strengths. While good performance is dependent on the choice of resin, reinforcements and engineering, a major role in the success of any product rests primarily on the quality of workmanship that goes into it.

Quality products are, by and large, the result of successful blending of methods and materials engineering with good performance from individual workers and programmed machines.

Responsibility rests with top management, through production supervisors and quality control departments to effect proper controls and insure that all products meet quality standards.

THE QUALITY CONTROL PROGRAM

Who is at fault if poor quality equipment or parts incorrectly fabricated arrive at the customer's plant? Is the employee who

made the equipment, the Quality Control Department, or the Company responsible? Actually, all are responsible.

Quality Control can help create a company's reputation, break its reputation, or do nothing whatsoever to establish its reputation. The results are directly attributable to how much effort management puts forth to promote effective standards of quality. This effort generally starts with top management recognizing that successful programs require leadership, guidance, and full cooperation among departments. Such action helps create a more positive quality environment within the whole organization and sets the tempo for an effective program.

Now, assuming that we have top management's participation zeroed in on quality control, where does the action start to discover and remedy the causes of defects?

Primarily it boils down to three check list items.

1. When is the product inspected?
2. Who inspects the product in fabrication?
3. How is the product inspected?

The presence of new standards for corrosion-resistant equipment issued by the Department of Commerce, NBS-PS-15-69, is not in itself enough to guarantee adherence to them, or to assure good performance from FRP equipment. Equipment should be inspected during and after construction. This most important function is generally handled by quality control inspectors. The Quality Control department is usually a branch of production management reporting to the executive head of the manufacturing division. The department head must be technically schooled in reinforced plastics and be thoroughly familiar with all phases of production. His know-how must include the ability to identify all forms of reinforcements, the purpose of each, and results expected. He should understand and be able to explain what could happen if reinforcements were used in the wrong sequence. He is able to routinely check laminate for uniformity, air entrapment, dry spots or foreign matter, and any cracking or crazing that would indicate a structural flaw or surface imperfection, in order to do the job efficiently.

The quality control inspector must be supplied with the customer's order, specifications, and a complete set of fabrication drawings. General arrangements and dimensions must be checked against drawings and customer's purchase order and details of construction checked for compliance with specifications.

In quality control, the inspection function helps to insure that products meet selected quality standards by rejecting all work that falls below standard.

In addition to the manufacturer, many of the larger companies, who regularly purchase reinforced plastics equipment, have a staff man or a small group of corrosion specialists assigned to provide expert inspection during fabrication of important purchases. This group is also involved in writing qualification procedures and complete specifications to insure that equipment meets service requirements, and to prevent costly downtime and excess installation costs due to faulty materials and inaccuracies. The fabricator knows these experts will be looking at materials used in the laminate, the proper sequence, repair procedures, sampling, construction accuracy, testing procedures, and overall quality of the finished product as specified in the order.

Too many failures and costly delays, since FRP emerged as a formidable corrosion resistant material, have brought about this concern about quality among purchasers. The problem is evident. Fabricators must provide their own in-plant inspections and build uniform quality into products or suffer the consequences. There are no short cuts to quality.

PROGRAM SIZE

Tailoring a Quality Control program to fit the plant size is the first important step towards achieving uniform quality in the product. A good plan, followed daily, is the key to successful

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management. This will instill the importance of quality into all levels of management and the work force. Whatever the program, Top Management must take an active part.

NBS-PS-15-69 provides a good training and reference base for production and inspection personnel. The information contained in this specification involves not only details of the materials used, appearance, dimensional tolerances, but also outlines testing programs.

A step-by-step plan of inspection from preparation of the tooling and molds to the final dimensional check with inspection during laminate lay-up and fabrication should be established with responsibilities clearly defined.

For the smaller fabricator who does not require a full time quality control inspector, the responsibility must be assigned to supervisors, and management people so that someone always inspects the product before it leaves the plant.

As production capacity increases, a quality control person should be selected and trained to conduct inspections and tests during all phases of production. In the beginning, he may devote only part time to inspection with the balance utilized in areas such as inventory, job scheduling, or estimating, until such time as full time participation in quality control is required. The type of product and volume will dictate how much time is required for quality control. For this reason, it is difficult to prescribe when to establish a full time Quality Control program and how many personnel are required to man it.

The Quality Control Department should report directly to the Plant Manager or top manager in the organization. This will minimize problems that arise when production supervisors are pressed to meet deliveries and hold costs in line.

A few words of caution when setting up a program. Too much involvement by production line people may produce poor results. Relying on the person who produced the job to inspect it is not advisable as he generally overlooks his own mistakes or won't take time to check close enough. No doubt he will judge his work the same as when he made it.

Too much involvement by the top management in checking details to find errors is poor use of management's time. Management should be preventing errors—not looking for them.

Management must work on details that produce better results and programs to instill in each worker the importance of why a quality laminate or fabrication is necessary. When the worker is aware of how his workmanship may affect the customer, as well as his employer, more positive results are noticed.

THE COST OF THE QUALITY CONTROL PROGRAM

Many managers view a Quality Control program as a drain on profits and minimize its use. This viewpoint is obviously incorrect. A properly managed program will definitely increase profits and the return on investment will be as great as any other production activity.

Regardless of size, a Quality Control program will show positive results. The faster problems can be detected, the more costs will be saved. A part, costing a few dollars that is found faulty and rejected in the molding stage, could cause many thousands of dollars if it failed while in service. Loss of future business may be added to this with an untold amount of profits lost. The cost of the program, or the investment in it, are realistically designed to improve productivity and resultant profits through the elimination of costly errors and backcharges.

TECHNIQUES AND EQUIPMENT

After guidelines and responsibilities for the program are established, it is necessary to provide proper methods and equipment to get the job done. Check lists and drawings are a good place to start. Drawings can be used to check pertinent dimensions and retained as a record. A check-list to cover all other aspects of the job will

insure everything is investigated and serve as a permanent record. It may also be necessary to have a separate check-list for each different product. The following items should be a part of inspection of each product:

- Thickness

- Hardness

- Dimensions and tolerances

- Quality of laminate, including physical tests when required.

- Hydrostatic test, when required.

Visual inspection provides one of the simplest and most effective ways to judge the soundness of the laminate. By placing a light behind the wall or section of an unpigmented structure, the inspector can judge the uniformity of the laminate and can detect air bubbles, dry spots, internal cracking or other conditions indicating possible weakness in the structure.

Surface condition is another indication of laminate construction. A smooth, true surface is generally a sign of a well-made, uniformly-cured laminate. If exposed fibers exist on the corrosion surface, there is a rupture in the protective resin layer vital to corrosion resistance. This can easily be repaired. Exposed fiber bundles also indicate the likelihood that a surfacing mat is absent.

Industrial specifications often call for testing by cutting a section from the fabricated piece (overage of length, manhole, etc). Resulting cross section will reveal depth of surface layer as well as shape and conformity of laminate. Stressed areas often will be seen immediately as internal cracks. Cross section will also show the bond between layers and degree of wet-out fibers as well as position of the surfacing mat and thickness of the protective resin-rich layer.

Another test often used is Barcol hardness. This test is useful only for measuring relative hardness of pieces fabricated from a single type of resin. Results are meaningless when comparing different resins because each polyester will have its own inherent hardness. The Barcol hardness of a laminate is checked against the average ratings found in well-cured structures of the same resin and construction. If test values are lower, the inspector should immediately suspect an incomplete cure, which would result in poor corrosion resistance.

To determine complete cure, an "Acetone Test" has been developed. This involves application of a small amount of acetone on the resin surface. The person conducting test rubs the wetted surface lightly with a finger until the acetone has evaporated. If the surface softens or becomes tacky, the resin is not properly cured.

Modern electronics have made contributions that will assist greatly in the task of maintaining product quality. One of these contributions is the Ultrasonic Flaw and Thickness Tester. This type of equipment will greatly reduce the time required to properly check laminate thickness. It also makes it possible to determine the thickness in areas that are not accessible with normal measuring tools and gages. Flaw detection is also possible with this equipment. This is a valuable asset when determining the quality of a filled or opaque laminate.

Operation of the tester is relatively easy and convenient. A transducer or scanner is placed against the surface of the laminate. The conditions detected are transmitted by a cable to the instrument, where a graphic picture of the condition is produced by a cathode ray tube on a screen.

Models of these instruments are also available for continuous in-line monitoring for thickness and flaws. This can be very useful for continuous or machine-made pipe production.

There are a large number of instruments and devices on the market today designed for a range of product testing requirements. The task of maintaining quality in products can be made much easier through the use of these instruments.

PRODUCT TESTING

What type of production testing is necessary? Physical tests

should be attempted only on regular production runs. Chemical resistance tests should be conducted prior to producing the equipment. Qualified personnel suitably equipped to conduct the tests should be assigned or arrangements made with a qualified testing company to provide the service.

Physical testing should include tensile strength, flexural strength, flexural modulus, and hardness. In some cases, other tests such as impact strength, compressive strength and shear strength are required. Glass content test should be included with all test runs. The appropriate ASTM test methods are described in NBS-PS-15-69.

Routine inspection and testing of incoming materials should be conducted to qualify the resins and reinforcements. Retesting may be necessary if materials remain in storage for long periods of time.

To give emphasis on the products or equipment of most concern, separating them into categories by service conditions will be helpful. One group would be the mild chemical service conditions with normal load conditions, such as small exhaust systems. For this group physical tests other than hardness should not be necessary.

The materials testing and good visual inspection should be enough to insure a quality product. It is recommended that tests be run from time to time to determine if changes in production methods or personnel doing the work have altered the physical properties of the laminates.

The severe service group of equipment can be broken down into sub-groups. A different degree of testing for the sub-groups may be desired. Test specimens should be taken from cut-outs for nozzles, manholes or other openings. If there are no suitable cut-outs, extra material should be produced, such as an extra foot of pipe or duct. Where this is impractical, such as on large tank shells, a separate lay-up should be made for testing, using the same construction and following the same time sequence as the production item. On very critical applications, it is recommended that a separate lay-up should be made and tests run before production starts. This gives a double check on materials that have been in stock. Sometimes it is found that the coupling agent on fiberglass has deteriorated, giving low laminate physicals.

Accurate records of all tests should be made and kept as a permanent record.

Hydrostatic testing is a requirement for tank and pipe production. Due to production methods, each part has a distinct character of its own. It is these characteristics that we are testing and not just the design. All tanks should receive a hydrostatic test with liquid levels and pressures at least equal to those expected when in service. Some applications may require higher pressures for testing. Deflections and strains should be measured and checked with design conditions for compliance. All pipe should be hydrostatically tested before going into service. In many cases where connections or section shapes make this difficult, this can be done after installation at the customer's plant. Machine made or high volume produced pipe requires 100% testing before shipping to customer.

Vacuum applications should be given the same consideration for testing as pressure applications.

Product testing such as that previously described has become very important to equipment users. Many costly failures have occurred in equipment where it was assumed that the physical properties of the laminate met the design specifications.

APPEARANCE

Before any equipment is released for shipment to the customer, take a good look at it. Are you proud of it? Appearance usually reflects the character of the product and that of the producer. A good looking product indicates pride in it by the manufacturer which usually follows through the entire production of the equipment, including the quality control program.

SUMMARY

If reinforced plastics are going to survive under the increasing demands for performance in industrial applications, it is imperative that manufacturers adhere to strict quality control programs. Workable programs must be designed that will obtain the necessary results. Qualified people with proper tools to do the job are the keys to a successful program. Methods and tests have been developed and equipment is available to do the job, the rest is up to Management. Management must concentrate on higher goals for quality and Customers should insist on management achieving these goals.

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304 stainless steel sheet; soft aluminum sheet; PVC-epoxy plastisols having various concentrations of glass fiber and/or sand or glass spheres. (The formula for each matrix material is shown in Appendix A.)

THE EROSION OF GLASS SPHERE/GLASS FIBER REINFORCED PLASTIC MATERIALS VERSUS METALS

by

HERBERT L. JONES*

ABSTRACT

Erosion data obtained on the weight loss of coated plates and lined pipes due to solid/solid abrasion, without the complicating facts of **corrosion**, demonstrate that glass-fiber and glass-sphere filled thermoplastic materials can out-perform their metal counterparts, in spite of strikingly lower surface hardness. When filled with spherical fillers, having ratios of large-to-small spheres of at least 3:1 and when combined with chopped glass fiber, remarkable increases in erosion resistance are accomplished.

Furthermore, when the above liner system is utilized in flexible, high-strength substrates, such as a filament wound pipe, the performance increases are even more marked. The benefits of a systematic combination of liner formulation and substrate selection are clearly delineated.

INTRODUCTION

It has long been noted in the lining of chemical pipe, pumps, etc. with both metal and non-metal materials that the relationships between corrosive failures in the field and laboratory evaluations have shown wide theory/practice discrepancies. With isotropic materials having pronounced galvanic breakdown, such as most metals, the **erosive** attack by a slurry of at a "90°-elbow" can be easily isolated because the cause of the **corrosion** itself can be separated and counterattacked by techniques, such as cathodic protection.(3)

However, with a composite polymeric structure, such as lined filament-wound pipe, the process of corrosion itself is quite complicated and is thus less easily isolated for the purpose of erosion study. It is, therefore, necessary to eliminate liquids from the erosion system and substitute purely mechanical methods of eroding the surface. It was, with this goal in mind, that this project was undertaken.

As stated above, corrosion of polymeric materials are complicated and often involve combined effects of defusion, solution, ionic attack, swelling, etc. Hence, where the **substrate** itself (and not only the liner) is subject to corrosion, the isolation of liner phenomena is obviously impossible. This again, is the rationale behind attempts to isolate characteristics of the **eroding system**, including the combined liner and substrate.

The data discussed in the paper demonstrates quite clearly that this total system analysis is amply justified.

USE OF TABER ABRASION DATA COMBINED WITH SHORE HARDNESS AS EROSION INDEX

Shown in Table I below are Taber abrasion data and Shore Hardness of the following materials:

TABLE I

TABER** WEAR FACTOR RESULTS AND COMPARISONS WITH SURFACE HARDNESS

Wear Factors	Shore Hardness
Steel . 55	D 100
Al 73	D 96
Sample A** 300	D 75
B** 450	D 80
C** 425	D 56

The data shown above corresponds very closely with that described by Lee and Neville (1) in which gypsum, steel, aluminum, and filled epoxy are compared. Taken by itself, such data is of little value in predicting erosive performance.

The conventional Taber test method is not cumulative but is determined by the following equation whereby the weight loss (or volume loss) is calculated for 5,000 cycles and expressed as a Wear Factor or Wear Index:

$$\text{Wear Index} = \frac{\text{WT. Loss (Grams)} \times 1000 \text{ Cycles}}{\text{SP. Gr.} \times 5000}$$

If the weight loss per cycle is a constant, then the Wear Factor will remain unchanged during any number of cycles of abrasion. Indeed, with the exception of work hardening effects in metals, this is precisely what happens with both a hard alloy, such as 304 stainless steel, and a soft nonferrous material, such as the 1100 aluminum chosen for this work.

However, for anisotropic materials, such as those containing fibrous and/or particulate reinforcement, the Wear Factor can vary considerably, especially when one has a very soft matrix material holding very hard, brittle materials such as glass and sand in position (see Figure I). Under such conditions, the Wear Index is not important, but rather the weight-loss/time curve. The principle involved is that the impacting particles of varying sphericity strike a particular surface with a particular momentum. The resistance of the entire cross section, including liner and substrate, is dependent upon the following factors:

- The concentration and size of the liner reinforcements
- The angularity, angle of attack and momentum of the impacting solids
- The modulus of the substrate (e.g. steel, aluminum, or filament fiber glass)
- The modulus and quality of adhesion within the matrix material

In selecting thermoplastics to provide the background in this study, some compromise had to be made regarding the matter of adhesion to the substrate. Very soft materials commonly used in industry for highly corrosive conditions (e.g. Teflon) could not be applied under our laboratory circumstances such that adequate adhesion between liner and pipe could be achieved. Hence, the use of a modified polyvinyl-chloride plastisol, in which an epoxy resin and hardener were used to improve adhesion to the substrate but still maintain a somewhat "thermoplastic"-like mechanical rubbery condition, was required.

Shown in Figures 2 and 3 are the Wear Factor and weight loss data for the glass sphere, reinforced PVC/epoxy. From these data

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**Appendix A.

it is clear that the initial "gouging" action of the impacting solids was followed by a drastic **reduction in weight loss** and improved wear resistance because of increased exposure of the finer hard particles to the impacting "solids". Furthermore, the pattern of high initial loss, followed by a leveling out was pronounced in the re-inforced liner.

Figures 4 a, b, c show the cross sections of worn surfaces of a sphere reinforced liner with and without glass fiber. The bridging benefits of the fibers and the value of good sphere/polymer bonding are apparent.

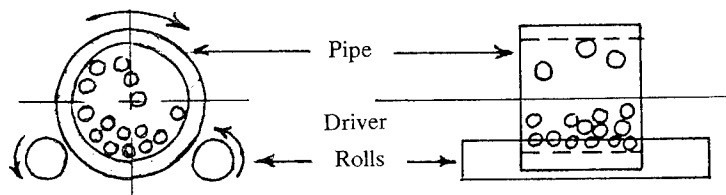
Both optical photomicrographs and electron photomicrographs confirmed these phenomena, although because of the transparency of the materials, it was difficult to properly photograph this condition.

The difference between Figures 4 a and 4 b is that the particles have been lost from the matrix in 4 a but not in 4 b. Figure 4 c shows the inclusion of glass fibers having a length of approximately 5/8 inch. These data combined with those in Figure 2, establish beyond question that one may select a matrix material to suit a given **corrosive** condition and at the same time impart improved erosive properties by optimizing the formulation. This design latitude is theoretically possible with all materials except that with metals having high conductivity and susceptibility to oxygen concentration cell breakdown (3), such optimization is more difficult.

EFFECT OF RIGIDITY OF THE SUBSTRATE ON EROSION CONDITION

It has long been recognized that **soft**, but highly corrosion-resistant coatings applied to the impellers of pumps and on the inside of pipes have often outperformed harder coatings simply because of their ability to absorb the kinetic energy of the impacting solids. However, where the sphericity of the impacting particle is low (i.e. angular particles with sharp edges), the phenomena is much more complex. The role of the substrate itself, then, becomes a factor, particularly when one compares a rigid backing, such as with steel, versus a flexible backing, such as in a filament wound pipe.

In order to confirm the direct effect of substrate flexibility on degree of erosion, three six-inch pipes were tumbled as shown below:



In the lined pipes the **liner** formulation was optimized for (a) filler/polymer ratio and (b) ratio of "small" glass spheres (or round sand) at -425 to -600 mesh to "large" spheres at -100 to -150 mesh. It was found that polymer/filler ratio could not fall below 3.5/1 and the ratio of large-to-small spheres was optimum at 1/3, but could be as high as 1/1.

These sample specimens were filled with Corundum cylinders (approximately 3/4" long x 1/2" diameter), and the pipes were tumbled at approximately 100 RPM at room temperature, with the Corundum cylinders filling about 1/3 of the cross section of the pipe specimen. The pipe specimens were approximately 4" long, closed at each end.

The data shown in Figure 5 demonstrate that the coated steel (i.e. rigid substrate with a reinforced PVC/epoxy liner) lost the most matrix material, whereas the filament wound part having a filled, reinforced liner lost the least material. The uncoated steel lost considerable material, and the unreinforced liner/wound pipe lost somewhat more than the reinforced liner.

Aluminum conduit was also evaluated, but the weight loss was so pronounced that no correlation could be established with any of the other data.

EFFECT OF TEMPERATURE

The steel and filament, "soft" lined 6" pipes were rotated for approximately 5,000 cycles at 200°F. Although the hardness of the soft, lined filament-wound pipe decreased to a shore hardness of approximately 10, the two curves of weight loss versus time for the pipes remained essentially unchanged, which reaffirmed that the most important factors in liner selection are (a) the type of substrate; (b) high quality adhesion; and (c) proper reinforcement using particles and fibers.

A point regarding adhesion was brought out when an attempt was made to erode a 6" pipe lined with a continuous glass reinforced polypropylene sheet, where no special efforts were made to promote liner/steel adhesion, other than preparation of the metal surface by sanding followed by fusion of the sheet to the metal under pressure. Only a few hundred cycles of exposure to the Corundum cylinders were necessary to yield delamination between the plastic and the metal, whereas the PVC epoxy (where adhesion had been optimized) showed no delamination whatsoever.

SUMMARY

It has been conclusively established that the following factors are important in the use of filled organic composites as protective coatings in erosive/corrosive resistant liners for pumps and pipes:

1. The Taber abraser may be utilized to determine the effects of long term erosive resistance of the coating itself by plotting cumulative liner weight loss versus time.
2. Tumbling of particles similar to those in the field without corrosive liquid inside the lined pipe can show quickly which systems function.
3. Hardness of the surface to be exposed to the erosive condition is not necessarily a factor when considered by itself.
4. Substrate flexibility for soft liners is as important as the selection of the liner itself.
5. The significance of **chemical adhesion** between liner and substrate is a vital factor in selection of the liner.
6. Use of reinforced liners, such as those described above, are advisable where non-contamination of the flowing fluid is possible (e.g. food fluids would not be recommended).

ACKNOWLEDGEMENT

Acknowledgement is given to David Archambault and Leroy Yglesias, San Jose State University, for assistance in preparation of this paper.

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APPENDIX A

I. Taber Abraser Test, model 174

Procedure:

Abrasive wheel CS-17 Load: 500 gram, Suction 90

The specimen was a round plate of 4 inches diameter, pre-ground to flat face.

II. Polymer/Reinforcement Formulas:

Polymer matrix formula:

Liquid epoxy/PVC Dispersion Resin/Plasticizer/Hardener/Stabilizer

Reinforcement:

Samples A and B

a. Potter Brothers: 3,000/CP-02 small glass spheres
1,721/CP-01 large glass spheres
ratio: 1721/3000 1/3

b. Solids (spheres)/liquid (PVC-Epoxy) 3.5/1

Sample C

No glass spheres

III. Pipe Liners—Olympia #1 sand used in ratio of 3.8 parts sand/1 part polymer. Results similar to above samples A, B, C.

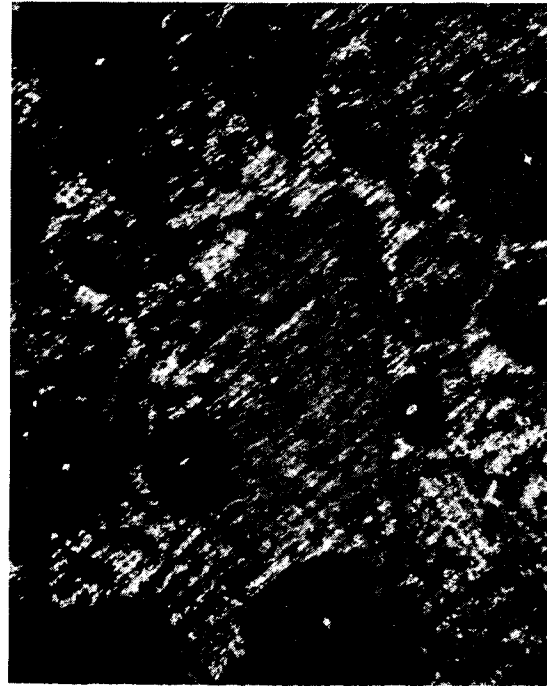


FIGURE 1
PHOTOMICROGRAPH OF GLASS SPHERE-
GLASS FIBER REINFORCED POLYMERIC
LINER AFTER EROSIVE WEAR

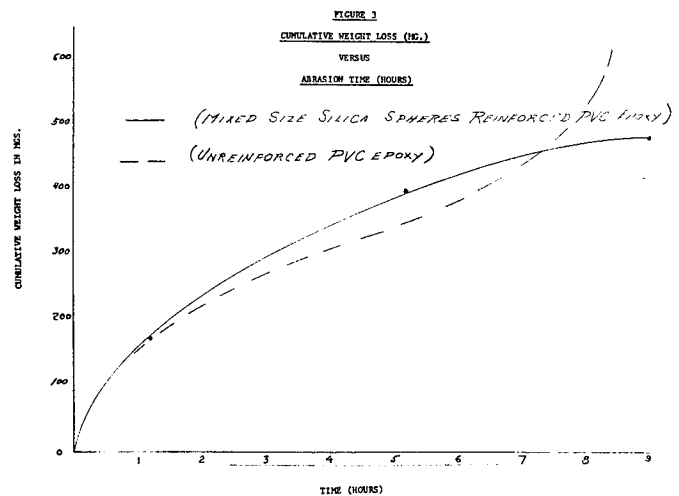
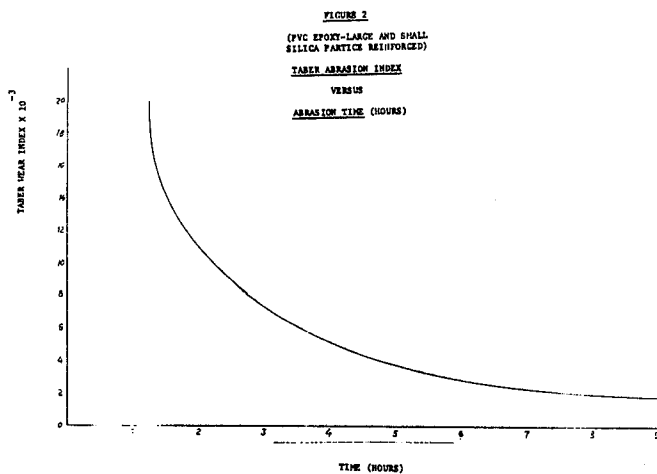


FIGURE 4

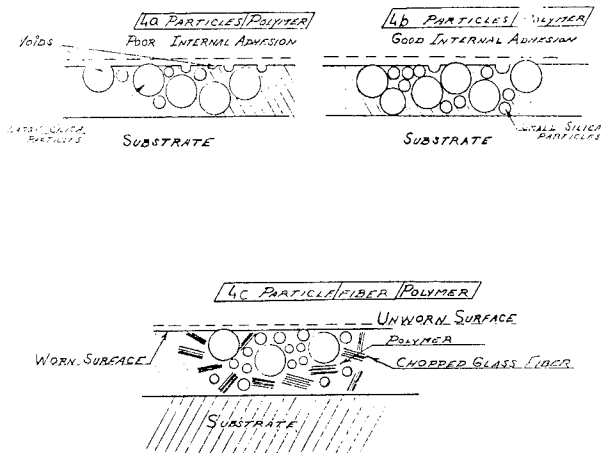
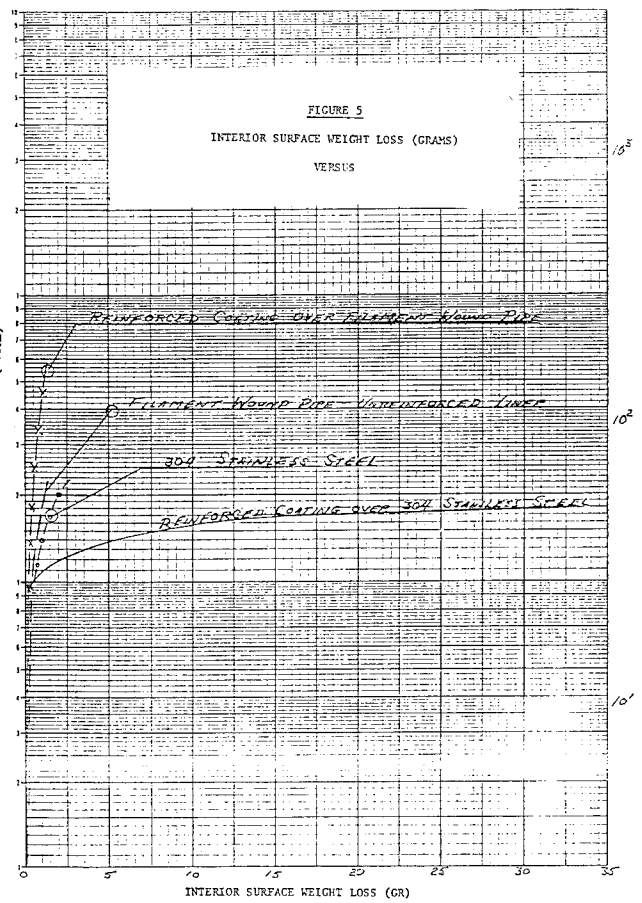


FIGURE 5

INTERIOR SURFACE WEIGHT LOSS (GRAMS)
VERSUS

EROSIVE EXPOSURE TIME (HOURS)



TESTING OF LARGE DIAMETER FIBER GLASS REINFORCED PLASTIC PIPE

by

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ABSTRACT

The problem of designing buried pipe, using fiber glass reinforced plastic as the basic engineering material, is one that requires major work because of the general lack of established design theories for flexible conduit using non-homogeneous material. As theories are developed, they must be proven by laboratory testing, as well as field or installed testing. This paper presents the testing approach required to verify design theories developed for large diameter buried flexible pipe as well as prove the reliability of pipe performance. The program presented discusses the correlation between the actual behavior of a 92-inch diameter pipe when installed with the predicted deflections and stresses of the pipe using the selected design theories. Laboratory testing results will show how the pipe laminate selected and structure provided produce exact material properties and stiffness inputs to the design equations to insure proper analysis.

INTRODUCTION

As products are developed, a point is reached when a full scale test program must be conducted to provide information that verifies the design theories and shows the product to be viable. Such a program was initiated for a large diameter fiber glass reinforced plastic pipe. The initial phase of this program has been documented in the following report.

Flexible pipe design theory is now in a period of change. The Spangler Theory is being supplemented or replaced by theory that includes moments and buckling considerations with deflections. Also new materials are being used for pipe fabrication. To determine the behavior of the flexible pipe made of contemporary materials and the accuracy of design theory, full scale pipe testing is required.

In the analysis of buried pipe, the combined behavior of the pipe and surrounding soil must be considered. In this buried pipe test program, it was necessary to collect data that is valuable for design-behavior correlation for a soil-pipe structure. These data included stress, deflection and soil behavior. Therefore, the pipe being tested was to be instrumented with strain gauges to reflect stresses and soil pressure cells and relative displacement gauges to reflect soil behavior.

From experience with underground tank installations two types of materials were found desirable for backfill: sand and pea gravel (or crushed stone). Sand was an inexpensive material requiring some labor to compact the material for a proper installation. Pea gravel was more expensive but did not require additional labor for compaction. Therefore, the testing program was to include both sand and pea gravel.

Testing program goals were to verify the design theory developed for flexible pipe design, determine the feasibility of Fiberglass[†]-

reinforced plastic as a construction material for large diameter underground pipe, and to investigate the behavior of flexible pipe in sand and pea gravel backfills.

DESIGN

Historical Background

Underground conduits constructed of wood, metal and concrete have been used for decades. Their shapes included circular, elliptical, rectangular, square, and combinations of these. These designs have gone virtually unchanged. Only within the past few decades have attempts been made to rationalize these methods of structural design. Pioneering work has been done at the University of Iowa's Engineering Experiment Station. Earlier works included those done by Marston, Spangler, Schlick and their colleagues from 1913 to 1941. Today most of the industries follow their thinking and many of the current methods are associated with these works in some way. Marston's work was in the area of load determination. Spangler established a deflection criterion for buried flexible pipes. Other notable works in the area of buckling and stresses include those by Luschner, Allgood, Molin, White, Layer, Cheney, Meyerhof, and Baikie. Later works based on elastic continuum approach are due to Hoeg and Burns and Richard.

Current Methods and Research

Magnitude and distribution of the loads on buried conduits depend upon the relative stiffness of conduit and soil. Therefore, pipes are broadly classified as Rigid or Flexible with separate design procedures for each. Load determination is usually the Marston-Spangler approach. This is a semi-empirical method where factors are based on an extremely small amount of experimental data obtained many years ago. They continue to use this method with virtually no modification. Some calculations made using this method have shown the load on a pipe to be as little as 40 per cent of the weight of the soil prism above the pipe. Experiments have shown that under similar conditions the loads sometimes were as high as 85 per cent of the soil prism.

For flexible culverts, whose cross section is circular, two major design procedures are commonly used. One is concerned with limiting the vertical deflection and the other is concerned in limiting the compressive stress in the pipe wall. Buckling has not been considered to a great extent by designers; nor the stresses due to bending. Large diameter pipes should be considered for buckling since they are susceptible for failure in a buckling mode. Again, where stiffeners are used on the pipe, bending stress becomes critical because for the same deflection the moments are higher for stiffer cross sections (and when the neutral axis depth is more, bending stress is worse). Trying to improve the proportioning of the structure by stiffeners automatically increases the bending stresses. So a bending stress check is necessary along with deflection and compressive strength checks.

Spangler's equation for deflection contains a soil parameter, which contains the controversial modulus of soil reaction, which cannot be measured in the lab. Many attempts have been made to relate the modulus of soil reaction to some laboratory-measured value.

Watkins and Nielson developed a Modpares device, which simulated a pipe being forced into the side of a fill. Nielson has developed various correlations between E' and the slope of the stress-strain curve from a triaxial test, the CBR value, the Hveem Stabilometer R-value, and the dry density. Currently recommended values for modulus of soil reaction are 700 and 1,400 psi, depending on the quality of compaction adjacent to the pipe, but experimentally determined values vary from 200 to about 8,000 psi.

Research is underway to incorporate fundamental soil parameters in the design. Soil-pipe system is considered to be an elastic continuum with an elastic inclusion of different properties. Hoeg, Burns and Richard did notable work in this area. Many of the limitations of the elastic continuum approach are overcome by breaking it up into a finite number of individual components called elements, inter-

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connected at a finite number of joints called nodal points. This method of analysis, called the finite element method, is superior over any other method today.

An ideal design method should consider the soil and the pipe as a composite unit, so that the interaction effect is considered, and the system treated as a three-dimensional non-homogeneous continuum. It should cover all depths of burial, various shapes of pipes, non-homogeneous modulus distributions in pipe and soil, any type of loading configurations and the whole range of stiffness from flexible to rigid.

Procedure and Calculations

Many of the applications of flexible pipe are for a trench installation and so only trench conditions are presumed in the following procedure and calculations. The weight of the soil prism above the pipe after properly discounted for arching in the soil is the load on the pipe. No more than 20 per cent discount is given for arching. The equation for the load is:

$$Q = (1 - A) H \sigma + Q_L$$

$$\text{where } A = \text{Arching coefficient} = 0.2 - 0.2 \left(1 - \left(\frac{H}{D}\right)^2\right) \text{ for } \frac{H}{D} \leq 1.0$$

$$= 0.2 \quad \text{for } \frac{H}{D} > 1.0$$

and Q_L , the live load intensity is calculated using the Boussinesq's equation:

$$Q_L = \frac{3Q_p H^3}{2\pi(H+L)^5}$$

Critical buckling pressure P_{CRI} is calculated using Luscher's equation:

$$P_{CRI} = \sqrt[3]{\frac{M_s EI}{D^3}} \quad \text{where}$$

$$C = 2\sqrt{B C_1}$$

$$C_1 = \frac{(1 - \nu_s)(1 - 2\nu_s)}{(1 + \nu_s)}$$

$$B = \frac{1 - \left(\frac{R}{R_o}\right)^2}{(1 + \nu_s) \left(1 + \left(\frac{R}{R_o}\right)^2 (1 - 2\nu_s)\right)}$$

Vertical reduction in diameter is calculated using Molin's modified Spangler's equation.

$$\frac{\delta_v}{D} = \frac{Q}{E'_s} \frac{0.083}{(S + 0.122)} \quad \text{where}$$

$$S = \frac{EI}{E'_s R^3}$$

Molin provided graphs to determine the values of E'_s for different soil compactions, depths of burial and water table conditions. The same value of the soil modulus is used in the following equations to determine the maximum moment in the pipe wall.

$$M = \frac{(0.25 S + 0.003)}{(S + 0.122)} Q R^2 \quad \text{for } S \geq 0.012$$

$$= \frac{0.50 S}{(S + 0.122)} Q R^2 \quad \text{for } S < 0.012$$

The calculations are done by the computer with output shown in Table I.

The variables used herein are the following:

A	Arching Coefficient
B, C, C ₁	Coefficients used in Buckling
D	Diameter of Pipe
E' _s	Molin's Secant Modulus
EI	Flexural Rigidity of pipe

H	Depth of Burial
L	Horizontal distance in Boussinesq's equation
M	Maximum moment in pipe wall
M _s	Combined Compression Modulus of Backfill
P _{CRI}	Critical buckling pressure
Q	Load on pipe
Q _L	Live load intensity
Q _p	Point load applied at ground surface
R	Radius of pipe
R _o	R + H
S	Stiffness factor
σ	Unit weight of backfill
δ _v	Vertical deflection
ν _s	Poisson's ratio of soil

TESTING PROGRAM

Test Pipe

Full scale large diameter pipe testing was on a 92 inch diameter pipe. This pipe was equipped with hemispherical end closures and a 22 inch diameter manway for access to the interior of the pipe during testing. The pipe length of 63 feet was deemed adequate to minimize the influence of the end closures and manway. The overall length of the pipe assembly was 71 feet. The pipe was designed to yield relatively low safety factors to allow adequate response. The structure was stiffened by ribs placed on 11 inch centers. The pipe wall was reinforced plastic mortar, .33 inches thick. The design is summarized in Table 1 and Figure 1.

Installation

The pipe was installed in a 21 foot deep trench with bottom dimensions being 14 feet by 75 feet. The top dimensions were 45 feet by 107 feet by the necessity to slope the side walls at a 45 degree angle starting 5 feet from the trench bottom.

Before placing the pipe in the trench, a two section base was prepared using pea gravel or sand. A loose plane bed of naturally compact pea gravel or loosely compact (81 percent Standard Proctor Density) sand was placed one foot deep in respective halves in the trench bottom. The pipe was then lowered and positioned in the trench.

Backfilling proceeded in two sections with each section covering half of the pipe. Pea gravel was dumped in one section without requiring any additional work other than shovelling the backfill under the pipe to fill voids. Sand was placed in one foot layers with the first layer being carefully placed and tamped under the pipe to fill voids. Each one foot layer was foot compact to an 84 percent to 86 percent Standard Proctor. Backfilling with pea gravel or sand continue to a depth of 6 inches above the crown of the pipe.

The remaining backfill was native soil, light gray sandy clay, placed by a D-7 Caterpillar bulldozer. No special care was taken to compact the native backfill as it was placed. At times the equipment would cross the pipe zone resulting in some compaction of the natural soil. The surface was finally smoothed to surface grade. The installation is shown in Figure 1.

It was interesting to note that foot compaction of the sand backfill, having a 5 percent moisture content, consistently yielded the desired 85 percent Standard Proctor Density. Pea gravel obtained a 99 percent Standard Proctor Density when placed with natural compaction.

Instrumentation

Before installation, the pipe was instrumented with CEA-09-250UW-120 strain gauges (made by Micro Measurements, Romulus, Michigan). Gauges were placed to reflect the behavior of both the pipe wall and rib crown in sand and pea gravel backfills. Design indicated the highest stresses were located at the extreme fiber of the rib crown. Also, the major emphasis in flexible conduit design is in relation to the circumferential properties. Therefore, the majority of the gauges were placed to detect circumferential strain on the rib crown. Circumferential strain in the pipe wall was predicted to be quite low in gravity flow pipe; however, strain values were of interest. Several gauges were

placed on the pipe wall circumferentially and longitudinally to detect these strains.

In an attempt to determine the soil behavior, soil pressure and relative displacement gauges were placed in the backfill materials during installation. The pressure cells used in this investigation were the double plate diaphragm type (Gloetzl Earth Pressure Cell made by Terrametrics, Golden, Colorado). It was anticipated that the 6 inch x 10 inch plate would yield an average soil pressure over a relatively large area and relate good results. Relative displacement gauges (Bison Soil Strain Gauge Model 4101A made by Bison Instruments) were used to indicate an increase or decrease in the backfill compaction at several points. It was felt that by knowing the relative displacement characteristics of the backfill, the general soil loading behavior could be indicated.

Pressure cells were placed in both pea gravel and sand backfills. Displacement gauges were distributed around the pipe in only the sand backfill since further compaction of the pea gravel was not likely.

Pressure cells were installed in a gypsum foundation centered on a rib located two ribs from the strain gauged rib. Strain gauges were applied with EPY-150 (made by BLH Electronics) epoxy cement to insure the bond and longevity. The gauges were sealed against moisture and protected against point loads that may be incurred by pea gravel with a liberal coat of Silastic 732 (made by Dow Corning). Additional moisture sealing was provided by a coating of M-Coat C (made by Micro-Measurements) prior to the application of the RTV.

FULL SCALE TESTING

The primary areas of interest for the behavior of flexible pipe are the following:

- * During initial installation.
- * Immediately after installation during the period of maximum backfill consolidation.
- * During pressurization.
- * During filling of the pipe and immediately thereafter during a period of consolidation of the bed.
- * During and after fully saturating the backfill material.
- * Long term behavior under natural conditions.

The testing program being reported is an investigation of the first five items mentioned. The long term behavior is being studied but will not be reported as the study will be continuing until 1975. In each area of interest the behavior has been monitored for both sand and pea gravel backfills. The results are as follows:

Immediately After Installation

After backfilling was complete, the pipe and backfill were left to the natural environment for seven weeks. During these seven weeks all gauges and deflections were being monitored while a weather log was kept. It was interesting to note that changes in strain gauge readings could be directly correlated to times of heavy rain.

In general, only minor changes were found in the strain gauge readings and deflections with a slight consolidation of sand backfill near the bottom of the pipe. The trend in the sand was for the pipe strain readings to approach zero while in the pea gravel the pipe strains became higher. The rib crown strains at the top of the pipe became less positive (where a positive strain indicates tension) in both backfill conditions. However, in the pea gravel, strains became negative indicating a change in force from tension to compression. In both sections of pipe, deflections indicated the pipe was deflecting positively. (See Figures 4 and 5).

During Pressurization

To determine the load sharing capability of the surrounding soil, the pipe was sealed and pressured eight weeks after installation. Internal pressure was applied to 12 psig over a five hour period. Instrumentation readings were monitored at 2 psig increments.

During Installation

When the pipe was placed in the trench, before backfilling started, all strain gauges were zeroed. As the backfill was placed, soil relative deflection gauges were located and zeroed. Soil pressure cells were not monitored until the backfilling was completed. Strain gauge data is provided in Figures 2 and 3.

Strain gauge readings in both the sand and pea gravel backfill sections indicate a shortening of the horizontal diameter. In the sand backfill, this behavior progresses throughout the entire backfilling while the pipe strains in the pea gravel tend to reverse directions when the native soil was placed as backfill. This indicates the pea gravel was more susceptible to overburden pressure than the sand.

After the backfilling was completed, the pipe was entered and deflection measurements were taken. It was found that in both sections the pipe was deflected negatively (a positive deflection being defined as a shortening of the vertical diameter). The initial deflection in the sand and pea gravel sections were -1.5 percent and -0.5 percent respectively (with deflection being expressed as percent diameter change). As predicted, the compaction of the sand backfill material induced a greater shortening of the horizontal diameter than the naturally placed pea gravel.

Soil instrumentation indicated no changes during the period of loading. Strain gauge readings in circumferential and axial directions were affected and indicated linear behavior. By comparing predicted strain values with the resulting values obtained from this testing, several are indicated. A typical response is provided in Figure 6.

The axial restriction of strain was significant. By prediction the unconstructed strain value was 700×10^{-6} in./in. while the measured value was 130×10^{-6} in./in. at 12 psig.

The circumferential pipe wall strain was mildly influenced by the surrounding soil restriction. By prediction the partially unconstrained (partial constraint axially) strain values for rib crown and pipe wall were 700×10^{-6} in./in. and 650×10^{-6} in./in. respectively, while the measured values for sand backfill were both in the $500 - 580 \times 10^{-6}$ in./in. range, and for pea gravel backfill were $650 - 710 \times 10^{-6}$ in./in. for the wall and $500 - 600 \times 10^{-6}$ in./in. for the rib crown at 12 psig.

Axial constraint was anticipated as pressure induced a relatively large displacement of the end caps. The large displacement allows the soil to accept load.

The lack of circumferential restraint indicates the relatively low compressive modulus of the soil. The radial displacement of the pipe is not sufficient to transmit force to the soil. The pea gravel, due to its higher modulus, was anticipated to accept a greater portion of load than the sand backfill. However, this was not evidenced by this test. Therefore, it is suggested that both material properties and material composition be reviewed when considering the confinement characteristics of a backfill for internal pressure pipe behavior.

During Filling and Consolidation of Bed

After eight weeks of natural settlement, the consolidation of the originally loose bed was to be investigated. Also the influence on the bottom ribs were to be viewed by filling the pipe with water. When the pipe was filled with water, instrumentation readings were taken at increments of half full, full and full after three days.

Soil relative displacement gauges indicated consolidation of .3 percent near the bottom of the pipe and .1 percent at spring line. There were no indications of consolidation above the spring line. Soil pressure cells indicated a .8 psi increase of pressure at spring line and no change at the pipe crown.

Strain gauge values were insignificantly influenced by the filling of the pipe. Strains were changed by only .006 percent, indicating a 120 psi change in stress in the rib crown.

During and After Backfill Saturation

The most significant changes were anticipated to take place when the entire backfill would be saturated. During the 10th and 11th weeks

after installation, water was pumped into the trench through pipes that discharged into the granular backfills at each end of the pipe. Instrumentation readings were monitored as the water table was elevated. No significant influence on soil or pipe behavior was indicated until saturation of the native backfill began. The water table was fully saturated and held for two full days by continuing the input of water. When the trench filling was discontinued, the water table quickly declined to the present approximate elevation at the pipe crown. (See Figures 4 and 5).

Soil instrumentation indicated considerable change as relative displacement gauges in sand yielded a .6 percent consolidation at the bottom, 2.4 percent consolidation at spring line and a 2.1 percent dilatation at the top. Pressure gauges increased 1.1 psi in the sand backfill at the pipe crown and a 1.8 psi drop in the pea gravel backfill at the pipe crown. Deflection measurements indicated a reduction in vertical diameter, positive displacement of 1.3 percent diameter in the sand backfill and 1.3 percent in the pea gravel. Concurrently, the horizontal diameter underwent a negative displacement of 1.3 percent in the sand backfill and 1.6 percent in the pea gravel.

Strain gauge data indicated a positive deflection. Compression in the rib crown at the top and bottom and tension at the spring line indicates this behavior in both backfill materials.

Less compressive strain in the pipe wall indicates a reduction in external load in the sand backfill. When the water table dropped, strains became more compressive indicating an increase in external pressure. This behavior reflects a reduction in overburden load when the ground water table rises for a sand backfill condition. This trend was not apparent in the pea gravel backfill zone. Strains in the pipe buried with pea gravel backfill were only slightly influenced by ground water elevation.

Some interesting results that are of consequence occurred unexpectedly and are not considered in the pipe design. The peak strain in the pipe rib crown was anticipated to be compression at the bottom and top. The resulting peak stress was rib crown tension at 10° from the bottom in the sand backfill and rib crown tension at the bottom in the pea gravel backfill. The partial explanation of these strains is the backfill causing initial distortion. However, in the sand backfill, the bottom rib crown tension was relatively small while the 10° tension was high. It was observed that a void ± 10°-15° from the bottom centerline extended along the entire length of the pipe. By having a void at center bottom, the pipe must deflect inward at center bottom to achieve uniform contact with the backfill. When the deflection occurs, an abrupt change in curvature is induced slightly removed from the bottom center-line. It is believed this behavior is indicated by the high tensile strain in the rib crown 10° from the bottom centerline. This behavior is evidence of the importance of eliminating voids from under a buried flexible pipe during installation.

For the sand backfill condition, the peak strains seem to be shifted counterclockwise. When deflection measurements were taken, findings indicated the distortion is not symmetrical about the vertical axis; rather, the line of symmetry is shifted 15° counterclockwise.

LABORATORY TESTING

The pipe design was predicated on several assumptions of material properties, geometrical properties of the pipe and soil properties. In-field testing has verified the predicted Standard Proctor Density of the backfill. Material properties of the pipe wall laminates have previously been found for the particular composition comprising the wall and rib laminates. However, the geometrical properties were undefined by testing.

A primary design parameter, flexural rigidity, can be readily determined experimentally to verify the calculated values. In design the transformed section approach has been used to determine the flexural properties of the pipe in the circumferential direction. The flexural rigidity, EI, is considered in buckling, deflection, and bending moment expressions. To experimentally verify this important parameter,

the presently accepted method of the ASTM was used - ASTM D2412 "External Loading Properties of Plastic Pipe by Parallel-Plate Loading." Several sections of pipe made immediately before and after the pipe test section was manufactured were tested by this method to determine the properties of the particular test section.

The parallel-plate test apparatus was assembled, test sections prepared and tests performed to determine the Stiffness Factor, SF, as defined in the ASTM test method. This value is, by design, identical to the flexural rigidity of the pipe section in the circumferential direction. The pipe cross section is shown in Figure 7 and the properties are indicated in Table 1. The predicted flexural rigidity of 72,800 in.²#/in. compared to the measured 80,000 in.²#/in. is acceptable considering process variations.

Another basic design assumption concerning the sectional properties of the pipe, the location of the neutral axis in flexure, was also investigated. As a design approach to ribbed structures, the local rib stiffness is assumed to be evenly distributed along a length of pipe equal to the rib spacing distance. By determining the location of the neutral axis, this approach is valid if the neutral axis does not vary in location along the pipe length.

By strain gauging a section of pipe both inside and outside, placing the section in flexure and observing the strain distribution, the neutral axis can be located. This was accomplished with a ribbed section of pipe loaded in the parallel-plate method. Strain distribution for several orientations of the gauge section in relationship to the top loading plate is shown in Figure 8. Testing shows the basic design approach for ribbed structures was valid as the neutral axis location was consistent.

DISCUSSION OF TESTING

From the results of the pipe testing, behavior was deduced primarily from the strain gauge data. Soil strains were helpful but in some cases relatively insignificant. Soil pressures were somewhat inconclusive as the reading accuracy was relatively poor when attempts were made to distinguish .1 psi changes. In most cases the soil data confirmed the pipe behavior determined by strain gauge data and deflection measurements.

The behavior patterns are different for sand and pea gravel backfills. The pipe buried in sand seemed to behave more similarly to predicted behavior than the pea gravel installation. Main behavior points of a pipe buried with sand backfill are as follows:

Pipe Diameter Changes in Sand

The compaction required to densify sand backfill causes a shortening of the horizontal diameter. The magnitude of this shortening is predicted to be directly proportional to the compactive effort used to consolidate the backfill and inversely proportional to the flexural rigidity of the pipe.

Sand Behavior When Pipe is Pressurized

Sand backfill has very slight acceptability to low pressure forces transferred from a pressurized pipe. It is predicted that ability to accept pressure forces from the pipe is proportional to the pipe diameter, density of the backfill and pressure; and inversely proportional to the extensional rigidity, EA.

Effect on Sand from Filling Pipe

Filling a buried pipe with water tends to consolidate the underlying backfill but insignificantly affects the pipe stress.

Effect of Water Saturation on Sand

Saturation of sand backfill has little effect on behavior.

Effect of Water Saturation on Natural Backfill in Sand

Saturation of native backfill above a sand backfilled pipe has a significant effect on behavior. Backfill was consolidated, the vertical

diameter was shortened and stresses developed in predicted directions. The overburden pressure was decreased by the rise in water table.

Voids in Sand

Voids under the pipe play a significant part in causing local stress concentrations.

Correspondingly, the main pipe behavior points installed with pea gravel backfill are as follows:

Change in Pipe Diameter in Pea Gravel

Side pressure of naturally placed pea gravel caused a shortening of the horizontal diameter. As native backfill was placed, the pipe deflected positively indicating the fluid behavior or shifting of the pea gravel.

Pea Gravel Behavior when Pipe is Pressurized

The pea gravel did not exhibit the ability to accept load transferred from a pressurized pipe at 12 psig.

Effect on Pea Gravel When Pipe is Filled

When the pipe was filled with water, there were no significant changes.

Effect on Soil with Saturation of Pea Gravel

Saturation of the pea gravel resulted in no significant behavior change.

Effect of Water Saturation on Native Backfill in Pea Gravel

Saturation of the native backfill above a pea gravel backfilled pipe had a major effect. The pipe deflected positively as anticipated. A reduction in overburden load was experienced by the pressure cell in the pea gravel when the water table was raised; however, this behavior was not exhibited by the pipe strains.

SUMMARY AND CONCLUSIONS

Behavior of the installed pipe to date indicates that fiber glass reinforced plastic pipe is a viable product. Low stresses and deflections prove good performance in this trial installation which subjected the structure to several severe conditions. This excellent behavior has been exhibited for both medium density sand and pea gravel backfill installations.

Design procedures developed for flexible pipe predicted deflections of 2.31 percent diameter change and stresses of 6900 psi in the rib crown. Maximum recorded strains in the rib crown indicates a stress of 7600 psi. This high stress is believed to be caused by local distortion, resulting from a void located at the bottom of the pipe. The next highest stress was indicated as 4500 psi which is less than that predicted. The measured deflection of the pipe in sand backfill was 1.5 percent. In the pipe wall, the maximum compressive stress was predicted to be 2600 psi. By strain data the maximum wall stress is 1800 psi. These comparisons indicate the design to be slightly conservative for short term behavior, but long term behavior is expected to yield slightly higher stresses than are now exhibited by the pipe.

Results of the full scale test program suggests the validity of the design procedure used for flexible pipe design. By accepting the cognizance of the design, the basis for design of any diameter pipe has been established. The most significant variable in pipe performance is the installation. With a proper installation, it is shown that a flexible reinforced plastic pipe is a reliable structure.

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COMPUTER DESIGN PRINTOUT

JOB NAME TEST PIPE

DIAMETER OF PIPE	92	INCHES
DEPTH OF BURIAL	12	FEET
MOLIN'S MODULUS	230	PSI
CONSTRAINED MODULUS	1600	PSI
STD. PROCTOR	85	PERCENT

MODULUS OF WALL	1500	KSI
WALL BND. STRENGTH.	30	KSI
WALL CMP. STRENGTH.	28	KSI
WALL TNS. STRENGTH.	12	KSI
MODULUS OF FABMAT	2000	KSI
MODULUS OF FW	6000	KSI
CRN. BND. STRENGTH	20	KSI
CRN. CMP. STRENGTH	24	KSI
CRN. TNS. STRENGTH	20	KSI

WALL THICKNESS	.33	INCHES
RIB SPACING	11	INCHES
HOOP STIFF.	72.76	K-IN ² /IN

LOAD ON PIPE	8	PSI
VERT. DEFLECTION	2.3	PERCENT
CRI. BKLN. PRESSURE	50.33	PSI
MAXIMUM MOMENT	219.63	LB-IN/IN
RING COMPRESSION	1115.15	PSI
WALL BND. STRESS	1573.91	PSI
CRN. BND. STRESS	5145.94	PSI
FACTOR OF SAFETY (Buckling) 6.29		
F.S. AT WALL (BND. + CMP.)	10.84	
F.S. AT CROWN (BND. + CMP.)	3.41	
F.S. AT CROWN (BND. + TNS.)	4.68	

○ - 1' backfill *

□ - 4' backfill *

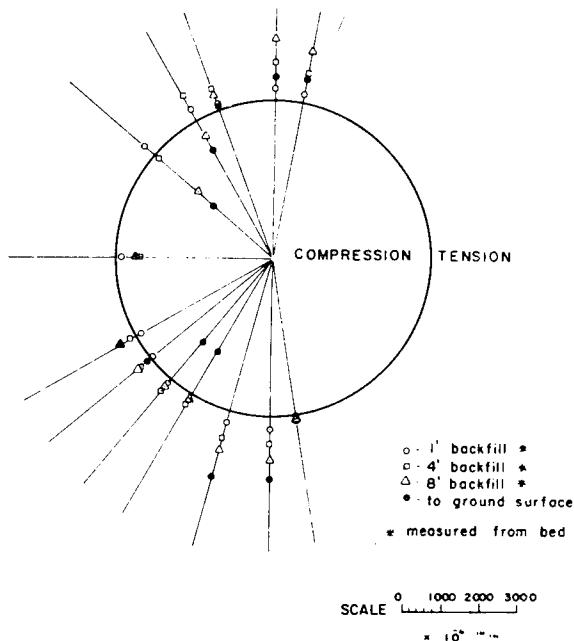
△ - 8' backfill *

● - to ground surface

* measured from bed

SCALE: 0 1000 2000 3000
 $\times 10^6$

STRAIN GAGE READINGS - PEA GRAVEL BACKFILL
DURING INSTALLATION
RIB CROWN CIRCUMFERENTIAL



TEST PIPE INSTALLATION

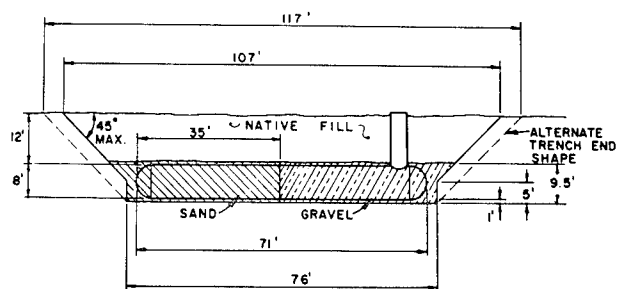


Fig. 1.

STRAIN GAGE READINGS- SAND BACKFILL
INITIAL BEHAVIOR AFTER INSTALLATION
RIB CROWN CIRCUMFERENTIAL

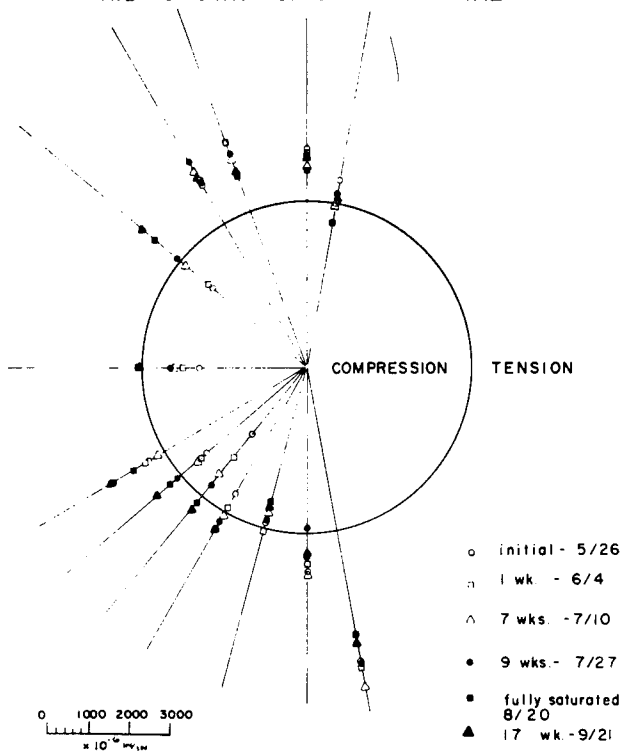


Fig. 4.

STRAIN GAGE READINGS- PEA GRAVEL BACKFILL
INITIAL BEHAVIOR AFTER INSTALLATION
RIB CROWN CIRCUMFERENTIAL

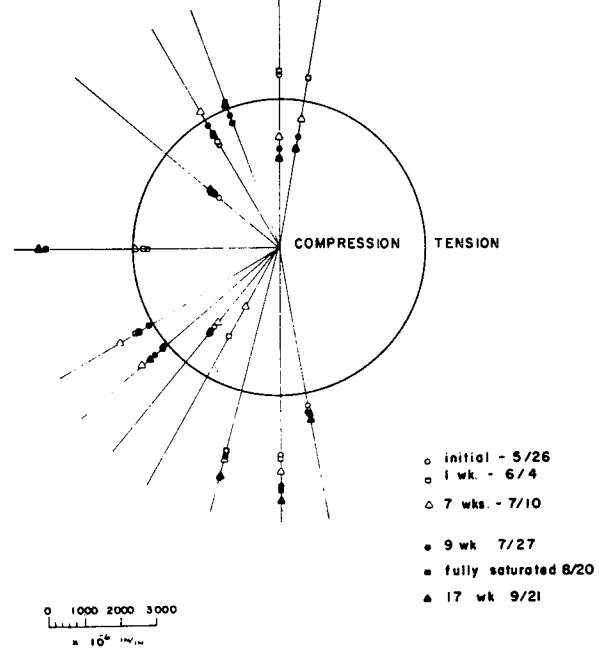


Fig. 5.

STRAIN GAGE READINGS- SAND BACKFILL
INTERNAL PRESSURE AT 8 WKS.
RIB CROWN CIRCUMFERENTIAL

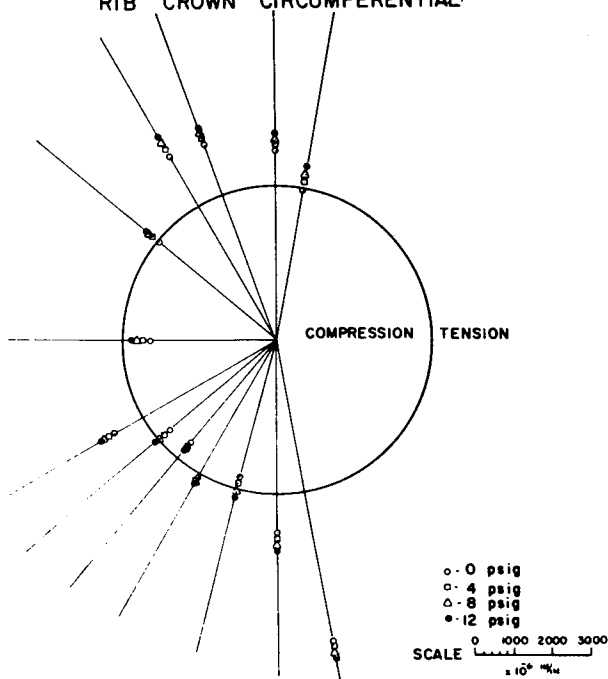


Fig. 6.

TEST PIPE CROSS SECTION

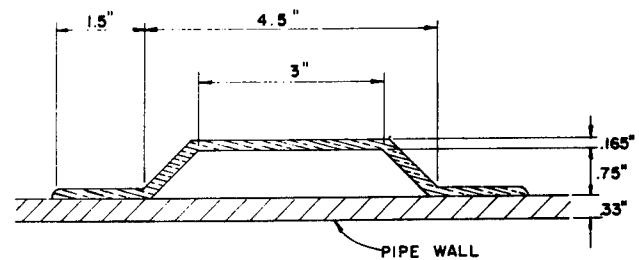
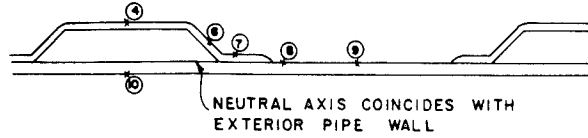


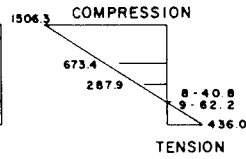
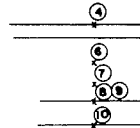
Fig. 7.

STRAIN PROFILES FOR NEUTRAL AXIS DETERMINATION

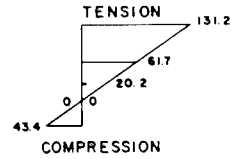
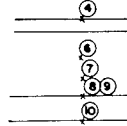


0° ORIENTATION

STRAIN VALUES AS $\frac{IN}{IN} \times 10^6$



45° ORIENTATION



90° ORIENTATION

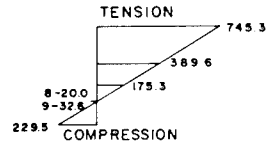
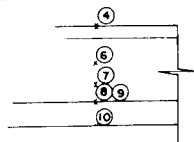


Fig. 8.

IMPORTANT CURE CRITERIA FOR CHEMICAL RESISTANCE AND FOOD HANDLING APPLICATIONS OF REINFORCED PLASTICS

by
PETER VARCO*

ABSTRACT

Significant differences in the nature of the cross-linked polymer result from using various catalyst systems and cure conditions for the fabrication of reinforced plastic equipment. Measurement of residual monomeric styrene in the laminate is a useful technique for developing optimum curing systems and for quality control. A number of practical examples using a vinyl ester resin for the fabrication of chemically resistant and food handling equipment in Europe are described.

INTRODUCTION

The cure criteria for thermoset resins used in all types of glass reinforced plastics (G.R.P.) are important, but this is particularly true for high chemical resistance and food handling applications. One of the causes of failure in these critical applications is insufficient cure of the resin, so that it does not achieve its optimum properties.

This paper describes a fundamental study of different cure systems which are being used in Europe today for fabrication of G.R.P. equipment based on vinyl ester resins. An extensive number of experiments have been conducted to highlight the main characteristics of different cure systems and these are related to practical workshop fabrication. The vinyl ester resin described is manufactured through the addition reaction of an epoxy resin with an acrylic monomer and is diluted with 45 % styrene.

EXPERIMENTAL PROCEDURES

Laminate Fabrication

Flat laminates were laid up using a reinforcement construction as outlined in A.S.T.M. C581-68 and shown in Figure 1. The following precautions were taken to eliminate extraneous experimental errors. The resin and glass were preconditioned to a temperature of $23 \pm 1^\circ\text{C}$ and this temperature was maintained during the room temperature cure. All the resin, peroxides and accelerators used were from the same production batch and these components were well mixed before laying up. All bubbles were rolled out of the laminate to stop any "local" air inhibition and a suitable film used to eliminate air inhibition at the laminate surface. Post cures were conducted in a forced air circulation oven which had reached a steady state at the chosen temperature before the laminates were post-cured.

Gel Time Measurements

Gel times were measured with a Tecam¹ gel time meter, on a 100 gm resin mass which was contained in a glass container inserted in a water bath at $23 \pm 1^\circ\text{C}$.

Residual Monomeric Styrene Measurements

For each measurement of residual styrene a sample of laminate was cut into small pieces of approximately 0.1 gm. Approximately 3 gm of these pieces were weighed and mixed with 25 ml of methylene chloride in a sealed jar. These were kept in the dark for at least 48 hours to allow the unreacted styrene to dissolve. Complete dissolution of the styrene with the above technique was checked several times by conducting measurements with laminate samples which were ground into a fine powder. Samples of the above solution were studied with gas phase chromatography and the level of styrene monomer quantified by comparison of the peak area with that from standard solutions. All the measurements of residual styrene were expressed as a weight percent of the laminate mass. It should be born in mind that these laminates typically contained 80% resin. This is representative of a chemically resistant Inner Surface and Interior Layer such as that described in the NBS-PS 15-69 standard for contact molding. However, the total resin content of a laminate is typically between 30 and 60%.

The absence of homopolymerised styrene was established by analysis of the preceding solutions with gas chromatography—mass spectrometry. This showed that no styrene dimers or trimers were present in the thermoset matrix. Taking into consideration all the potential experimental errors and the reproducibility which was achieved, these measurements of residual styrene are accurate to within $\pm 5\%$.

Barcol Hardness Measurements

Barcol Hardness was measured at 23°C with a Barcol Hardness Tester², model 934-1, by taking the average of five values recorded over different parts of the laminate. Measurements were made with the laminates after the different post-cure cycles and plotted graphically against residual styrene content to determine the approximate correlation reported later.

Correlation With Workshop Fabrication

Reinforced plastics are manufactured by a wide variety of fabrication techniques in many environmental conditions. This means that careful attention should be paid to selection of the catalyst system along with the temperatures and times employed for curing and post-curing. The main criteria to be considered are as follows:

- desired gel time
- working temperature and humidity
- effect of the mold as a heat sink
- effect of post-cure
- exotherm or laminate thickness
- mixing errors
- coats

Clearly no experiments can fully correlate with all the above criteria, particularly the exotherm or laminate thickness. However, the experimental conditions are similar to those which are frequently used to fabricate a chemically resistant Inner Surface and Interior Layer such as that described in the NBS-PS 15-69 standard for contact molding.

DISCUSSION OF CURE SYSTEMS

Curing systems with the following catalysts are discussed:

- methyl ethyl ketone peroxide (M.E.K.P.)
- methyl ethyl ketone peroxide plus an aliphatic perester
- cumene hydroperoxide
- dibenzoyl peroxide

The curing system based on M.E.K.P. is given the most attention since it is so frequently used and is carried on stock in nearly every fabricator's workshop.

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¹A product of Techne Cambridge Ltd., England.

²A product of the Barber-Coleman Company, U.S.A.

Methyl Ethyl Ketone Peroxide, Cobalt Octoate, Dimethyl Aniline System Available Grades

Several types of methyl ethyl ketone peroxide (M.E.K.P.) are available with different active oxygen contents which are normally in the range 8-11% active oxygen. The composition of the M.E.K.P. also plays an important role in the curing. Pure M.E.K.P. is very explosive, therefore commercially available grades are supplied as solutions with a certain amount of phlegmatising agent such as dimethyl phthalate.

Cobalt octoate accelerator is commonly available as 1%, 6% or 10% solutions in dioctyl phthalate and white spirit diluents. Selection of one of these concentrations depends primarily on the way of working. A 1% solution gives the smallest mixing error and is more suitable when only small quantities of cobalt are used. A 10% concentration does not give a good solution and is suitable when a high concentration is needed and excellent measurement and mixing equipment are available. However, this high concentration grade introduces the minimum amount of dioctyl phthalate diluent into the resin which may be important for high chemical resistance and foodstuff applications. Cobalt octoate is also available in other diluents such as styrene.

Dimethyl aniline accelerator is available as a 100% technically pure grade, but it is more commonly used as a 10% solution in styrene to minimise mixing errors. This accelerator is usually used with room temperature cure systems for vinyl esters, but often omitted for curing at elevated temperatures with fabrication techniques such as filament winding when a long gel time is required.

Influence of Peroxide Type

Table 1 illustrates the influence on curing of the type of M.E.K.P. with a fixed accelerator system of cobalt octoate in dioctyl phthalate and dimethyl aniline in styrene. The standard M.E.K.P. which was studied was a representative sample of a peroxide type which contains a minimum of 9.0% active oxygen. This grade is widely used in Europe, particularly for room temperature curing. It was compared with a recently introduced M.E.K.P. grade containing minimum 8.4% active oxygen and a grade of methyl isobutyl ketone peroxide containing minimum 10.1% active oxygen. A good quality M.E.K.P. which is sold in the U.S. was also compared. Substantial differences between the standard grade and the other recommended types was found. The recommended types gave both a faster gel time and a lower residual styrene content or better resin through-cure after post-curing.

Influence of Peroxide Level

Other studies on the important parameters which influence cure were conducted with the standard M.E.K.P. type since this is so widely used. However, the trends which were found are probably typical for all M.E.K.P. types and are indicative of the characteristics of other curing systems.

Table 2 indicates the influence of varying the level of peroxide with a constant concentration of accelerators. Increasing the quantity of peroxide in the range of 1.0 to 4.0 parts per hundred of resin p.h.r. resulted in the following. The gel time decreased from 83 to 24 minutes, i.e. the peroxide level clearly influences gel time, but the effect is not dramatic. More important, for all the cure and post-cure conditions, the quantity of residual styrene decreased in a manner which was directly related to the peroxide level. With all these systems the residual styrene levels after 1-3 days at room temperature were relatively high in the range 15 to 2.8%. Residual styrene levels after post-curing were fairly high with 1.0 to 1.5 p.h.r. peroxide, but reasonably low with 2.0 to 4.0 p.h.r. peroxide. 0.5 p.h.r. of standard peroxide, with this relatively high quantity of accelerator, produced laminates which did not gel either at room or elevated temperatures. However, 0.5 p.h.r. of higher activity peroxides was found to give a reasonable cure.

Influence of Ratio of Peroxide to Accelerator

Table 3 shows that after a heated post-cure fairly similar residual styrene levels were obtained over a wide range of gel times, with ratios of catalyst to accelerator which can be approximately as follows:

Standard methyl ethyl ketone peroxide	1.0-1.5%	1.5-2.0%
cobalt octoate, 1%	1.0-3.0%	1.0-3.0%
dimethyl aniline, 10%	0 -0.5%	0 -1.2%

It is interesting to note that with a peroxide level of 0.5 p.h.r. only formulation 23 gelled. Formulations 9 and 22 with a higher accelerator level did not gel in the laminate at room temperature or elevated temperature.

INFLUENCE OF POST-CURE

Tables 1, 2 and 3 show that a heated post-cure has a big influence on the residual styrene level and polymer cross-link density. Room temperature curing with the M.E.K.P. systems produced rather high residual styrene levels in the range 6 to 14%, except in those formulations with 3 or 4 p.h.r. of peroxide. Better room temperature curing might be achieved in the workshop due to higher exotherm. Table 7 shows that no significant change in residual styrene content occurred after 30 days at room temperature with either M.E.K.P. or other catalysts which were studied.

Residual styrene levels after various post-cure cycles were measured for every laminate. As a general comment, it is clear that the post-curing temperature is more important than the time of post-curing. A number of practical points should be kept in mind. In practice, the fabricated equipment is subjected to a gradual temperature change to minimise thermal shocks. Further, many fabricators do not employ a post-cure for all equipment due to the cost involved, and others do not have facilities to post-cure above 80°C. A post-cure is also affected by a hot chemical environment such as a gas stream at 80°C, while the situation with a chemical environment at ambient temperature is less favourable. There are many variables and differences in opinion in this area, but sound quality control techniques to check resin cure are certainly important.

Methyl Ethyl Ketone Peroxide, Aliphatic Perester, Cobalt Octoate, Dimethyl Aniline System

The aliphatic perester has a higher critical temperature than M.E.K.P. and produces free radicals during the reaction exotherm and heated post-cure. This cross peroxide system therefore initiates a smoother reaction over the complete curing and post-curing cycle.

Table 4 shows that addition of an aliphatic perester to the normal M.E.K.P. cure system has little influence upon the gel time, but results in somewhat lower residual styrene values. After post-curing, this cross peroxide system consistently produces a low residual styrene content over a wide range of gel times, which is desirable for food handling applications.

Cumene Hydroperoxide, Vanadium Compound, Promoter BS³ System

Table 5 shows that this cumene hydroperoxide system is unique in producing a relatively low residual styrene content with a room temperature cure. It is suitable for producing a short gel time and is typically used with a gel time of around 15-20 minutes at the temperatures normally encountered in a workshop. This system is useful for curing gel coats, thin films, working at low temperature or producing a good cure at room temperature when a heated post-cure is not available.

Dibenzoyl Peroxide, Dimethyl Aniline, Accelerator NLF³ System

Table 6 shows that the dibenzoyl peroxide system produces similar residual styrene contents to the standard M.E.K.P. system,

³A product of Akzo Chemie Nederland B.V., Holland.

except that the values after post-curing are characteristically high. Accelerator NLF is useful for giving a short gel time with a reasonably low residual styrene content after a room temperature cure. This cure system is relatively non-moisture sensitive and is therefore suitable for working under relatively moist conditions such as on-site repair work and flooring compounds.

Cure System versus Resin Properties

Curing involves decomposition of the peroxide to form free radicals which are first used up by reaction with the inhibitors contained in the resin. A free radical reaction between the vinyl groups of the styrene and vinyl ester then occurs and gelation takes place. The reaction propagates by further cross-linking of the vinyl groups and finally terminates as all the free radicals react into the thermoset matrix. Accelerators speed up the reaction and a temperature increase from the exotherm or post-cure increases the molecular mobility and forwards the reaction.

The different residual styrene values which were measured must reflect differences of the resin matrix or degree of cure. Measurement of residual styrene is a very useful technique for laboratory investigations to study different cure systems. However, the question arises: how do these measurements relate to important resin properties like chemical resistance and mechanical properties?

The laminates used for chemical resistance tests on vinyl ester resins have typically contained 0.1 to 1.5% residual styrene before exposure to chemicals. However, a great deal of equipment made with resins containing substantially more residual styrene, where a heated post-cure was not employed, has been giving satisfactory long life performance. In this respect, the nature of the chemical media is important in terms of its aggressivity and ability to affect a post-cure, as explained earlier. A relationship between mechanical properties and residual styrene can also be expected.

QUALITY CONTROL

The most widely used method to check resin cure is measurement of Barcol Hardness along with the acetone rub test to check for air inhibition. The following correlation between Barcol measurements and residual styrene values was found:

Barcol Hardness	Residual Styrene
0 - 5	30 - 10
5 - 20	10 - 8
20 - 25	8 - 4
25 - 35	4 - 1.5
35 - 40	1.5 - 0.01

However, the Barcol values are far less reproducible than residual styrene measurements and are dependent upon the type of reinforcement. For example measurements for laminates reinforced with 'C' veil, synthetic veil, chopped strand mat and filament winding roving are widely different for the same resin. Also measurements for a relatively rough surface such as a tank lining are different from measurements for a smooth surface fabricated against a mold. By measuring the laminate glass content, residual styrene values can be expressed in terms of the resin, so eliminating any dependence of the measurement upon the characteristics of the reinforcement.

It is suggested that measurement of residual styrene is a useful quality control technique for checking resin cure.

EXAMPLES OF CHEMICAL RESISTANCE APPLICATIONS

Figure 2 shows part of a gas scrubbing system at a NPK fertiliser plant of Superfos A/S, Denmark, which was engineered by Kavag, Germany. Flue gases from a rotary drying unit are scrubbed to produce a mixture of hydrochloric acid, hydrofluoric acid and phosphate dust at up to 60°C. The engineering company requested compliance with the German standard "Technische Regeln für Brennbare Flüssigkeiten (TRBF) 402 Blatt 1". This limits the residual styrene content of a glass reinforced polyester resin lami-

nate to a maximum of 2%.

Figure 3 shows a plant of Ferriklor AB, Sweden, to recover ferric chloride from waste pickling acids and scrap iron by oxidation with chlorine. The ferric chloride is then used to coagulate phosphorus in a waste water treatment plant. This is an ingenious method of helping solve two pollution problems simultaneously. The entire recovery unit consisting of G.R.P. tanks, reactors, absorption towers, piping and linings of concrete tanks was fabricated by Huberco, Sweden. This fabricator has been using the cumene hydroperoxide system almost exclusively for two years with very satisfactory results.

Figure 4 shows a 40 ft diameter 60 ft high tank which is used to store 2100 tons of 47% sodium hydroxide at 40°C at a U.K. terminal of Powell Duffryn Oil and Chemical Storage Ltd. The steel tank was given a G.R.P. lining on the roof, walls and floor by Prodorite Ltd., U.K., in the autumn of 1972. This is a typical example of non-ideal fabrication conditions where a heated post-cure is difficult to apply. The cumene system is suitable for curing the thin film resin flowcoat for such linings.

FOOD APPLICATIONS

There are many potential applications for reinforced plastics in the food industries where a number of advantages over conventional materials may be realised. In this area, the fabricator and end-user have a particularly high responsibility to assure satisfactory performance of the equipment and to check that it is safe for its intended use and meets the appropriate regulations and standards.

The vinyl ester resin described in this paper when properly formulated and cured complies with the FDA regulations, title 21, paragraph 121.2576. In addition various other approvals for food contact have been given, such as that by the Institut d'Analyse et d'Essais du Centre-Ouest in France. Some of the experience which has been gained in France with equipment fabricated from vinyl ester resins is as follows:

EXAMPLES OF FOOD HANDLING APPLICATIONS

Many road tankers such as those shown in Figures 5 and 6 for milk and wine transportation have been manufactured by Sovap. These tankers which are typically between 2400 and 6500 gallons are filament wound with a sandwich construction. Their unique feature is that they are 10 to 20% lighter than steel tankers, so they can carry substantially greater payloads.

Figure 7 shows a battery of filament wound tanks which were manufactured by Sovap for storage of 850,000 gallons of wine at CDC Sopagly (Dubonnet) Rivesaltes, France.

Figure 8 shows one of the presses sold by CMMC for production of wine, fruit juices and marmalade. These presses contain up to 2000 gallons and many have been exported, particularly to California.

Figure 9 shows water softener bottles manufactured by Plastiques Armés Mullerhof. These pressure tanks are fabricated by vacuum bag molding and have excellent cyclic fatigue properties.

STRICTER FOOD LAWS

The food laws are changing and becoming stricter in the E.E.C. and the Council of Europe countries which are working towards the idea of the following system. Lists of accepted materials (positive lists), similar to the previously mentioned F.D.A. list of approved materials, are being established. These are being combined with two types of limit on migration of ingredients into simulated food media. An overall limit of 10 mg/dm² (0.65 mg per square inch) surface of plastic and specific limits on certain ingredients in the range 10 to 0.01 mg/dm². Typical tests conducted on the plastic are exposures at 40°C for 10 days to the following media: water, 3% acetic acid (simulating acids like vinegar), 10 to 90% ethanol in water (simulating wine, beer and spirits) and edible fats or oils such

as sunflower oil.

Free monomers and ingredients in food packaging materials are under heavy scrutiny at present and low specific migration limits for styrene and phthalates are foreseen.

FABRICATION VARIABLES

The previous discussion on cure systems highlights a number of fabrication variables relevant to these proposed laws on food contact of glass reinforced plastics. Migration of ingredients into the food is minimised by selecting a cure system and manufacturing process which produce a laminate containing the minimum quantity of ingredients not reacted into the thermoset matrix.

The inhibitors in the resin and curing accelerators react into the matrix while suitable peroxide decompose and react after post-curing. The important raw materials employed are primarily styrene monomer and secondarily any diluents present in the cure system such as phthalates which are commonly used as diluents for cobalt octoate and M.E.K.P.

During fabrication, dust and powder are often generated by abrading. Thorough cleaning prior to post-cure is necessary, otherwise this powder can be fused to the surface in contact with food-stuffs and will be air-inhibited and so contain a high residual styrene content. The curing system and post-cure cycle should be selected to give a low residual styrene content in the laminate. Prior to its first contact with food, it is necessary to thoroughly clean the equipment to remove impurities from the laminate surface by treatment with steam or hot water for several hours. Much food handling equipment is disinfected by material such as bleach or hot dilute nitric acid and caustic solutions. In these cases the laminate must have suitable chemical resistance. Finally the internal surface of the laminate should be very smooth, with no micro-cracks, since these cannot be well disinfected and may cause rapid breeding of bacteria.

CONCLUSIONS

The catalyst system and cure conditions used for fabrication of reinforced plastic equipment are very important. Measurement of residual monomeric styrene in the laminate is a useful technique for studying the nature of the cross-linked polymer and for quality control.

The advantages of a given system may be exploited for specific fabrication techniques and circumstances for chemically resistant and food handling applications of reinforced plastics.

With the commonly used methyl ethyl ketone peroxide, cobalt octoate, dimethyl aniline system, the type of M.E.K.P. has a significant influence upon curing. The level of peroxide has a greater

influence upon curing than the ratio of peroxide to accelerator and it is better to obtain a long gel time by reducing the level of accelerator rather than reducing the level of peroxide. A heated post-cure is particularly necessary with this system to achieve optimum resin properties. Including a peroxide with a higher critical temperature than M.E.K.P. such as an aliphatic perester consistently produces very low residual styrene contents after post-curing.

The cumene hydroperoxide, vanadium compound, promotor BS system is unique in producing short gel times and good thorough-cure at room temperature. It offers advantages for applications such as curing gel coats, thin films and working at low temperatures.

There are many potential applications for reinforced plastics in the food industries. The European food laws are becoming stricter by combining lists of accepted materials of construction with overall and specific limits on the migration of ingredients from the plastic into the food. A number of precautions in this area have been described, including selection of a cure system to minimise the quantity of phthalate and residual styrene in the laminate.

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PETER VARCO

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Table 1. METHYL ETHYL KETONE PEROXIDE, COBALT OCTOATE, DIMETHYL ANILINE SYSTEM.
Influence of Peroxide Type.

FORMULATION	1	2	3	4	5	6	7	8
Vinyl ester resin	100	100	100	100	100	100	100	100
Standard methyl ethyl ketone peroxide (M.E.K.P.) active oxygen content 9 %	1.5	2.0						
Recommended M.E.K.P. active oxygen content 8.4 %			1.5	2.0				
Recommended high activity M.E.K.P. of U.S. origin					1.5	2.0		
Recommended methyl isobutyl ketone peroxide active oxygen content 10.1 %							1.5	2.0
Cobalt octoate, 1 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Dimethyl aniline, 10 %	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Gel time in minutes - on 100 gm at 23°C	50	40	22	20	23	22	23	21
RESIDUAL STYRENE								
1-3 days at 23°C	11.4	8.4	7.5	7.3	7.6	7.4	8.6	7.1
Above + 3 hrs at 80°C	2.2	1.3	0.4	0.05	0.2	0.06	0.3	0.3
Above + 3 hrs at 100°C	1.3	0.7	0.1	0.02	0.1	0.04	0.1	0.1
Above + 3 hrs at 120°C	0.9	0.2	0.1	0.02	0.07	0.03	0.08	0.04

Table 2. STANDARD METHYL ETHYL KETONE PEROXIDE, COBALT OCTOATE, DIMETHYL ANILINE SYSTEM.
Influence of Peroxide Level.

FORMULATION	9	10	1	2	11	12	13
Vinyl ester resin	100	100	100	100	100	100	100
Standard methyl ethyl ketone peroxide	0.5	1.0	1.5	2.0	2.5	3.0	4.0
Cobalt Octoate, 1 %	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Dimethyl Aniline, 10 %	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Gel time in minutes on 100 gm at 23°C	1300	83	50	40	38	30	24
RESIDUAL STYRENE							
1-3 days at 23°C	no gel	14.1	11.4	8.4	7.4	2.8	2.8
Above + 3 hrs at 80°C	no gel	5.2	2.2	1.3	0.8	1.0	0.1
Above + 3 hrs at 100°C		1.8	1.3	0.7	0.4	0.3	0.1
Above + 3 hrs at 120°C		1.3	0.9	0.2	0.2	0.2	0.06

Table 3. STANDARD METHYL ETHYL KETONE PEROXIDE, COBALT OCTOATE, DIMETHYL ANILINE SYSTEM.
Influence of Ratio of Peroxide to Accelerator.

FORMULATION	14	2	15	16	17	1	18	19	10	20	21	9	22	23	24
Vinyl ester resin	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Standard methyl ethyl ketone peroxide	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.0	1.0	1.0	0.5	0.5	0.5	0.5
Cobalt octoate, 1 %	3.0	3.0	1.0	3.0	3.0	3.0	1.0	3.0	3.0	1.5	1.0	3.0	1.0	0.5	1.0
Dimethyl aniline, 10 %	1.2	0.5	0.5	0	1.2	0.5	0.5	0	0.5	0.5	0.5	0.5	0.5	0.5	0
Gel time in minutes on 100 gm at 23°C	22	40	55	126	22	50	60	400	83	61	79				
RESIDUAL STYRENE															
1-3 days at 23°C	6.0	8.4	8.8	11.0	9.0	11.4	14.0	23.0	14.4	10.2	10.1	no gel	no gel	29	no gel
Above + 3 hrs at 80°C	1.5	1.3	1.2	1.9	1.3	2.2	2.4	5.8	5.2	1.8	1.7	no gel	no gel	13.2	no gel
Above + 3 hrs at 100°C	1.0	0.7	0.8	1.0	0.7	1.3	1.3	2.2	1.8	1.3	1.2			10.9	
Above + 3 hrs at 120°C	0.4	0.2	0.5	0.7	0.5	0.9	0.9	1.3	1.3	1.1	1.1			7.0	

Table 4. METHYL ETHYL KETONE PEROXIDE, ALIPHATIC PERESTER, COBALT OCTOATE, DIMETHYL ANILINE SYSTEM.
Influence of Cross Peroxide System.

FORMULATION	25	26	27	28	14	2
Vinyl ester resin	100	100	100	100	100	100
Standard methyl ethyl ketone peroxide	1.5	1.5	1.5	1.5	2.0	2.0
Aliphatic perester	0.5	0.5	1.0	1.0	0	0
Cobalt octoate, 1 %	3.0	3.0	3.0	3.0	3.0	3.0
Dimethyl aniline, 10 %	0.5	1.2	1.2	0	1.2	0.5
Gel time in minutes on 100 gm at 23°C	42	20	20	145	22	40
RESIDUAL STYRENE						
1-3 days at 23°C	4.0	3.8	2.0	7.4	4.9	6.4
Above + 3 hrs at 80°C	0.08	0.1	0.08	0.06	1.5	1.3
Above + 3 hrs at 100°C	0.04	0.08	0.04	0.03	1.0	1.3
Above + 120°C	0.02			0.02	0.4	0.2

Table 5. CUMENE HYDROPEROXIDE, VANADIUM COMPOUND, PROMOTOR BS SYSTEM.

FORMULATION	29	30	31	32
Vinyl ester resin	100	100	100	100
Cumene hydroperoxide, minimum 7.3 % active oxygen content	2.0	2.0	2.0	1.0
Vanadium compound	1.0	0.5	1.0	1.0
Promotor BS	0.5	0.5	1.0	0.5
Gel time in minutes on 100 gm at 23°C	9	10	8	15
RESIDUAL STYRENE				
1-3 days at 23°C	0.4	4.5	0.2	1.5
Above + 3 hrs at 80°C	0.04	0.05	0.1	0.9
Above + 3 hrs at 100°C	0.004	0.01	0.04	0.6

Table 6. DIBENZOYL PEROXIDE, DIMETHYL ANILINE, ACCELERATOR NLF SYSTEM.

FORMULATION	33	34	35	36
Vinyl ester resin	100	100	100	100
Dibenzoyl peroxide, pourable, minimum 2.65 % active oxygen content	2.0	3.0	2.0	2.0
Dimethyl aniline, 10 %	1.0	1.0	0.5	0.5
Accelerator NLF	0	0	0.03	0.05
Gel time in minutes on 100 gm at 23°C	30	18	18	16
RESIDUAL STYRENE				
1-3 days at 23°C	8.3	7.5	2.6	3.7
Above + 3 hrs at 80°C	3.5	2.6	2.3	2.5
Above + 3 hrs at 100°C	2.9	1.7	1.7	1.4
Above + 3 hrs at 120°C	2.4	1.4	1.6	1.1

Table 7. ROOM TEMPERATURE CURE WITH DIFFERENT CATALYSTS.

FORMULATION	14	2	18	30	31	34	36
Vinyl ester resin	100	100	100	100	100	100	100
Standard methyl ethyl ketone peroxide	2.0	2.0	1.5				
Dibenzoyl peroxide						3.0	2.0
Cumene hydroperoxide				2.0	2.0		
Cobalt octoate, 1 %	3.0	3.0	1.0				
Dimethyl aniline, 10 %	1.2	0.5	0.5			1.0	0.5
Vanadium compound				0.5	1.0		
Promotor BS				0.5	1.0		
Accelerator NLF							0.05
Gel time in minutes on 100 gm at 23°C	22	40	60	10	8	18	16
RESIDUAL STYRENE							
1-3 days at 23°C	6.0	8.4	14.0	3.5	0.2	7.5	3.7
14 days at 23°C	5.5	7.5	8.4	3.2	0.1	6.6	3.2
30 days at 23°C	5.0	6.3	7.5	2.1	0.1	6.6	3.2

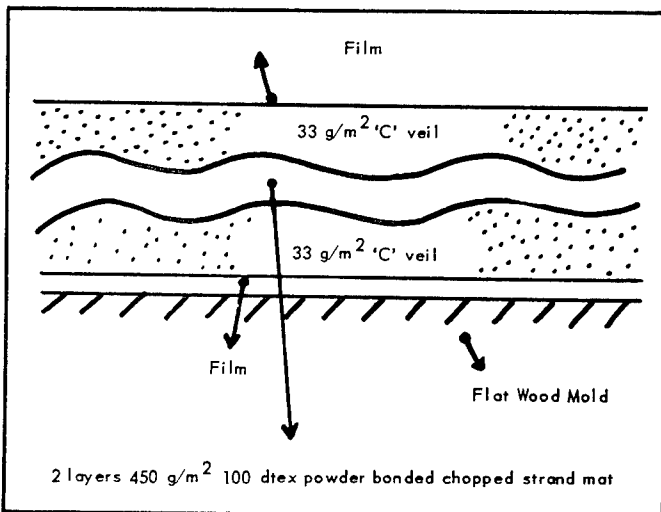


Fig. 1. Laminate Fabrication

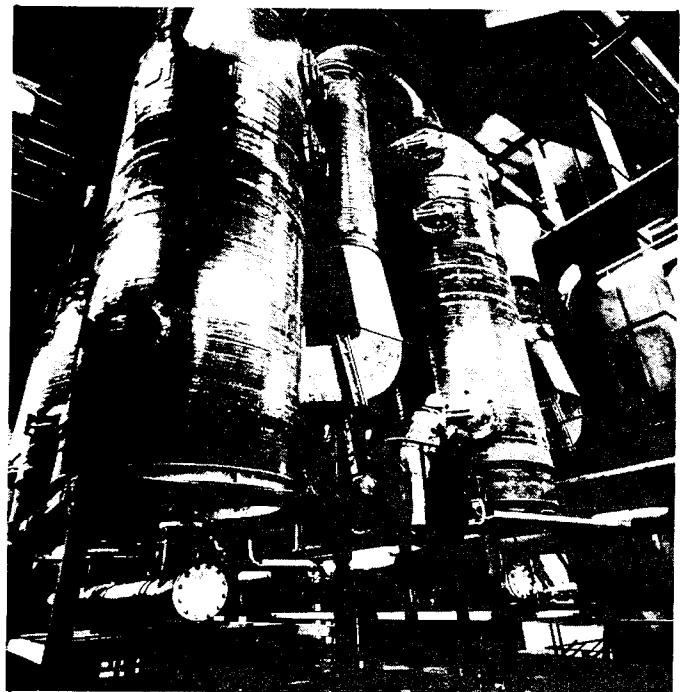


Fig. 2. Gas Scrubbing System at NPK Fertiliser Plant of Superfos A/S, Denmark

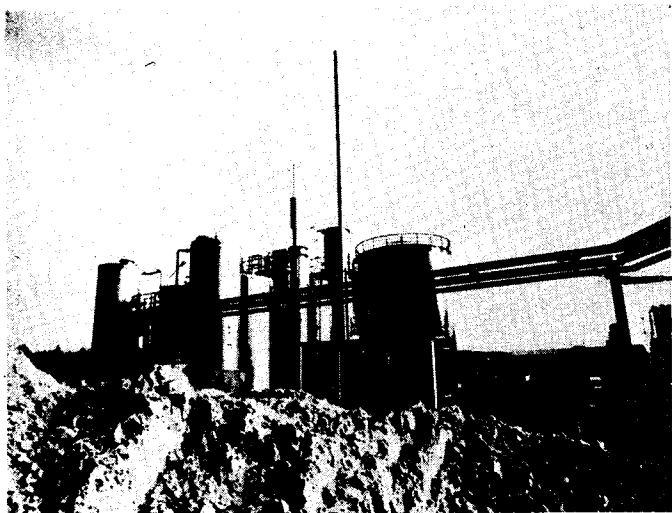


Fig. 3. Ferric Chloride Recovery Plant of Ferrichlor A.B., Sweden

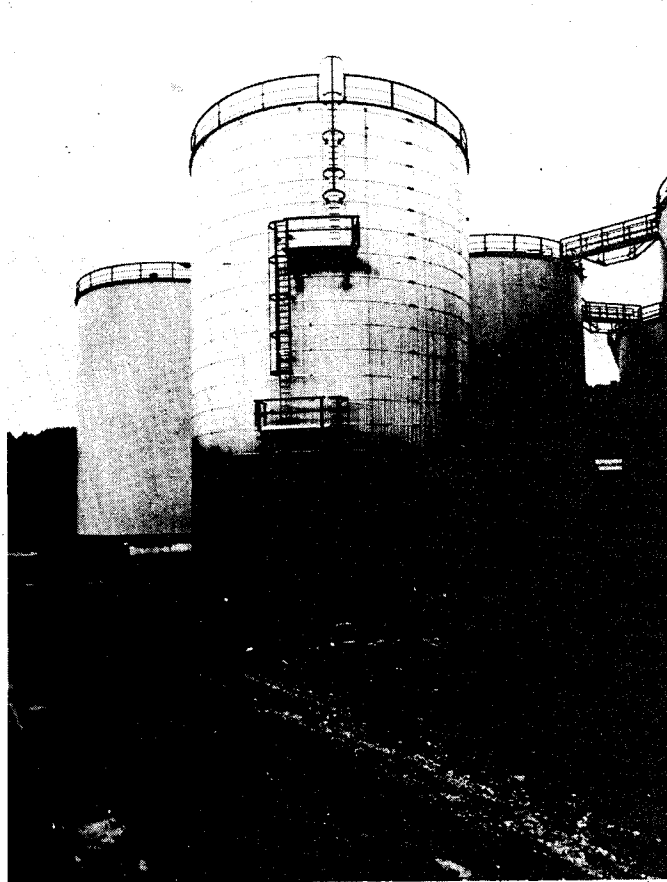


Fig. 4. 2100 mt G.R.P. Lined Steel Storage Tank of Powell Duffryn Oil and Chemical Storage Ltd., U.K.



Fig. 5. Filament Wound Road Tanker for Milk Transportation Fabricated by Sovap, France

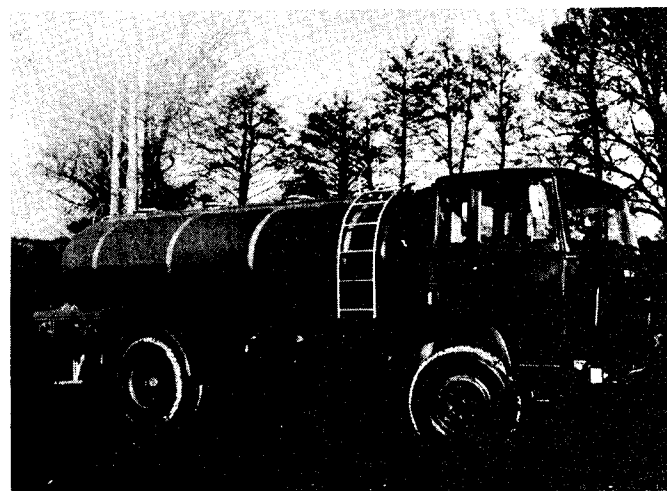


Fig. 6. Filament Wound Road Tanker for Wine Transportation Fabricated by Sovap, France

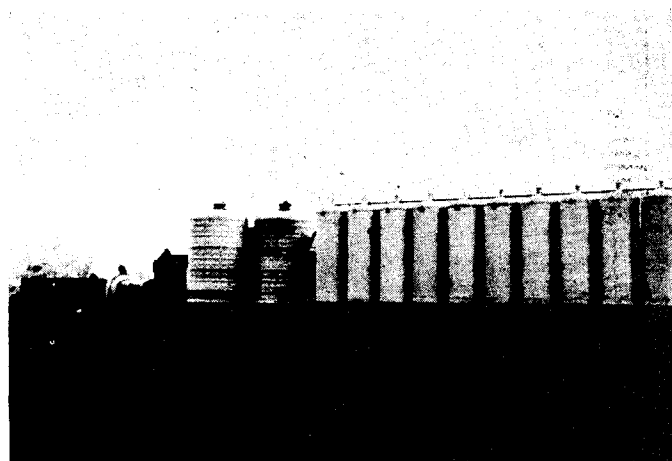


Fig. 7. Battery of Tanks Fabricated by Sovap for Storage of 850,000 gallons of Wine

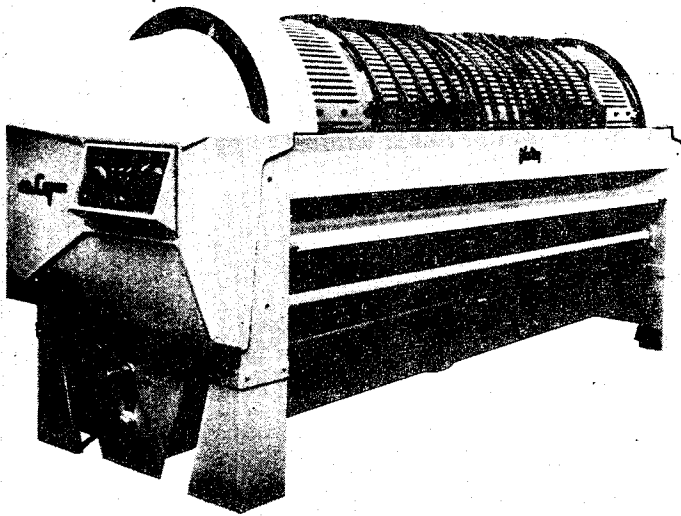


**Fig. 8. Press for Production of Wine, Fruit Juices and Marmalade
Manufactured by CMMC, France**

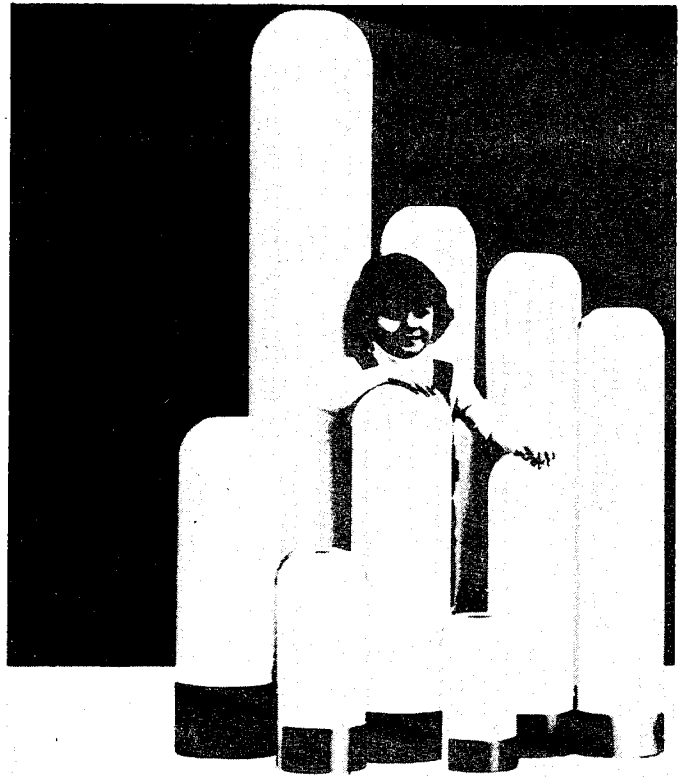


**Fig. 9. Water Softener Bottles Manufactured by Plastiques Armés
Mullerhof, France**

(Sec. 6-D) (1-2)

EFFECT OF LAMINATE QUALITY ON CHEMICAL RESISTANCE OF REINFORCED FRP STRUCTURES

by

R. E. McMAHON and R. J. LEWANDOWSKI*

ABSTRACT

The laminate Quality Task Force of the SPI Corrosion Resistant Structures Committee has undertaken a project to evaluate the effects on corrosion or chemical resistance of laminate imperfections which might or can occur in FRP fabrication. A test series of laminates were prepared by one fabricator, then corrosion tested by another fabricator and a resin manufacturer, controlled under test as specified per ASTM C-581 for a period of one year. The data in this paper indicates the quality factors that influence the possible degradation of reinforced plastic structures in service.

A correlation between poor quality and acceptable NBS Voluntary Product Standard PS15-69 quality fabrication has been attempted in this paper.

INTRODUCTION

It was decided during a meeting of the SPI Laminate Quality Task Force Group on September 17, 1968 that a project be undertaken to correlate and compile data to determine the effect of laminate quality on chemical resistance of FRP structures.

The late Henry Hasbrouck of Hasbrouck Plastics, our Task Force Chairman, volunteered to develop methods of preparing samples that would include various flaws, possibly common, in fabrication of FRP structures. A set of samples, including a control was sent to ICI America and Ceilcote Co. Each Company selected a group of test solutions in which the laminates containing the various flaws and including the control were immersed and tested according to ASTM C-581. The length of the test was 1 year. Ceilcote chemical test solutions included:

1. HCl—8%, ambient temperature
2. H₂SO₄—20%, ambient temperature
3. HNO₃—20%, ambient temperature
4. CH₃COOH—25%
5. distilled H₂O—180°F (83°C)
6. NaOH—10%, ambient temperature

A list of chemicals tested by ICI America include the following:

1. HCl—15%, 200°F (93°C)
2. CH₃COOH—25%, 200°F (93°C)
3. HNO₃—5%, 200°F (93°C)
4. NaOCl—5-1/4%, 125°F (88.5°C)
5. NaOH—5%, 175°F (80°C)

TYPES OF LAMINATES TESTED

The laminates incorporated in this study were prepared by Hasbrouck Plastics, Inc., seven laminates having definite faults in their quality and one control. It should be noted here the type of resin tested and cure system was a bisphenol-A fumarate polyester cured with 1% methyl ethyl ketone peroxide. Promoter system was cobalt naphthenate and dimethylaniline. The samples were al-

lowed to reach maximum Barcol hardness of the manufacturer's recommendation. The laminates were prepared in accordance with PS15-69 using commercially available reinforcements.

SAMPLE LAMINATE DESCRIPTION

1. Control sample. Standard laminate with minimum air bubble content. Resin vacuum deaerated.

2. Cracking and crazing. Sample similar to control sample with the exception of cracks introduced with the dropping of a 10 lb. hammer 2'.

3. Scratches. Similar to control sample with knife blade scratch made by hand.

4. Surface pits. Similar to control sample incorporating grains of rock salt in the surface during the layup. Salt washed out subsequently.

5. Inclusion of foreign matter. In order to test the effect of extraneous organic matter included in the layup, a series was made with a paperbook match imbedded under the "C" glass surface veil.

6. Blisters. Similar to control sample with air bubbles injected by a hypodermic needle beneath the "C" grade surface mat.

7. Similar to control sample except not deaerated. Small air bubbles distributed throughout laminate by use of a highly aerated resin.

During monthly examination of panels visually and through the use of the stereomicroscope, each test specimen was rated as follows:

1. **Very good**—no chemical effect.

2. **Good**—only slight or negligible chemical effect.

3. **Fair**—denotes a slight decline in chemical resistance with a minimal degree of degradation; however, laminate still capable of maintaining adequate protection.

4. **Poor**—system shows extensive chemical degradation such as blistering and heavy inner-fiber prominence. Sample somewhat opaque.

5. **Failure**—complete decline in chemical resistance with all protective characteristics destroyed.

Results of Ceilcote testing include: rating, percent flexural change, percent flexural modulus change, test interval 1 year.

Test Data			
HCL - Conc.	Rating	% Flexural Strength Change	% Flexural Modulus Change
#1	fair	-19.85	-28.78
#2	poor	-34.25	-42.20
#3	fair	-----	-----
#4	poor	-----	-----
#5	fair	-----	-----
#6	poor	-26.20	-30.88
H ₂ SO ₄ - 20%			
#1	good	+ 9.16	-13.19
#2	fair	- 5.24	-19.63
#3	fair	-----	-----
#4	fair	-----	-----
#5	good	-----	-----
#6	poor	+61.74	+12.42
HNO ₃ - 20%			
#1	good	+15.66	- 1.99
#2	poor	+31.55	-13.03
#3	good	-----	-----
#4	fair	-----	-----
#5	good	-----	-----
#6	poor	+37.55	+16.10
CH ₃ COOH - 25%			
#1	good	+ 7.26	-16.25
#2	fair	+22.20	- 9.98
#3	good	-----	-----
#4	fair	-----	-----
#5	good	-----	-----
#6	poor	+68.75	+24.23
Distilled H ₂ O - 180°F (83°C)			
#1	fair	-11.29	- 8.90
#2	failure	-44.48	-20.30
#3	poor	-----	-----
#4	poor	-----	-----
#5	poor	-----	-----
#6	failure	-46.40	+18.39

*Ceilcote Company
140 Sheldon Road
Berea, Ohio 44017

NaOH - 10%	Rating	% Flexural Strength Change	% Flexural Modulus Change
#1	good	+ 0.83	-14.72
#2	fair-poor	-24.82	-30.98
#3	fair	-----	-----
#4	poor	-----	-----
#5	fair	-----	-----
#6	poor	- 0.55	-13.19

Test panel #7 not tested. It should be noted here that on test panels #3, #4 and #5 we have not published the physical properties change. This was due to the unrealistic properties variation collected from our original data; and with consideration of the type of flaw or fault in quality of the laminate such as a match stick imbedded, it was impossible to correlate accurate physical properties of such a small area involved in the laminate over a one year study. A mathematical analysis of the results obtained indicated these properties were not valid.

ICI AMERICA'S TEST RESULTS

The test environment fundamentally for nearly all environments is water. A test of each of the variables in deionized water for 12 months at 200°F was completed. This test revealed the cracks, the scratch and the match had no effect on the resistance when compared visually to the control. The pits show no effect on the slide, but some blistering developed opposite to the pit. The bubbles lead to a slightly deeper discoloration, but the most notable effect is the blister. This coupon showed a definite change in color of the coupon and size of the surface deterioration.

15% hydrochloric acid (HCl) at 200°F (93°C) is a much more aggressive environment, but it did little to the control except change the color. In the "crack sample" more veil whitening is found and wicking effects throughout the cracks are apparent. The scratch, bubbles and the mat displayed no apparent effect. In fact, we can hardly see the match due to the color change. The pit shows no effect that, again, a blister was developing opposite to the photographed surface. The "blister coupons" shows a slightly deeper coloration of the coupon and a few signs of attack including pitting on the surface and increased surface veil prominence. The 25% acetic acid (CH₃COOH) environment at 200°F (93°C); the control looks excellent. The pit shows only very localized attack on the opposite side of the pit. With the blisters, we again find a development of a serious corrosion attack compared to the control. The sample shows severe surface veil whitening, a change in color and probably severe loss of strength.

5% nitric acid (HNO₃) at 200°F (93°) was the toughest acid environment tested. There was near whitening and slight loss of gloss on the control, and all of the other samples except the blistered sample. The blistered sample shows up poor as a loss of color and surface deterioration is quite evident.

Sodium hypochlorite 5-1/4% (NAOCL) at 125°F (88.5°C) is a strong oxidizing environment. The control shows little attack, slight whitening is the only effect. The same holds true for the cracks, scratches, pits, small air bubbles, even the bookmatch turned bleach white; but has not affected the chemical resistance of the surrounding resin. Again, the blister shows signs of deteriorating chemical resistance.

Sodium hydroxide 5% (NaOH) at 175°F (80°C) is an extremely aggressive environment. Even in the control, surface effects are found such as crazing, and "mud cracking" after drying out. This phenomena slightly more pronounced in the cracking sample. The scratches, bubbles, pit and the bookmatch are equal to the control. The only acceleration occurs in the blister sample. Here, there is evidence of surface deterioration and additional severe swelling has occurred which doesn't show up in the photo. These indicate a severe loss of strength in the coupon.

CONCLUSIONS

The results of this evaluation have shown that there is a correlation between poor quality and poor chemical resistance. Each component of the attacking environment along with the type of flaw must be considered carefully and separately. The results of the two studies indicate the defects might best fit into three categories.

1. nondetrimental—scratches, small foreign matter inclusions and small bubbles

These defects would not merit any special treatment or repair except for aesthetic purposes.

2. detrimental to surface only—cracking, surface pits

In environments which normally attack the laminate surface, such as strong oxidizing agents, these could be of concern. Many applications, as seen in our tests herein, would be unaffected by these defects and no special repair would be required. When repair is desired, a simple sanding and top-coating with a paraffinated resin is sufficient.

3. detrimental to long term service—blisters

This defect represents any sizeable blister, dry spot or delamination below the C-veil surface. When reinforced plastics are exposed to hot aqueous solutions, the solution rapidly permeates the polymeric structure. The rate of this permeation depends on the environment and the resin type and laminate construction. Distilled water, for example, travels randomly through the structure at a determined rate of permeation; and where a detrimental type of flaw exists, the solution quickly attacks this area of vulnerability. With a solution in which the molecular size is large, permeation will be much slower.

It is, therefore, recommended that this type of detrimental flaw be completely ground out, rebuilt with "C" grade surfacing veil, mat and resin, then topcoated with a non-air inhibited resin system to complete an effective repair.

RONALD E. McMAHON

Ronald E. McMahon, Technical Advisor, Ceilcote Company, graduated from Kent State University with a B.S. in Chemistry. He joined Ceilcote Company in 1953 as a Research Chemist and has engaged in the development work of reinforced plastic laminates, corrosion resistant linings and monolithic toppings. He is a Senior Member of the SPE, Chairman of the SPI Task Force Group on Fire Retardancy for Reinforced Plastics, a member of the National Association of Corrosion Engineers; and he is qualified in one or more phases in the field of corrosion control.

The authors have dedicated the inspiration for this study and initial fabrication of the FRP test specimens to the memory of the late Henry Hasbrouck of Hasbrouck Plastics Corporation.

(Sec. 6-E) (pp. 1-8)

THE FLEXIBILITY AND CHEMICAL RESISTANCE OF UNSATURATED POLYESTERS—MEANS OF TESTING AND THEIR RELATIVE MERITS

by

H. R. EDWARDS*

ABSTRACT

Resin-formulating and mechanical-property studies have shown that the flexibility of unsaturated polyesters can be increased by formulation modifications that change the cross-link density and/or the aliphatic content of the polymer. An example is the incorporation of adipic acid or various glycols into the polymer chain. A method has also been developed for predicting the flexibility of a given polyester formulation from the calculated cohesion energy of the raw materials.

Flexibility, defined as the ability of FRP parts to deflect without cracking, is measured more successfully by the crushing of specimens of filament-wound pipe—ASTM Method D2412—rather than by the tensile elongation of clear resin castings. Results show that an increase in flexibility is usually accompanied by a corresponding decrease in heat distortion temperature and in moduli, and often in strength.

Chemical-resistance data obtained to date on laminates of flexible polyesters indicate that unsaturated polyesters containing dipropylene glycol offer the best resistance to a wide range of corrosive media.

INTRODUCTION

Unsaturated polyesters with optimum flexibility and chemical resistance are especially important to the fabricators of FRP pipe and structures. Although some flexibility is desirable to relieve handling and installation problems, too much flexibility could reduce the strength of FRP parts. Among the many means of flexibilizing resins, the most common are the blending of highly flexible additives (including monomers) and the incorporation of flexibilizing raw materials into the polymer chain. There has been a need, however, for a method that will predict how such modifications affect the resins. In addition, there has been no general agreement on the best way to test flexibility or to determine how additives that impart flexibility will affect other mechanical properties of the modified resins.

A study was therefore undertaken to: (1) define flexibility in terms of appropriate tests, (2) develop a practical way to predict it for any given resin formulation, and (3) assess its impact on the associated properties and chemical resistance of the cured resins. The study involved a series of resins in which increased flexibility was achieved by reducing unsaturation in the polyester and incorporating common aliphatic raw materials (adipic acid, dipropylene glycol and/or diethylene glycol) into the polymer chain.

Previous work by Bunn,¹ who related melting point to the cohesion energy and flexibility of polymers, proved particularly helpful

in the development of a suitable method of prediction. After modification to reflect the cross-linking of thermosetting resins, his system results in a "Flexibility Factor" that can be used to predict resin flexibility as measured by "deflection to crack" tests.

Because the flexible resins were developed to be used in corrosive environments, substantiation of their resistance to chemical attack was included in the study. Results to date indicate that, of the flexibilizing raw materials surveyed, dipropylene glycol gives the broadest resistance to chemical attack.

EXPERIMENTAL

Materials

Data were obtained for the twenty-three resins whose composition and properties are summarized in Appendix A. Raw materials included isophthalic acid, adipic acid, maleic anhydride, and propylene, dipropylene, ethylene, diethylene, neopentyl, and TMPD² glycols. All resins were synthesized by a two-stage method.³ Saturated acids and glycols were first reacted to an acid value below ten. Then, the unsaturated acid was added and the resin processed to a Gardner-Holdt viscosity of U-W at 60% solids inhibited styrene and an acid value of less than twenty on a solids basis.

Clear castings were prepared by catalyzing the resin with 1% benzoyl peroxide and curing it at 135°F (57°C) for sixteen hours. A post-cure schedule of one hour each at 180°F (82°C), 220°F (105°C), and 250°F (121°C) followed.

Symmetrical flat glass laminates were constructed as specified in ASTM Method C581. They consisted of two plies of 1½ oz/ft² chopped strand mat (E glass) between two plies of 10 mil surface veil (C glass). The resins were gelled with a room-temperature system of 60% methylethylketone peroxide in dimethyl phthalate and cobalt octoate adjusted to a pot life of approximately twenty minutes. The laminates were post-cured four days at 150°F (66°C).

Two-inch (50.8 mm) inside diameter pipe specimens were made with a commercial grade of filament winding roving. The resins were catalyzed with 1% 2, 5-dimethyl - 2, 5-bis (2-ethylhexanoyl-peroxy) hexane and were then heat cured. No liner was used.

Test Procedures

Mechanical properties of the cured specimens were measured by the following ASTM Methods:

- D638 Tensile Properties of Plastics
- D648 Deflection Temperature of Plastics Under Load
- D790 Flexural Properties of Plastics
- D2412 External Loading Properties of Plastic Pipe by Parallel-Plate Loading

Before flexural testing at elevated temperatures, the specimen was held fifteen minutes at the test temperature.

Deflection of the flexural coupon at room temperature until the resin cracked was expressed as the distance travelled by the instrument crosshead divided by test span.

Chemical resistance was tested according to ASTM Method C581. The standard of comparison was a corrosion resistant isopolyester containing one mole of isophthalic acid, one mole of maleic anhydride, and 2.2 moles of propylene glycol.

Calculation of Flexibility Factor

Bunn's system, which is based on the calculation of a "unit cohesion energy" for thermoplastic polymers, has been modified to adjust for thermosetting resins and to account for our practical experience with certain raw materials. The following rules govern calculation of a Flexibility Factor for a known unsaturated polyester formulation.

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¹Bunn, C.W., J. Polymer Sci. 16, 323 (1955).

²TMPD is a registered trademark of Eastman Chemicals Products, Inc.

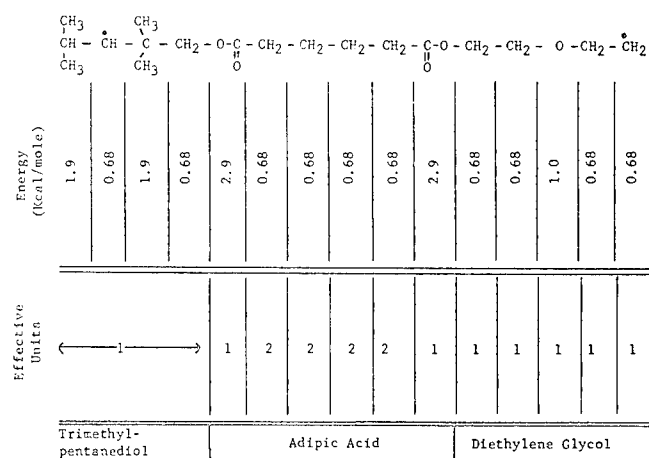
³Amoco Bullentin IP 7 C, p.5.

1. Sum the cohesion energy for a polymer of one formula molecular weight using the following values for the chemical groups involved.

Chemical Group	Cohesion Energy (Kcal/mole)
—CH ₂ —	0.68
—C ₆ H ₅ —	3.9
—CH=CH—	1.7
—CH (CH ₃)—	1.36
—C (CH ₃) ₂ —	1.9
—O—	1.0
—CO—O—	2.9

- a. Assume no glycol excess.
- b. Assume no hydroxyl or carboxyl end groups in the condensed polymer.
2. Sum the "effective units" in the subject polymer.
 - a. Ester and ether groups are always individual effective units.
 - b. Other chemical groups are only additive functions when two or more $\text{—CH}_2\text{—}$ groups are adjacent. Otherwise the effective units remain one regardless of the groups present in the molecule.
 - c. When four or more $\text{—CH}_2\text{—}$ groups are adjacent, the effective units are doubled.

Example:



3. Divide polymer cohesion energy by effective units.

B. Calculation of unsaturation levels

$$\text{moles of unsaturation} \times \frac{1000}{\text{formula mol. wt. of the condensed polymer}} = \text{unsaturation/1000 gms}$$

1. If the saturated acid/unsaturated acid mole ratio is less than 1 or greater than 2, adjust the formula to the closer of those ratios. Glycols should be adjusted to show no glycol excess and maintain the same mole ratio between the hydroxyl elements as in the original formula. This has no effect on cohesion energy calculations!

Example:

<u>Raw Material</u>	<u>Original</u>	<u>Adjusted</u>
Isophthalic Acid	3 moles	2 moles
Maleic Anhydride	1 mole	1 mole
Propylene Glycol	3 moles	2.25 moles
Diethylene Glycol	1 mole	0.75 moles

C. Calculation of Flexibility Factor

$$\text{Flexibility Factor} = (\text{cohesion energy/effective unit}) \times (\text{unsaturation}/1000 \text{ gms})$$

Table I contains the cohesion energies and effective units for the raw materials used in this study. A sample calculation follows.

Sample Calculation:

<u>Raw Material</u>	<u>Moles</u>	<u>Energy (Kcal/Mole)</u>	<u>Effective Units</u>	<u>Mol. Wt.</u>
IPA (C ₆ H ₄)	2	3.9 (7.8)	1 (2)	76 (152)
Maleic Anhydride (C ₂ H ₂)	1	1.7 (1.7)	1 (1)	26 (26)
Diethylene Glycol (C ₄ H ₈ O) ₃		3.72 (11.16)	5 (15)	72 (216)
ester groups (CO ₂)	6	2.9 (17.4)	1 (6)	44 (264)
(Total)		(38.06)	(24)	(658)

1.59 Kcal/effective unit

The value Kcal/unit is related to the flexibility of the uncured chain, but cross-link density must be accounted for. Thus, assigning molecular weights to the chemical groups gives a chain weight of 658 for the sample calculation. Since there is one mole of unsaturation per 658 grams of chain, one can calculate 1.52 moles of unsaturation per 1000 grams, which is an arbitrary value denoting cross-link density. A Flexibility Factor is obtained by multiplying the cohesion energy per unit by the moles of unsaturation per 1000 grams of chain. In this case the Flexibility Factor is 2.42.

RESULTS AND DISCUSSION

Tests of Flexibility

The commonly used tests evaluated for determining (measuring) flexibility were tensile elongation, deflection of a flat laminate, and crushing of a two-inch filament wound pipe.

Tensile elongation of the clear resin casting can fluctuate considerably even within the same casting. The shrinkage that necessarily occurs during cross-linking causes the development of stresses in unreinforced castings. Unless these stresses are relieved, the casting will break inconsistently when placed in tension. Filling the casting with glass fibers reduces shrinkage and absorbs some of the applied stress. Figure 1 shows how the clear casting's tensile elongation correlates with that of the laminate. Note that tensile elongation of the laminate is limited to 2½% (approximately that of randomly oriented glass fibers).

As shown in Figure 2, a clear relationship exists between both the flexural and tensile moduli and the tensile elongation of unreinforced castings. Moduli of a resin fluctuate less than the tensile elongation and may be a better indicator of flexibility.

In a test to determine the relationship of flexural modulus to resin flexibility, test specimens of flat laminates were deflected until the resins cracked. However, since the flexural modulus of laminates sometimes fluctuates due to subtle differences in glass wet-out, the flexural modulus of the clear resin casting was correlated with the cracking phenomenon. These results, shown in Figure 3, indicate that a flexible resin generally has a flexural modulus less than one-half million psi (3.445×10^6 kPa).

Deflecting a flat laminate proved to be a good method for assessing the flexibility of the resin alone. It is as damaging to break glass fibers as to crack the cured resin. However, the fracture of glass fibers is not very noticeable in a flat laminate. As a result, the data are misleading from a practical stand-point.

Fracture of either resin or glass is readily discernable when a filament wound pipe section is deflected per ASTM D2412. A correlation is shown in Figure 4 between both the load and deflection sustained by the pipe and the heat distortion temperature of the cured clear resin.

Flexibility Parameters

Figure 5 shows a good relationship between the percent deflection that occurs when the pipe cracks in the crushing test and the resin's calculated Flexibility Factor. Figure 6 shows that the Flex-

ibility Factor is also useful in predicting good crush strengths for the range 2.4-4.0.

The calculated Flexibility Factor and the measured clear casting properties—flexural modulus and tensile elongation—give a set of parameters indicating strength and flexibility. The nine resins listed in Table II meet or exceed the following strength and flexibility minimums:

- clear casting tensile strength ≥ 8000 psi
- clear casting flexural strength ≥ 15000 psi
- 2" pipe crush strength ≥ 1300 lbs/6 inch length at crack
- 2" pipe deflection $\geq 22\%$ at crack
- laminate deflection $\geq 6\%$ at crack

The following ranges for parameters most closely associated with flexibility can be applied, in general, to these nine flexible, but strong, resins: 1.) clear casting flexural modulus $0.400-0.500 \times 10^6$ psi, 2.) clear casting tensile elongation 2.5—6.5%, and 3.) Flexibility Factor 2.4-4.0.

The Flexibility Factor is the best indicator of resin strength and flexibility. All resins with a Flexibility Factor below 4.0 were flexible. Only one resin with a Flexibility Factor between 2.4 and 4.0 was not strong. No one parameter is absolute, however. Neither can a resin be deemed inadequate if its modulus or elongation is outside the prescribed limits. It can be stated though, that a resin meeting all prescribed parameter ranges will also possess good strength and flexibility. Resins E, M, N, R, and S meet these criteria.

Figure 7 shows a correlation between heat distortion temperature and the calculated Flexibility Factor. The more flexible the resin, the lower the heat distortion temperature.

Strengths (Figure 8) and moduli (Figure 2) of clear resin castings are generally related to tensile elongation. Properties of the clear resin castings are reflected in the FRP composite. While the tensile strengths go through an ultimate, the moduli decrease steadily as elongation increases. Heat increases the flexibility of the cured resin and similarly affects its mechanical properties. Figure 9 shows that the standard corrosion resistant isopolyester peaks in strength about 25°C below its heat distortion temperature. As shown in Figure 10, the flexural modulus of this resin reflects the increased flexibility induced by elevated temperatures. A study of the other resins (R, T, W, X, and Y) in these graphs confirms that ultimate strength is reached 10 to 30°C below a resin's heat distortion temperature and that moduli decrease with increased heat just as they do with increased elongation. Flexibility of the resin must be considered with the anticipated environment. A resin optimized in flexibility for room temperature conditions may not be adequate at elevated temperatures if it loses strengths and moduli.

Chemical Resistance

All twenty-three resins were screened for one month to select those having the best chemical resistance. The results, given in Table III, indicated that only three of the strong, flexible resins in Table II—R, T, and W—were stable enough to be included in a year-long testing program. Since we were concerned with establishing chemical resistance over a pH range, diethylene glycol and adipic acid containing resins were not included because of their relatively poor performance in 5% sodium hydroxide at 49°C. Poor results occurred in all three screening media when adipic acid was used with an ether glycol (resins A, D, F, G, H). Resistance to acetic acid was reduced when the glycols were only ethylene and/or diethylene (resins M, N, P, S). Sulfuric acid posed no problems except when adipic acid was used with an ether glycol. However, neopentyl glycol upgraded the resistance to caustic (compare resins B and C; also resins J, V, and X).

Up to now, only three months of the one-year test have elapsed. Data show in Appendix B (one month), Appendix C (three months), and summarized in Table IV indicate that the flexible resins will prove satisfactory in many of the media.

CONCLUSIONS

Although clear casting tensile elongation depicts trends in flexibility, it does not appear to be an accurate gauge for depicting the flexibility of an individual resin. The same may be said of flexural modulus. Thus, measurement of a resin's ability to deflect in laminate form without fracturing resolves many discrepancies observed in the clear resin casting. This may be achieved in the flexure of a flat laminate or the crushing of a cylindrical (pipe) laminate. However, the latter test is preferred as being more reliable. A very high elongation resin gives the illusion of imparting extraordinary flexibility to a flat laminate; the glass fibers often undergo stress cracking before the resin. Practically speaking, this should conclude the test, but there is no distinct crack to signal this. When fibers in a curved position are stressed, fracture of the glass is very apparent. It is for this reason that the crush load sustained also relates well to flexibility.

The calculated Flexibility Factor gives the resin formulator an excellent predictor of resin flexibility. In this study, every resin with a Flexibility Factor less than 4.0 was truly flexible. A combination of the Flexibility Factor with clear resin casting, flexural modulus and tensile elongation gives assurance of good strength and flexibility.

Too much flexibility substantially lowers strengths and moduli. Since heat increases flexibility and affects its associated properties, heat distortion temperature with respect to the anticipated environment is important when selecting a flexible resin. A structural resin should never be subjected to temperatures higher than 10°C below its heat distortion temperature unless the impact of reduced strengths and moduli has been assessed.

The resins currently being tested for chemical resistance have a desirable blend of flexibility, heat distortion temperature, and chemical resistance. These resins, which contain dipropylene glycol, exhibit the good resistance to acids for which isophthalate polyesters are noted. The testing also indicates that these resins are acceptable in some dilute basic media.

For good overall chemical resistance, ester and ether groups must be protected. Aromatics and α -methyl groups protect them better than do straight-chain aliphatics. Although dipropylene glycol resins were selected for long-term chemical resistance testing, many resins that contain diethylene glycol showed promise in acidic media.

Six-month results from the one-year test will be presented at the 1975 Annual Conference of the SPI Reinforced Plastics/Composites Institute.

HAROLD R. EDWARDS

Harold R. Edwards (Dan) is a chemist in the Amoco Chemicals Technical Service Laboratory. The laboratory is located at the Amoco Research Center in Naperville, Illinois.

Mr. Edwards joined Amoco in 1967 after receiving his bachelor's degree in chemistry from Illinois Institute of Technology. At Amoco, he has been involved in resin formulation and synthesis and in testing the resin in glass fiber composites. He is a member of the National Association of Corrosion Engineers, Society of Plastics Engineers, and the American Society for Testing and Materials (secretary D20.18.11). He is also a member of the SPI program committee and the SPI corrosion resistant structures subcommittee, and of the ASME ad hoc task group on FRP pipe.

APPENDIX A

RESIN FORMULATIONS, FLEXIBILITY FACTORS, AND MECHANICAL PROPERTIES

ASTM TEST	A	B	C	D	E	F	G	H	J	K*	L	M	N	P*	Q	R	S	T	U	V	W	X	Y*
RESIN IDENTIFICATION																							
ISOPHTHALIC ACID (MOLES)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ADIPIC ACID (MOLES)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MALEIC ANHYDRIDE (MOLES)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PROPYLENE GLYCOL (MOLES)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
DIPROPYLENE GLYCOL (MOLES)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ETHYLENE GLYCOL (MOLES)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
DIETHYLENE GLYCOL (MOLES)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
NEOPENTYL GLYCOL (MOLES)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
TMPO GLYCOL (MOLES)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
GLYCOL EXCESS (% OF TOTAL)	5	10	2	5	10	5	5	5	10	10	7	5	5	EG5	PG7	PG7	EG5	PG5	PG5	PG5	PG5	PG5	PG5
KCAL/CHAIN	49.8	41.5	46.5	48.5	32	37.2	41.2	62	33.1	44.8	43	38.3	42.3	82.3	35.7	37.7	36.8	40.4	38	34.9	39.5	36.6	50.3
KJ/CHAIN	209	174	195	203	134	156	173	260	139	188	180	160	177	345	150	158	154	169	159	146	166	153	211
EFFECTIVE CHAIN UNITS	31	25	23	39	19	31	25	47	12	16	12	24	18	51.8	18	15	22.2	16.8	12	12	15	12	17
KCAL/UNIT	1.6	1.65	2.0	1.25	1.7	1.2	1.65	1.3	2.75	2.8	3.6	1.6	2.35	1.6	2.0	2.5	1.65	2.4	3.2	2.9	2.65	3.05	2.95
KJ/UNIT	6.74	6.96	8.47	5.2	7.05	5.03	6.92	5.53	11.55	11.73	15.01	6.68	3.84	6.65	8.31	10.53	6.94	10.07	13.26	12.18	11.03	12.77	12.39
CHAIN MOL. WT	936	704	816	824	534	638	722	1012	568	568	778	658	742	404	613	655	632	707	673	610	697	645	695
UNSATURATION/1000 GMS	2.14	2.84	2.45	2.43	1.87	1.57	1.39	1.98	1.76	1.76	1.29	1.52	1.35	2.47	1.63	1.53	1.58	1.41	1.49	1.64	1.43	1.55	1.44
FLEXIBILITY FACTOR	3.45	4.7	4.95	3.0	3.14	1.9	2.3	2.6	4.86	4.9	4.6	2.4	3.2	3.96	3.2	3.84	2.6	3.4	4.7	4.8	3.8	4.7	4.25
1/8" CLEAR CASTING																							
FLEX. STR., PSI X 10 ⁻³	D790	12.4	19.5	17.0	11.7	17.1	6.0	3.8	12.4	22.3	19.5	14.2	17.1	17.9	21.2	21.5	18.6	21.7	20.8	14.5	17.2	16.8	22.1
MPa		85	134	117	81	118	41	26	85	154	134	98	118	123	146	148	128	150	143	100	119	116	152
FLEX. MOD., PSI X 10 ⁻⁶	D790	3.04	.486	.454	.299	.450	.135	.072	.314	531	528	.462	.451	.458	.515	.528	.494	.478	.500	.491	.516	.488	.576
MPa X 10 ⁻³		2.09	3.35	3.13	2.06	3.10	0.93	0.50	2.16	3.66	3.64	3.18	3.11	3.16	3.55	3.64	3.40	3.29	3.45	3.38	3.56	3.36	3.97
TENS., STR., PSI X 10 ⁻³	D638	7.0	9.4	10.6	6.7	11.1	3.5	2.2	6.9	9.3	12.2	8.5	10.2	10.9	10.6	12.2	11.1	12.6	8.9	9.2	10.6	9.7	8.3
MPa		48	65	73	46	76	24	15	48	64	84	59	70	75	73	84	76	87	61	63	73	67	57
TENS. MOD., PSI X 10 ⁻⁶	D638	218	.494	.421	.243	.425	.136	.086	.296	505	505	.458	.428	.477	.462	.511	.481	.469	.484	.466	.504	.466	.539
MPa X 10 ⁻³		1.50	3.40	2.90	1.67	2.93	0.94	0.59	2.04	3.48	3.48	3.16	2.95	3.29	3.18	3.52	3.31	3.23	3.33	3.35	3.47	3.21	3.71
TENS. ELONG., %	D638	18.5	2.5	3.6	22.7	5.8	50+	50+	12.2	1.8	2.4	1.8	6.5	3.6	2.8	2.7	2.7	5.3	1.8	1.9	2.2	2.2	1.6
HDT, °C	D648	51	88	88	47	54	38	33	45	88	84	84	49	51	84	75	71	58	63	86	81	86	77
LAMINATE																							
DEFLECTION TO CRACK, %	D790	14.3	6	8	13	8.3	16	14.7	14	6	5	4.2	12.7	7.5	10.5	6.8	6.5	12.2	6.2	3.8	—	6	5.1
TENS. ELONG., %	D638	2.4	1.5	2.1	2.5	2.2	2.3	2.4	2.2	1.4	1.6	1.1	2.3	2.1	1.6	1.8	1.8	2.3	1.8	1.1	1.5	1.8	1.4
2 INCH (ID) PIPE																							
DEFLECTION TO CRACK, %	D2412	—	17	21	32	31	—	27	35	15	6	6	25	22	23	27	22	31	30	9	8	25	20
LOAD AT CRACK, LBF/6"	D2412	—	1300	1350	1600	1675	—	950	1700	1100	560	500	1600	1300	1400	1700	1600	1700	1600	750	700	1800	1500
NEWTONS/6"			5785	6008	7120	7454		4228	7565	4895	2492	2225	7120	5785	6230	7565	7120	7565	7120	3338	3115	8010	6675

*CHAIN MOL. WT. AND UNSATURATION/1000 GMS. ADJUSTED PER INSTRUCTIONS

APPENDIX B

ONE MONTH ASTM C581 CHEMICAL RESISTANCE

MEDIUM	INITIAL	TOLU/ISO	50/50	FREE	NaOH	50%	SOIL-H ₂ O	NH ₄ OH	HAC	DIST.	H ₃ PO ₄	Na ₂ CO ₃	UREA	EtOH	HCl	HNO ₃	NaCl	H ₂ SO ₄	VIN.
CONCENTRATION		75/25	50/50	AMOCO	2%	pH4	pH10	1N	25%	H ₂ O	15%	10%	38%	50%	71	71	71	25%	25%
TEMPERATURE, °C		25	25	25	25	38	38	49	49	49	49	49	49	71	71	71	71	71	71
CORROSION RESISTANT ISOPOLYESTER																			
FLEX. STR., PSI X 10 ⁻³	15.6	13.9	15.9	13.9	12.2	12.7	13.4	15.9	16.1	15.3	15.8	14.1	14.4	16.4	15.5	15.0	14.7	17.2	21.5
MPa	107	96	110	96	84	88	92	110	111	105	109	97	99	113	107	103	101	119	148
FLEX. MOD., PSI X 10 ⁻⁶	.907	.799	.860	.865	.754	.727	.822	.758	.806	.711	.764	.802	.791	.722	.836	.674	.837	.837	.871
MPa X 10 ⁻³	6.25	5.51	5.93	5.96	5.20	5.01	5.66	5.22	5.55	4.90	5.26	5.53	5.45	4.97	5.76	4.64	5.77	5.77	6.00
BARCOL HARDNESS	48	46	46	48	42	41	41	35	44	43	43	39	38	38	42	41	45	43	43
APPEARANCE		0	0	0	0	0	0	1,4	0	3	0	0	1	0	0	1,3	0	0	3
RESIN "R"																			
FLEX. STR., PSI X 10 ⁻³	18.9	1.6	14.9	16.2	13.5	18.4	21.6	16.4	20.1	20.1	16.0	14.9	16.5	16.2	17.4	16.1	28.7	25.0	22.3
MPa	130	11	103	112	93	127	149	113	138	138	110	103	114	112	120	111	198	172	154
FLEX. MOD., PSI X 10 ⁻⁶	.708	.053	.536	.838	.774	.781	.857	.625	.689	.777	.710	.760	.758	.526	.733	.641	.964	.916	.788
MPa X 10 ⁻³	4.88	0.37	3.69	5.77	5.33	5.38	5.90	4.31	4.75	5.35	4.89	5.24	5.22	3.62	5.05	4.42	6.64	6.31	5.43
BARCOL HARDNESS	44	0	23	42	41	39	37	22	32	38	38	34	34	27	36	35	42	40	32
APPEARANCE		6	5	0	0	3	3	1,4	0	2,3	2	2	1	6,7,8	2	1,2	0	0	2,6
RESIN "T"																			
FLEX. STR., PSI X 10 ⁻³	19.2	1.7	14.7	16.5	16.9	20.5	14.4	16.4	23.5	21.5	22.1	16.8	17.5	16.1	16.8	21.2	22.5	18.1	17.2
MPa	132	12	101	114	116	141	99	113	162	148	152	116	121	111	116	146	155	125	119
FLEX. MOD., PSI X 10 ⁻⁶	.856	.080	.440	.758	.826	.774	.733	.571	.610	.744	.747	.746	.691	.456	.722	.661	.671	.703	.644
MPa X 10 ⁻³	5.90	0.55	3.03	5.22	5.69	5.33	5.05	3.93	4.20	5.13	5.15	5.14	4.76	3.14	4.97	4.55	4.62	4.84	4.44
BARCOL HARDNESS	41	0	19	37	41	38	36	16	31	36	37	38	33	19	35	34	38	33	32
APPEARANCE		6	0	0	0	3	3	1,4	0	2,3	2	2	1	6,7	2	1,2	0	0	2,6
RESIN "W"																			
FLEX. STR., PSI X 10 ⁻³	19.4	1.5	14.8	15.6	17.8	15.2	15.8	16.9	20.4	19.5	17.5	14.9	14.2	15.7	18.1	18.2	19.6	22.9	18.9
MPa	134	10	102	107	123	105	109	116	141	134	121	103	98	108	125	125	135	158	130
FLEX. MOD., PSI X 10 ⁻⁶	.856	.070	.484	.774	.872	.742	.772	.637	.672	.761	.711	.708	.680	.480	.749	.714	.721	.840	.747
MPa X 10 ⁻³	5.90	0.48	3.33	5.33	6.01	5.11	5.32	4.39	4.63	5.24	4.90	4.88	4.69	3.31	5.16	4.92	4.97	5.79	5.15
BARCOL HARDNESS	48	0	20	32	40	36	36	20	33	36	32	38	33	22	35	35	36	40	

APPENDIX C

THREE MONTH ASTM C581 CHEMICAL RESISTANCE

MEDIUM	INITIAL	TOLU/ISOCT		LEAD		NaOH	50% SOIL-H ₂ O	NH ₄ OH	HAc	DIST.	H ₃ PO ₄	Na ₂ CO ₃	UREA	EtOH	HCl	HNO ₃	NaCl	H ₂ SO ₄	VIN.	
CONCENTRATION		75/25	50/50	FREE	2%		pH4 pH10	1N	25% H ₂ O		15%	10%	38%	50%	15%	5%	SAT'D	25%	EGAR	
TEMPERATURE, °C		25	25	25	25		38 38	49	49 49	49	49	49	49	71	71	71	71	71	71	
CORROSION RESISTANT ISOPOLYESTER																				
FLEX. STR., PSI X 10 ⁻³	15.6	11.4	15.0	14.0	12.8		13.4 16.2	13.4	14.1 14.9	15.3	11.5	14.8	14.8	14.4	13.0 14.2	14.4	19.9	14.1		
MPa	107	79	103	96	88	92	112	92	97 103	105	79	102	99	90	98	99	137	97		
FLEX. MOD., PSI X 10 ⁻⁶	.907	.776	.789	.848	.734	.753	.797	.681	.748 .820	.786	.696	.770	.749	.698	.719	.831	.864	.720		
MPa X 10 ⁻³	6.25	5.35	5.44	5.84	5.06	5.19	5.49	4.89	5.15 5.65	5.42	4.80	5.31	5.16	4.81	4.95	5.73	5.95	4.96		
BARCOL HARDNESS	48	43	44	45	44	44	46	35	44 42	45	44	41	42	43	42	44	44	42		
APPEARANCE		0	0	0	0	0	0	1,4	0 3	0	0	1	3	0	1,3	0	4	3		
RESIN "R"																				
FLEX. STR., PSI X 10 ⁻³	18.9	DISCONTINUED	DISCONTINUED	16.3	16.2	15.5	17.5	12.7	24.2 17.8	19.3	15.7	17.3	11.7	26.2	16.6	17.0	13.5	13.9		
MPa	130			112	112	107	121	88	167	123	133	108	119	81	181	114	117	93	96	
FLEX. MOD., PSI X 10 ⁻⁶	.708			.746	.771	.804	.770	.471	.685	.760	.778	.702	.688	.527	.933	.636	.744	.707	.581	
MPa X 10 ⁻³	4.88			5.14	5.31	5.54	5.31	3.25	4.72	5.24	5.36	4.84	4.74	3.63	6.43	4.38	5.13	4.87	4.00	
BARCOL HARDNESS	44			35	42	40	39	5	34	39	35	38	24	28	39	34	40	40	32	
APPEARANCE				0	0	3	3	1,6	3 2,3	2	2	1,3	5,6,8	1,6	1,2	0	0	6		
RESIN "T"																				
FLEX. STR., PSI X 10 ⁻³	19.2			16.4	18.4	19.3	18.1	13.0	22.8 15.7	20.5	18.9	19.0	15.8	15.6	12.9	21.8	15.2	15.6		
MPa	132			113	127	133	125	90	157	108	141	130	110	107	89	150	105	107		
FLEX. MOD., PSI X 10 ⁻⁶	.856			.636	.813	.747	.693	.434	.632	.679	.742	.705	.666	.500	.681	.613	.686	.701	.546	
MPa X 10 ⁻³	5.90			4.38	5.60	5.14	4.77	2.99	4.35	4.68	5.11	4.86	4.59	4.69	4.22	4.73	4.83	3.76		
BARCOL HARDNESS	41			24	38	40	34	0	32 35	35	34	24	26	33	35	41	34	30		
APPEARANCE				0	0	3	3	1,6	0 2,3	2	2	1	5,6,8	1,4	1,2	0	0	6		
RESIN "W"																				
FLEX. STR., PSI X 10 ⁻³	19.4			15.6	16.4	16.2	16.4	13.2	18.1 19.2	20.3	16.9	14.0	15.3	15.3	17.2	18.0	18.4	15.8		
MPa	134			107	113	112	113	91	125	132	140	116	96	105	105	119	124	127	109	
FLEX. MOD., PSI X 10 ⁻⁶	.856			.650	.778	.749	.783	.502	.650	.777	.786	.699	.625	.530	.699	.667	.721	.800	.611	
MPa X 10 ⁻³	5.90			4.48	5.36	5.16	5.39	3.46	4.48	5.35	5.42	4.82	4.31	3.65	4.82	4.60	4.97	5.51	4.21	
BARCOL HARDNESS	48			27	38	40	35	7	34	37	36	36	25	29	35	36	38	36	33	
APPEARANCE				0	0	3	3	1,6	0 2,3	3	2	1	5,6,8	1	1,2	0	4	6		

TABLE I

COHESION ENERGY FOR RAW MATERIALS

Raw Material	Cohesion Energy (Kcal/mole)	Effective Units
Isophthalic Acid	3.9	1
Maleic Anhydride	1.7	1
Adipic Acid	2.72	8
Propylene Glycol	2.04	1
Dipropylene Glycol	5.08	3
Ethylene Glycol	1.36	2
Diethylene Glycol	3.72	5
Neopentyl Glycol	3.26	1
Trimethylpentanediol (TMPD)	5.30	1
Ester Linkage	2.9	1

TABLE II

RESINS POSSESSING STRENGTH AND FLEXIBILITY

Resin Identification	Clear Casting Flex. Mod. (psi x 10 ⁻⁶)	Clear Casting Tens. Elong. (%)	Flexibility Factor
E	0.450	5.8	3.14
M	0.451	6.5	2.4
N	0.458	3.6	3.2
P	0.515	2.8	3.96
Q	0.528	2.7	3.2
R	0.494	2.7	3.84
S	0.478	5.3	2.6
T	0.500	1.8	3.4
W	0.488	2.2	3.8

TABLE III

CHEMICAL RESISTANCE SCREENING (ONE MONTH)

<u>Resin Identification</u>	<u>25% H₂SO₄ at 71°C</u>	<u>25% HAc at 49°C</u>	<u>5% NaOH at 49°C</u>
A	-	-	-
B	+	+	-
C	+	+	0
D	-	-	-
E	+	-	-
F	-	-	-
G	-	-	-
H	-	-	-
J	+	+	0
K	+	+	-
L	+	0	0
M	+	-	-
N	+	-	-
P	+	0	-
Q	+	+	-
R	+	+	+
S	+	-	0
T	+	+	0
U	+	+	-
V	+	+	+
W	+	0	0
X	+	+	+
Y	ND	ND	ND
Standard	+	+	+

+ = acceptable
 - = unacceptable
 0 = borderline
 ND = no data

TABLE IV

THREE MONTH CHEMICAL RESISTANCE RESULTS

<u>Medium</u>	<u>Conc.</u>	<u>Temp. (°C)</u>	<u>Std. Corrosion Resistant Isopolyester</u>	<u>Resin "R"</u>	<u>Resin "T"</u>	<u>Resin "W"</u>
Toluene/Isooctane	75/25	25	A	U	U	U
Toluene/Isooctane	50/50	25	A	U	U	U
Lead Free Amoco	91 Octane	25	A	A	T	T
Sodium Hydroxide	2%	25	A	A	A	A
50/50 Soil/H ₂ O	pH 4	38	A	A	A	A
50/50 Soil/H ₂ O	pH 10	38	A	A	A	A
Ammonium Hydroxide	1 N	49	A	U	U	U
Acetic Acid	25%	49	A	A	A	A
Distilled Water	all	49	A	A	A	A
Phosphoric Acid	15%	49	A	A	A	A
Sodium Carbonate	10%	49	A	A	A	A
Urea	38%	49	A	T	T	T
Ethanol	50%	71	A	U	U	U
Hydrochloric Acid	15%	71	A	A	A	A
Nitric Acid	5%	71	A	A	A	A
Sodium Chloride	sat'd	71	A	A	A	A
Sulfuric Acid	25%	71	A	A	A	A
Vinegar	all	71	A	A	T	A

Note 1: Resins are rated by percent retention of flexural strength, flexural modulus, Barcol hardness, and by general visual appearance.

- a) resin is acceptable to date if all retentions are above 65% (A)
- b) resin is borderline and requires further testing if any retention is 50-64% (T)
- c) resin is unacceptable if any retention is less than 50% or if structural damage occurred (U)

FIGURE 1
PERCENT TENSILE ELONGATION OF THE
LAMINATE VS. CLEAR CASTING

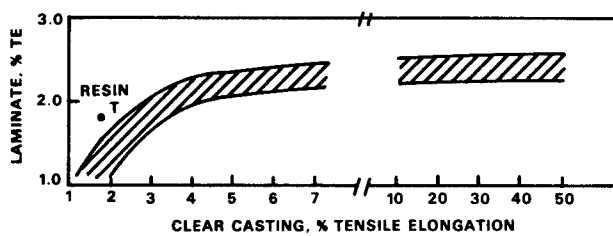


FIGURE 3
PERCENT FLAT LAMINATE DEFLECTION
TO CRACK VS. CLEAR CASTING FLEXURAL MODULUS

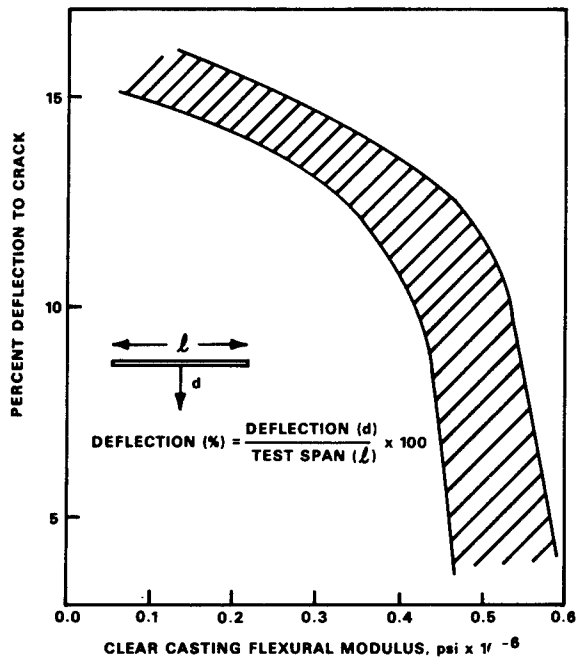


FIGURE 5
DEFLECTION OF PIPE AT CRACK VS.
FLEXIBILITY FACTOR

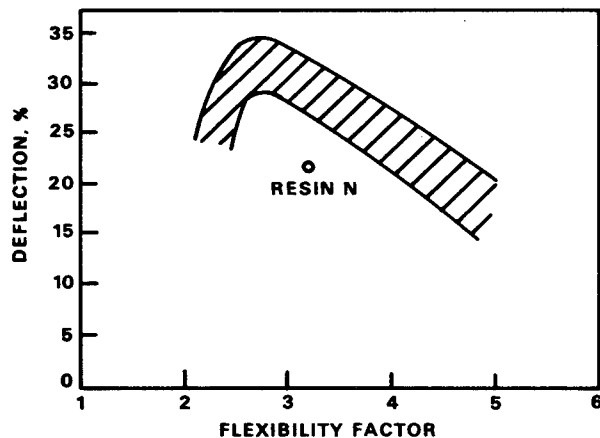


FIGURE 2
CLEAR CASTING MODULI (BOTH FLEXURAL AND TENSILE)
VS. TENSILE ELONGATION

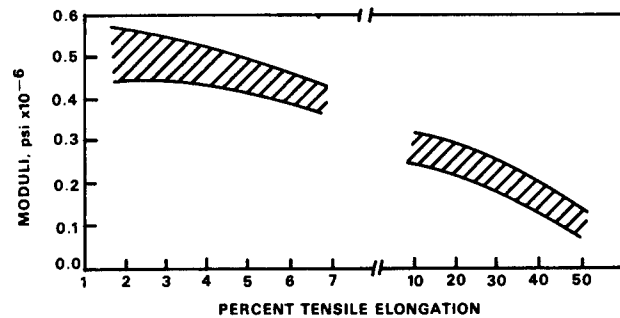


FIGURE 4
CRUSH PROPERTIES AT CRACK VS.
CLEAR CASTING HEAT DISTORTION TEMPERATURE

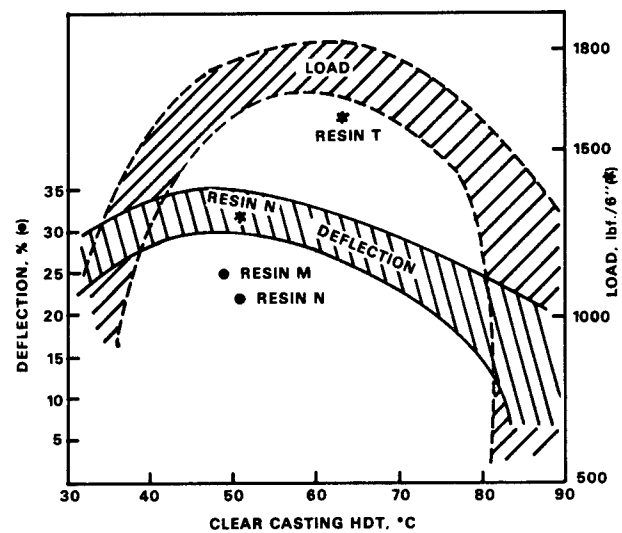


FIGURE 6
LOAD AT PIPE CRACK VS. FLEXIBILITY FACTOR

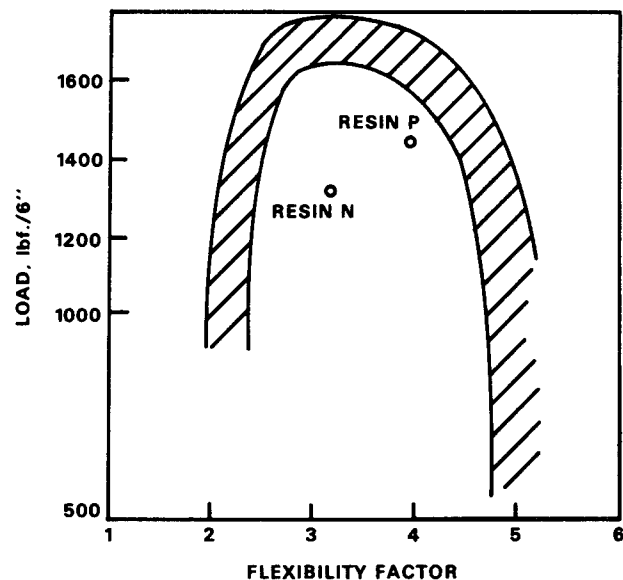


FIGURE 7
CLEAR CASTING HEAT DISTORTION
TEMPERATURE VS. FLEXIBILITY FACTOR

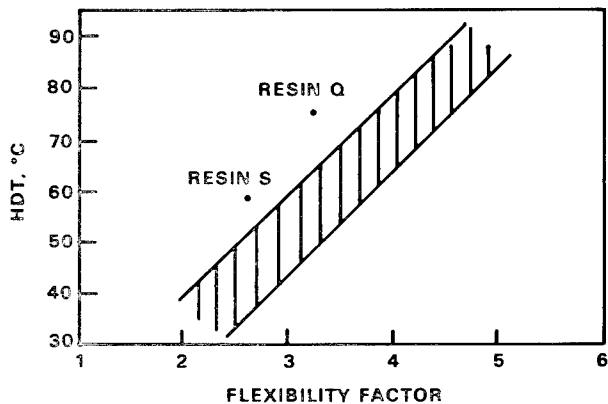


FIGURE 9
LAMINATE FLEXURAL STRENGTH VS. TEMPERATURE

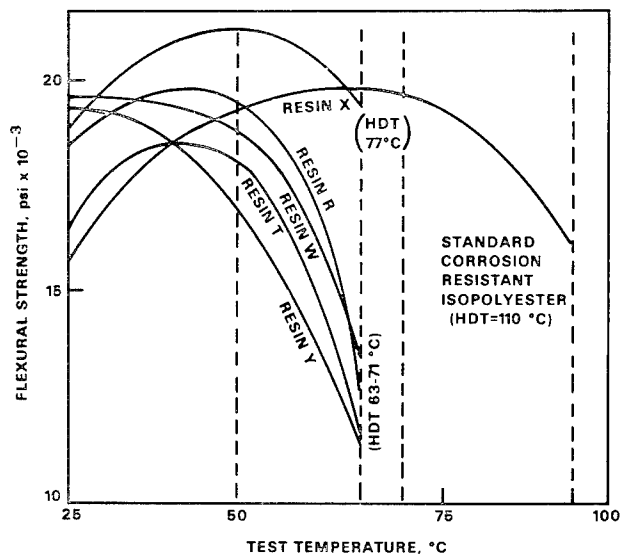


FIGURE 8
CLEAR CASTING STRENGTHS VS. TENSILE ELONGATION

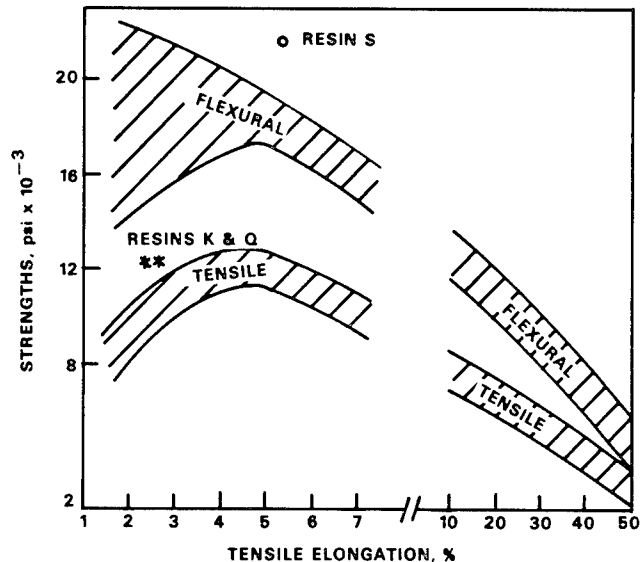
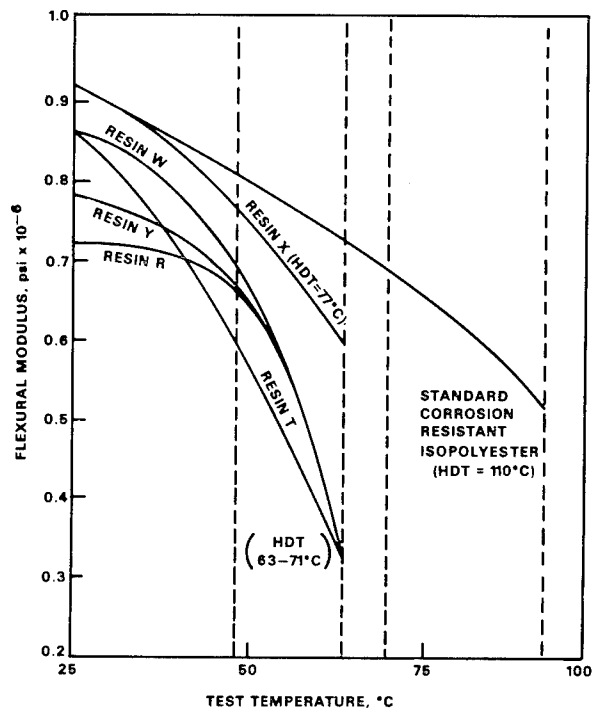


FIGURE 10
LAMINATE FLEXURAL MODULUS VS. TEMPERATURE



SECTION FOUR

EVALUATION AND TESTING

DESIGN, PRODUCTION AND TESTING OF LARGE DIAMETER REINFORCED PLASTIC UNDERGROUND EFFLUENT PIPE

by

J. ALBERT ROLSTON* and AGNAR GILBU**

ABSTRACT

The design parameters for underground Fibreglas reinforced sewer pipe have been studied in an extensive program of computer optimization. The design study has included the structural parameters of the pipe wall, the properties of the soil surrounding the buried pipe, and the interactions between the flexible pipe and the adjacent soil zone.

A continuous process for making large diameter tubular structures is being used by the NCP Division of Owens-Corning to produce underground effluent pipe. This versatile, continuous process provides a large range of diameters from 24" to 138". A continuously traveling steel ribbon mandrel makes it all possible.

To prove the long range stability of large diameter Fibreglas reinforced plastic pipe in underground service, a creep testing program was initiated in May, 1972. This study will continue for an indefinite period. The effects of various dead loads are being studied for pipe sections exposed underwater.

INTRODUCTION

In making reinforced plastic pipe, there is a large variation of possible materials and material combinations to choose from. In the past, filament winding was almost the only method used for RP pipe. Today, pipe is made by:

- 1) Filament winding
- 2) Contact molding (hand lay-up)
- 3) Spray-up
- 4) Centrifugal molding
- 5) Continuous winding

The different methods mentioned can vary within large limits; materials in the pipe laminates may consist of:

- a) 15 - 70% fiber glass
- b) 0 - 40% filler
- c) 30 - 75% resin
- d) Small amounts of other additives

The fiber glass reinforcement can be used as:

- 1) Continuous fiber
- 2) Chopped fiber
- 3) Mat
- 4) Woven roving, etc.

Filler

The filler type used varies from a silica flour to coarse sand. Sand is not only a cheap filler, but it is also used to:

- a) Improve abrasive resistance
- b) Improve compressive strength
- c) Lower shrinkage
- d) Lower thermal expansion

Resins:

The most used resin is unsaturated polyester resin. This is available in four different grades:

- a) Orthophthalic polyester resin.
- b) Isophthalic polyester resin.
- c) Bisphenol A polyester resin.
- d) Epoxy vinyl polyester resin.

In addition, pure epoxy resin is widely used. The resin accounts for chemical resistance. Of the polyester resins mentioned, orthophthalic resin is less resistant than isophthalic, and bisphenol resin is better than isophthalic resin.

Based on what is mentioned, orthophthalic resin is used in easy environments while bisphenol A resin is used in the most corrosive environments. The most widely used resin for pipe is still isophthalic resin, which has excellent resistance against water degradation, against normal soil attack, and against sewage.

It is important in a design approach to utilize the glass fiber as well as the other laminate components in an optimum manner. Before thinking of the laminate buildup, one must determine the exposure of the structure:

Forces

- Internal pressure
- Soils load
- Traffic load
- Vacuum
- Shear loads
- Deflection
- Buckling forces
- Beam loads
- Compressive stresses
- Flexural stresses

Other loads such as torsion, water hammer or impact.

Environments

- Weather attack, U.V.
- External environment in ground
- Internal environment

Both size of stress, and direction are important.

In regard to stresses, it is important that the various allowable stress levels (related to the ultimate strengths) be of the same magnitude. This is not always easy to obtain. For example, when making a buried 25 psi pipe, the main problem is of a stability nature and not of a direct stress nature. If a filament wound pipe were used for this application, one would normally end up with a safety factor of 5-8 against buckling, but with 40 against internal pressure. This means, in reality, that the reinforcement was not used efficiently.

In pipe design, one should pay attention to how the interaction between stress and environment influences the future properties of the laminate. This is shown in Fig. 1.

Pipe Design: Pipe can generally be classified in 3 different groups:

- a) Underground pipe
- b) Above ground pipe
- c) Sub-aqueous pipe

In this paper, we will deal only with the first mentioned type.

Buried Pipe: For a buried pipe we generally deal with the following design parameters:

- a) Deflection
- b) Moment
- c) Thrust
- d) Buckling

In the calculation of (b) and (c), these should be added together; that is, compressive stress due to thrust should be added to the compressive component from bending stresses caused by moments. This is very important.

Deflection: Until recently Spangler's work¹ (done in 1940) has been the basis for design of all flexible underground pipes. Spangler's basic

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**Owens/Corning Fibreglas Corp., Conroe, Texas

work was to determine deflection. He believed that this was the main design parameter. His formulas can be used for calculating deflections as well as moments. His formula for deflection is:

$$x = D_1 \frac{KW_c R^3}{EI + 0.061eR^4}$$

Where D_1 = deflection lag factor

K = bedding constant

W_c = load on pipe per unit length.

R = mean radius of pipe

EI = stiffness factor of pipe

e = modulus of passive pressure of side fill.

As one can see from the formula, there are many constants that have to be selected.

Jan Molin² in Sweden worked with Spangler's formula and changed it according to his practical experiments with RP pipe to:

$$\frac{\delta_v}{D} = \frac{0.083W}{E'_s \left(\frac{EI}{E'_s R^3} + 0.122 \right)}$$

where

$$\frac{\delta_v}{D} = \text{vertical deflection}$$

W = soil load

E'_s = soil modulus

EI = pipe stiffness

$E'_s \times R^3$ = soil stiffness

From this formula, we can clearly show how much the soil properties mean for the behavior of the pipe.

Generally

$$\frac{EI}{E'_s R^3} \text{ is small related to the constant } 0.122$$

This means that E'_s (soil modulus outside the bracket) has the largest influence on the pipe deflection. In addition to deflection, Molin also worked out a moment equation and showed the variation of soil modulus related to compaction and burial depth (see Figs. 2 and 3). The distribution of loads and reactions around a flexible pipe is described by many authors, and in good agreement to what Spangler described in his work. This is shown graphically in Fig. 4.

The magnitude of the reaction forces per unit area depends on the backfill method, and generally will be higher than the action forces on the top of the pipe.

When calculating the forces acting on the pipe, we also have to take into consideration the dynamic loads. The influence will depend on the burial depth as shown in Fig. 5.

The graph shows that the influence of live loads is high for pipe with a backfill cover of up to 3 feet, but it is reduced rapidly as the burial height increases. Based on this, we do not recommend installations of flexible pipe for traffic exposure unless a burial depth of 4 ft. is assured. (With lower backfill special precautions must be considered).

Moments and Thrust: The moment equation we have found to be best suited for buried flexible pipe made from reinforced plastic is the one derived by Molin:

$$M = \frac{0.50S}{S + 0.122}$$

where M = Moment

$$S = \text{Stiffness factor} = \frac{EI}{E'_s R^3}$$

When solving this equation, one can find fiber stress with the following formula:

$$\text{Stress due to moment} = \frac{Mc}{I}$$

c = distance between neutral axis and fiber

I = moment of inertia

This gives the maximum stress due to moment. It is considered for tension and compression. To this stress, we have to add the compressive stress due to external soil pressure, which is:

$$\sigma_c = \frac{PR}{t}$$

σ_c = compression stress, psi

P = soil pressure, psi

t = pipe wall thickness

If the pipe has an internal pressure, one has to add the tensile stress due to moment to the tensile stress due to internal pressure. (This will give a conservative design).

Normally compressive strength is not a serious factor, but should, however, be checked.

Regarding Buckling: There are many different formulas for buckling of a buried cylinder. We have found Jay Allgood's formula³ transitional buckling, most useful.

$$\sigma_{crit.} = \bar{C} \frac{M_s EI}{D^3}$$

M_s = type of soil modulus

EI = pipe stiffness factor

D = pipe diameter

$\bar{C}$ = special factor for buckling equation, related to Poisson's ratio for soil.

The buckling calculation is an important factor in pipe design. Frequently, it is as important as deflection.

Design Conclusions: From the above discussions, one can see that stability is the most important design factor. Because of this, one should take a careful look on the causes of the stability of the pipe/soil system:

- soil modulus
- pipe modulus
- pipe moment of inertia

(b) and (c) are what we call pipe stiffness, EI
 I is a function of wall thickness

$$I = \frac{Wt^3}{12}$$

Based on this, one can see that it is cheaper to obtain a higher stiffness by using a low E and a slightly thicker wall than to increase the modulus by using expensive glass fiber. We have taken even more advantages of this effect by designing underground structures utilizing ribbed structures (See Fig. 6).

When we know the stresses we can increase the moment of inertia and modulus where needed. It is up to each designer to utilize these possibilities.

Testing of RPM Pipes:

Short term tests and long term creep tests have been used to expand the knowledge of reinforced plastic mortar (RPM) pipe. Short term tests (standard ASTM coupons) were used to examine the effect of sand filler in fiber glass reinforced polyester laminates. Long term creep tests were made to predict the elastic behavior of pipe sections under water for long periods.

Effect of Sand Content:

Flat laminates were made with a constant volume of glass (10.9%) equivalent to a 22% (wt.) glass content with no filler. As sand content was increased (replacing the resin) the volume per cent glass was constant, but the weight per cent decreased.

The laminate compositions are shown in Table I.

The short term properties of the flat panels (measured by ASTM standard tests) are listed in Table II and plots of the data may be seen in Figures 7 and 8.

Discussion:

These tests indicated that replacement of resin by sand up to 35% by wt. had no major effect on the short term strength (from ASTM standard coupons) in reinforced plastic structures except for the hoop tensile strength. The flexural strength was seemingly unaffected by sand content; this is explainable if one assumes a layer of glass fibers near the surface which carries the major stress in flexure. The modulus in tension showed little change from sand content; both the compression modulus and flexural modulus increased. This would be expected since sand particles would not contribute in tension but would react to compression stresses.

CREEP TESTS OF 24 INCH DIAM. PIPE:

Plastic Creep: Plastic creep occurs in most reinforced plastic structures under stress. Studies of glass fibers^{6,7} have shown that creep (static fatigue) does occur due to moisture attack. Very few reports have covered the subject of creep in reinforced plastics. Several test method reviews^{8,9,10} describe testing methods for creep, but the best review paper on creep seems to be the work of Drs. Bott and Barker¹¹ of the University of Birmingham. A more recent paper by Carlstrom and Rumberg¹² is similar to the experiments reported here. In their work, pipe sections were deflected under water at several temperatures to measure the "creep modulus." From the straight line log-log plot of creep modulus the value at 50 years could be extrapolated and used (with a suitable safety factor) for pipe design. The data gave a straight line plot, even at 75°C (165°F). Curves were also plotted for load relaxation at constant deflection.

Experimental Tests:

Testing equipment was set up for 12 specimens loaded under water at room temperature. A photograph of the apparatus is shown in Figure 9. At each of the 12 positions, a stainless steel loading plate

transferred the weight of lead blocks to the pipe specimens. The specimen dimensions were 5" wide rings cut from 24" diameter pipe. Four specimen types were used (see Table III):

- a) Hoop wound
- b) Layered RPM
- c) Blended RPM
- d) All chopped strand

Three specimens of each type were first soaked in 120°F water with 1% of a nonionic detergent at zero load for 30 days prior to transfer to the testing apparatus. The initial deflection was one inch (4.2%) or two inches (8.4%).

Deflection measurements were made at a major and minor load level for three points in each time decade (1, 2, 5, 10, 20, 50, — hours). The deflection change for the load difference between major and minor loads was used to compute the elastic modulus at each time period.

The equation used for calculation of modulus was:

$$D = 0.149 \frac{WR^3}{EI}$$

Where D is the pipe deflection, W is the load in pounds, R is the radius of the pipe, E is the hoop modulus of elasticity and I is the moment of inertia. The source of the equation was Roark's **Formulas for Stresses and Strain**, McGraw-Hill, N. Y., 1954, p. 156. This equation assumes two point loading 180° apart on a circular ring. At low deflections with a flat plate, this equation is assumed to be valid.

Experimental Tests:

The data for up to 2000 hours of testing are shown in Table IV. One specimen of each type is being continued at 4% initial deflection to 10,000 hours.

A log-log plot of the data may be seen in Fig. 10. The best straight line for each data set is extrapolated to 440,000 hours (50 years).

Discussion of Results

The data tend to confirm the theory in that the high glass hoop wound structure had a very low creep rate in comparison with layered RPM or chopped strand.

Modulus values seemingly were unchanged during the test period. In the first few hours an apparent modulus increase occurred in most specimens; it is possible this represents a residual stress condition resulting from the creep.

At 8% initial deflection the slope of the creep curve appears to be nearly parallel to the line for 4% initial deflection. This was unexpected. With higher stress (driving force) one might expect a more rapid rate of creep as occurs in metallic systems.

Plastic creep without a change in modulus will allow the underground pipe to pick up more soil support and reduce the wall stress. Thus buckling safety factors in the pipe may remain constant or even actually improve during the life-time of the structure.

Production and Applications:

Owens-Corning large diameter pipe is produced by a unique method using a filament winding machine made by the Danish firm, Drostholm. The Drostholm machines at Conroe, Texas give OCF the size range capability from 2 ft. diameter to 12 ft. diameter. Each machine has a cantilevered mandrel comprised of an endless steel ribbon which feeds onto a rotating support; the steel ribbon advances forward one ribbon width for each rotation. At the unsupported end, the steel ribbon is guided back through the hollow shaft to the beginning. Fig. 11 is a photograph of the discharge end of a Drostholm machine. In effect this machine gives OCF the capability of making a

continuous large diameter reinforced plastic pipe which can be cut to any length. By using various combinations of hoop windings, chopped strands, fillers or rib attachments, a wide variety of structures are feasible.

Current Owens-Corning Fiberglas large diameter pipe products are:

- (1) Manholes for off-street use by municipalities or industries,
- (2) Power plant cooling water intake and discharge lines, and
- (3) Effluent pipe for industrial waste or municipal sewage.

Manholes: Manholes or manways for access to sewer, water or other buried utilities have traditionally been made from fabricated brick, monolithic concrete or precast concrete. All of these are slow to install, heavy, and in some cases, find slow delivery. Owens-Corning Fiberglas manholes are available in long lengths, quick delivery and only require light installation equipment such as a back hoe. The estimated installed cost in a normal installation is about equal to conventional construction; but add muddy conditions, deep holes, or even mildly corrosive conditions and OCF manholes are much less expensive. Fig. 12 shows a part of the variety of lengths of manholes awaiting shipment from the OCF plant in Conroe, Texas. Fig. 13 shows a manhole installation.

Power Plant Piping

In large flow power plant cooling water systems, pipe line sizes often approach 12 ft. diameter. A twelve foot I.D. concrete pipe requires a 12 inch wall and weighs over three tons (6,300 lbs.) per ft. The maximum length is 8 feet.

In contrast, an Owens-Corning Fiberglas rib-wall pipe, twelve feet diameter, weighs 300 lbs per ft., comes in fifty foot lengths and in acidic water experience shows it will outlast the concrete pipe. And in addition, it costs no more and perhaps less than the concrete counterpart. Fig. 14 shows a part of a recently installed 9 ft. diameter power plant cooling water line.

Effluent Pipe

In this era of "clean up the environment," many of the waste products are acidic and react rapidly with exposed concrete or metal piping. Coatings are subject to pinholes, damage or abrasion, but Owens-Corning Fiberglas RPM pipe can withstand severe environments at modest cost. Fig. 15 shows several 40 ft. sections of 36 inch pipe used for effluent lines at a large paper company.

AGNAR GILBU

A chemical engineering graduate in 1962 at Bergen, Norway, he was engaged in alkyd and polyester resin development for Joton A/S; later he worked at the Central Institute for Industrial Research studying influences of food products on plastics and vice versa.

In 1964, in a research program at the Free University of Berlin, he studied plastics/paper combinations.

From 1966 to 1971, Mr. Gilbu was project manager of the plastics division of Vera Fabrikker A/S Norway, principally working in FRP pipe and tanks.

In 1971 he joined Owens/Corning Fiberglas Corporation where he is Process and Product Development Manager at the Conroe, Texas plant of the NCP Division.

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J. ALBERT ROLSTON

With a B.S. and M.S. in chemical engineering from North Carolina State University (1941 and 1952), Mr. Rolston has had a varied career in mineral processing, physical metallurgy teaching and research, ultra-high speed rotation research and filament winding. His experience in filament winding began in the late fifties at the University of Virginia with the application of filament wound structures to high speed rotating devices. From 1962 to 1964 he was manager of filament winding research at Spaulding Fibre Co., Tonawanda, N. Y.

In 1964 he joined Owens/Corning Fiberglas Corp. in Granville, Ohio as a Senior Research Engineer in filament winding reinforcements development. His current position is Project Manager for Large Diameter Pipe Development.

Mr. Rolston holds a P.E. license (Virginia) and has a number of publications in filament winding and reinforced plastics, including 10 years (1960-1970) as editor and publisher of Quiksort Reinforced Plastics Abstracts. He holds committee offices in AICHE (Materials Engineering Div.) and is a member of NACE.

TABLE I
CONSTRUCTION OF SAND FILLED LAMINATES

Sand	Minus 8 mesh/plus 200 mesh (masonry sand)
Continuous Glass	OCF Type 30 Roving
Chopped Glass	OCF Spray-Up Roving
Polyester Resin	OCF Isophthalic Polyester (Gelled at RT and cured 1 hr. at 235° F)

<u>wt % of constituents</u>				
<u>Type</u>	<u>Sand</u>	<u>Continuous Glass</u>	<u>Chopped Glass</u>	<u>Resin</u>
I	0	11.7	13.2	75.1
II	9.6	11.1	12.6	66.7
III	18.9	10.5	11.6	59.0
IV	25.7	8.8	9.7	55.8
V	34.9	6.2	15.8	43.1

TABLE II

SHORT TERM PROPERTIES OF SAND-FILLED FLAT PANELS

Strength data in thousands of psi

Modulus data in millions of psi

<u>PROPERTY</u>	<u>CONSTRUCTION TYPE</u>				
<u>HOOP DIRECTION*</u>	I	II	III	IV	V
Tensile strength	21.1	16.8	15.7	13.5	12.0
Tensile Modulus	1.90	1.75	1.81	1.81	2.45
Compressive Strength	30.6	26.7	31.9	28.4	26.0
Compressive Modulus	1.28	1.28	1.47	2.11	2.46
Flexural Strength	21.8	28.1	21.8	24.9	--
Flexural Modulus	1.26	1.36	1.26	1.84	--
<u>AXIAL DIRECTION*</u>					
Tensile Strength	9.0	6.1	6.6	6.2	8.4
Tensile Modulus	1.34	1.32	1.45	1.50	2.08
Comp. Strength	23.4	22.5	25.9	21.2	--
Compressive Modulus	0.92	1.04	1.23	1.45	--
Flexural Strength	9.6	8.0	11.2	12.7	--
Flexural Modulus	0.87	0.89	1.29	1.33	--

* Hoop direction is parallel to continuous strands

* Axial direction is perpendicular to continuous strands

TABLE IIICOMPOSITION OF 24 INCH PIPE SECTIONS FOR CREEP TESTS

<u>Type of Structure</u>	<u>% Fiber Glass</u>	<u>Fiber Glass Form</u>	<u>% Sand</u>	<u>% Resin</u>
Hoop Wound	70	Continuous	None	30
Chopped strand	25	Chopped	None	75
Layered RPM	30	Continuous	35	35
Blended RPM	25	Chopped	35	40

TABLE IV

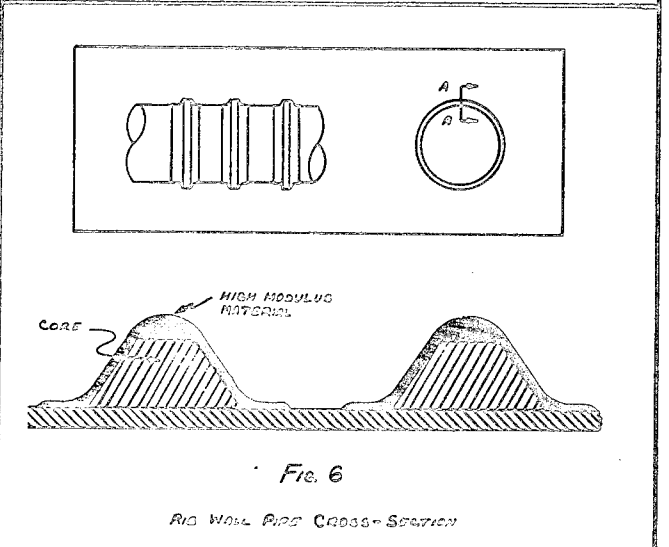
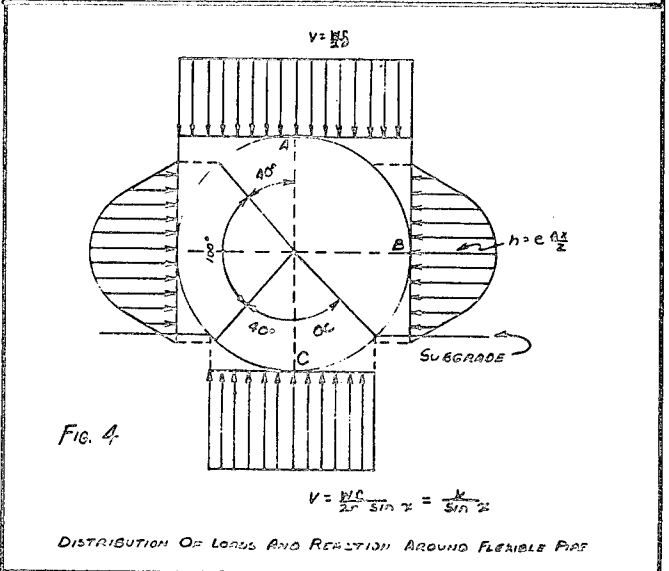
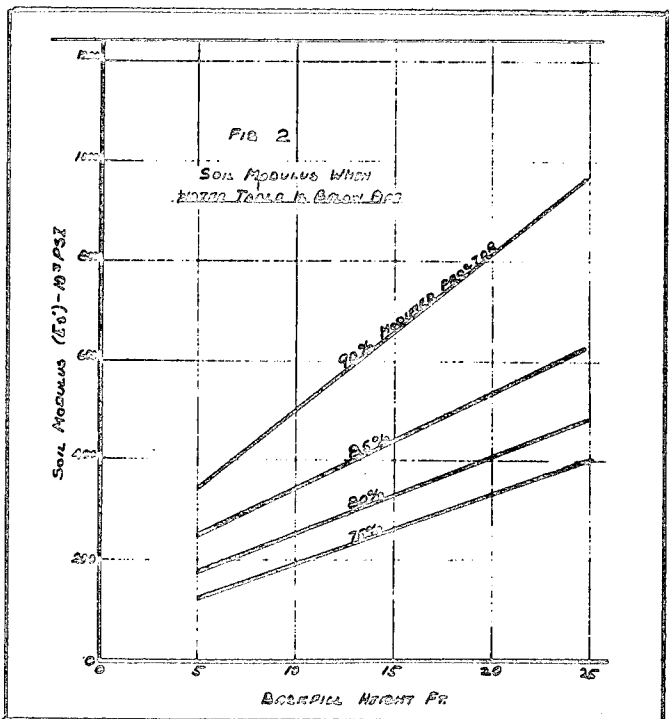
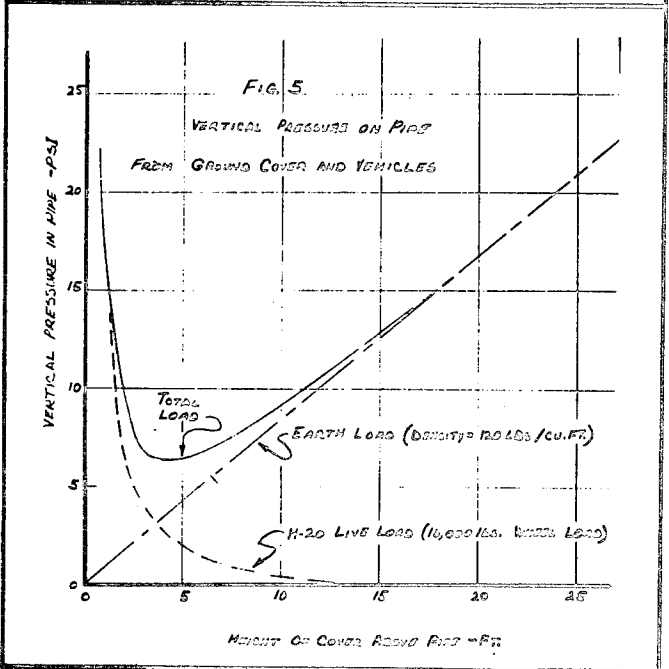
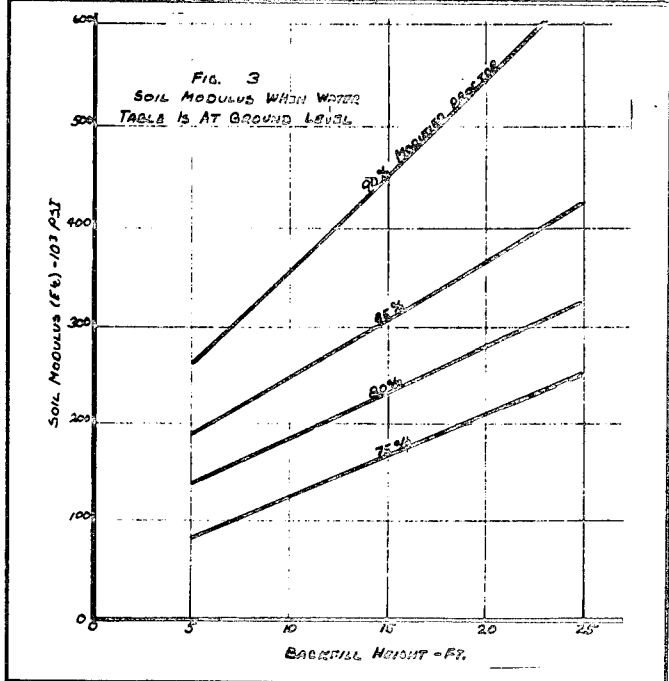
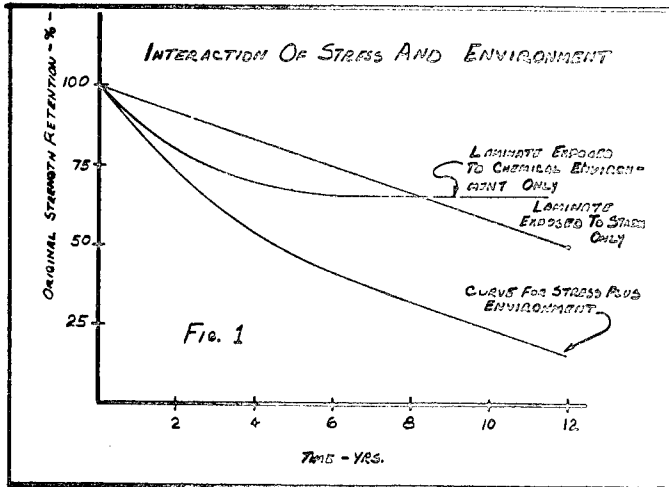
CREEP TESTS OF 24 INCH DIAMETER PIPE

Conditions: Flat Plate Loading

Pipe Submerged Under Water at Room Temp. (70-80°F)

- - - HOURS OF TEST - - - -

SPECIMEN AND PROPERTY (Ave. of 3 Points)	0.1	1.0	2	5	10	20	50	100	200	500	1000	2000
<u>Hoop Wound</u>												
Deflection (%)	4.21	4.26	4.23	4.24	4.26	4.29	4.30	4.33	4.34	4.36	4.38	4.54
Modulus (10 ⁶ psi)	4.36	4.30	4.53	4.63	4.53	4.53	4.68	4.38	4.58	4.58	4.58	4.58
<u>Chopped Strand</u> (no filler)												
Deflection (%)	4.14	4.27	4.31	4.40	--	4.45	4.53	4.59	4.67	4.72	4.79	--
Modulus (10 ⁶ psi)	1.17	1.21	1.24	1.22	--	1.24	1.26	1.25	1.25	1.25	1.26	--
<u>Layered RPM (Low Load)</u>												
Deflection (%)	4.18	4.36	4.40	4.48	4.54	4.55	4.65	4.69	4.77	4.84	4.91	5.14
Modulus	1.25	1.33	1.32	1.33	1.38	1.36	1.38	1.36	1.40	1.34	1.36	1.33
<u>Layered RPM (High Load)</u>												
Deflection (%)	7.51	8.26	8.44	8.59	--	8.86	9.00	9.13	9.23	9.32	9.53	--
Modulus (10 ⁶ psi)	1.14	1.24	1.24	1.23	--	1.22	1.22	1.23	1.24	1.23	1.25	--
<u>Blended RPM (Low Load)</u>												
Deflection (%)	4.18	4.41	4.52	4.56	4.63	4.75	4.84	4.88	4.93	5.01	5.18	5.35
Modulus (10 ⁶ psi)	0.99	1.15	1.21	1.17	1.19	1.19	1.19	1.22	1.20	1.19	1.15	1.13
<u>Blended RPM (High Load)</u>												
Deflection (%)	8.48	8.80	9.00	9.15	9.65	9.64	9.82	9.95	10.19	10.40	10.70	--
Modulus (10 ⁶ psi)	1.08	1.23	1.22	1.22	1.20	1.14	1.20	1.18	1.19	1.19	1.21	--



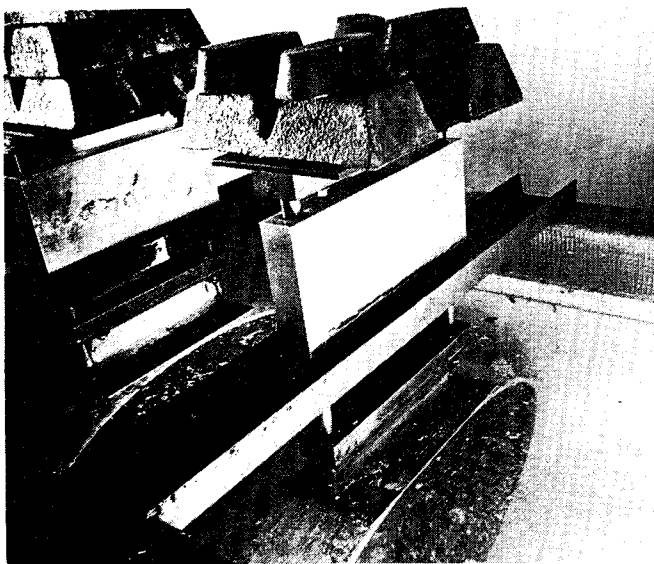
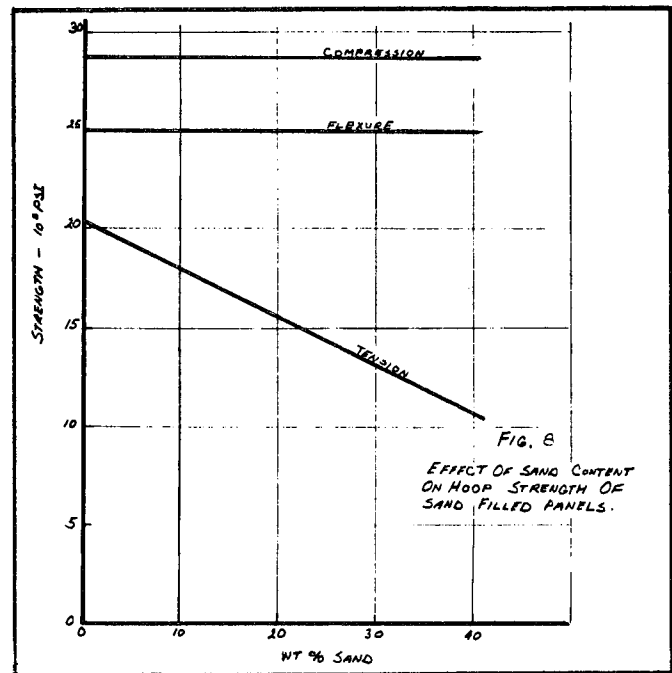
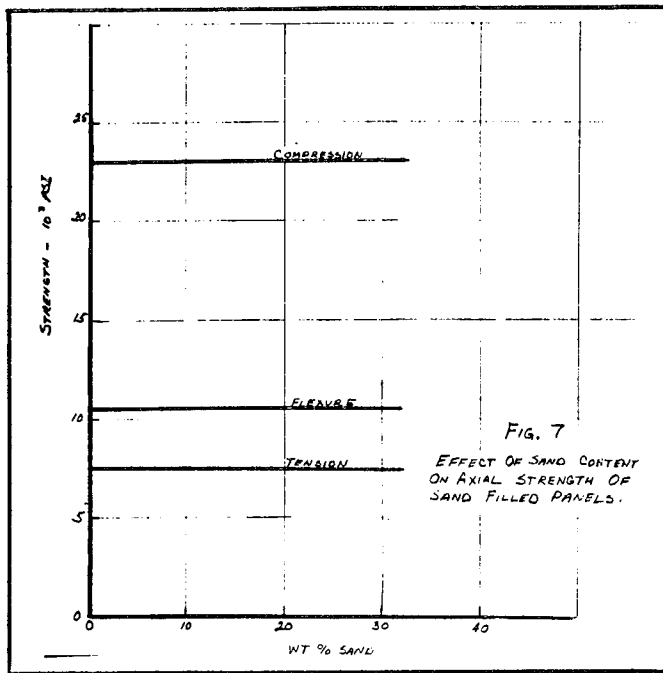


Fig. 9. 24 Inch Diameter Pipe Specimens In Creep Testing Apparatus.

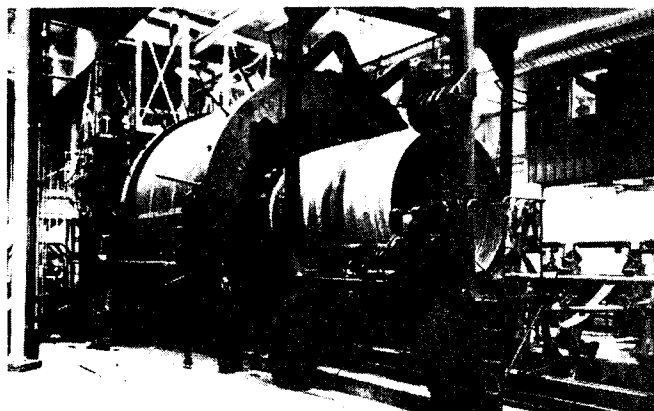
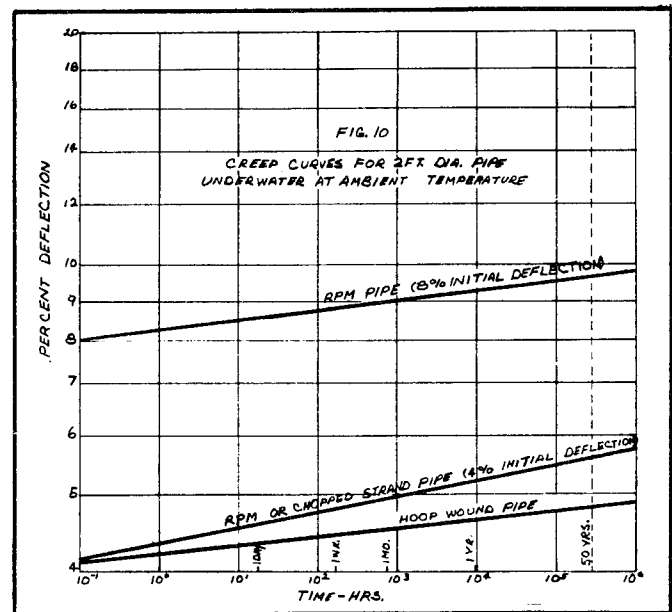


Fig. 11. Discharge End of Drostholm Machine Showing Rib Wall Pipe Section Emerging From Oven.

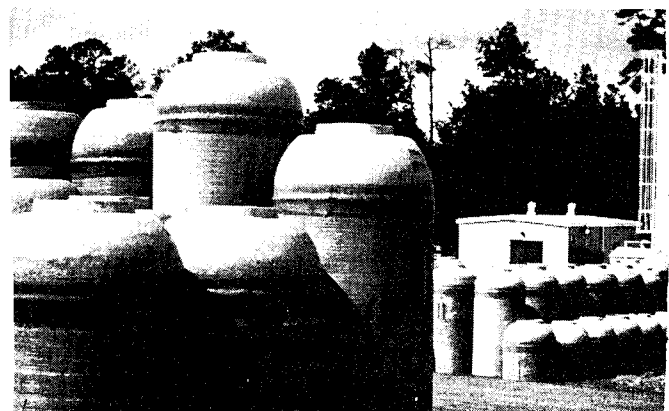


Fig. 12. Manholes Ready For Shipping.

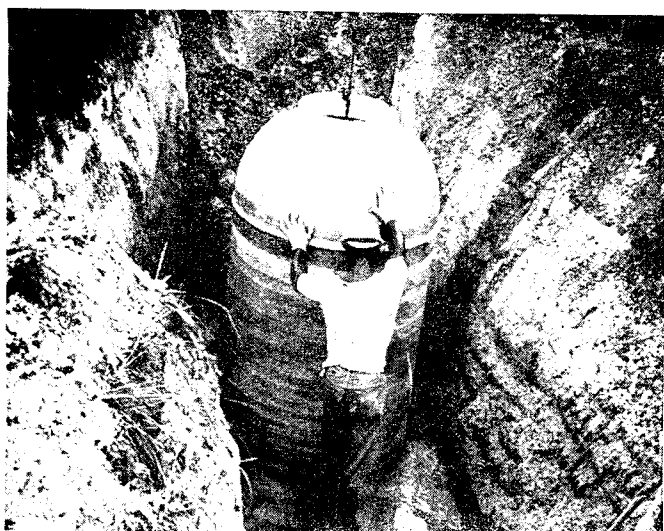


Fig. 13. Installation Of An Owens-Corning Fiberglas Manhole.

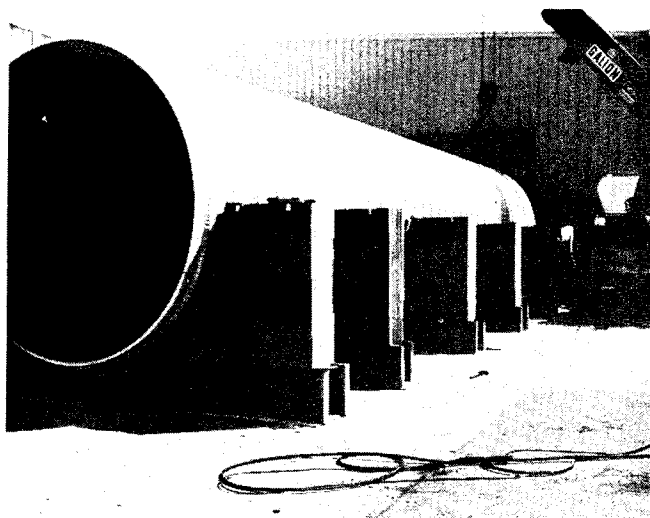


Fig. 14. Testing A 50 Ft. Length of 9 Ft. Diameter Rib-Walled Pipe.

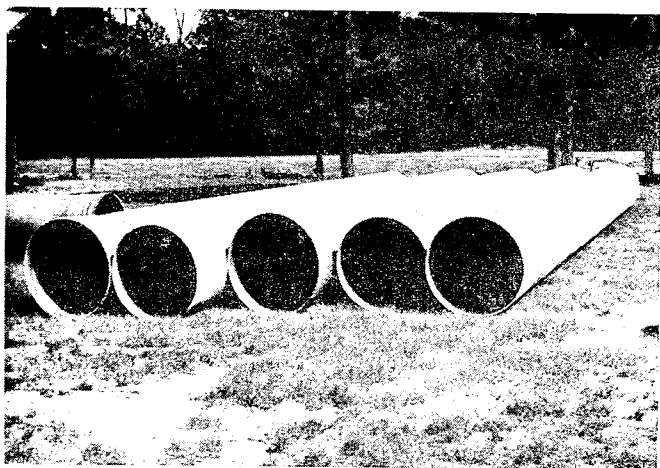


Fig. 15. Sections of 3 Ft. Diameter By 40 Ft. Long Effluent Pipe Ready For Shipping To A Major Paper Manufacturer.

SPIRALLY WOUND FIBER GLASS REINFORCED PLASTIC PIPE FOR CONDENSER CIRCULATING WATER APPLICATIONS

by

T. C. POPE, JR.*

ABSTRACT

This is the first installing in the world of 108-inch diameter FRP pipe for condenser circulating water application at a large electric power plant. This paper discusses the bases underlying the decision to use FRP pipe in this application, design parameters selected, testing, installation procedures, joint design, and unique pieces included in the installation.

In late 1969 the Orlando Utilities Commission decided to embark upon a major expansion of its Indian River Power Plant which then consisted of one 95 MW and one 225 MW generating unit located on the brackish Indian River near Cape Kennedy, Florida. To provide for the ever increasing demand for electric energy in the rapidly expanding area of Orlando, and taking into account the impact of Walt Disney World, it was determined that a 325 MW unit should be installed.

In order to maintain the outstanding architectural treatment of the existing building and still accommodate this larger unit, the basement floor of the addition had to be lowered seven feet. Because of a tight construction schedule, ideas were considered which would alleviate having to construct a circulating water tunnel under the basement floor slab. During these considerations it was learned that large diameter FRP pipe was becoming available. After investigating the corrosion resistance, the relative light weight, flow characteristics, and strength of the basic pipe and the welded joints, it was concluded that such a system could be designed to be hung on pipe hangers similar to other plant piping systems (see Figure No. 1).

Preliminary estimates indicated a minimum savings of \$ 20,000 and a reduction in construction time of at least five weeks on the in-plant circulating water lines.

Having determined the desirability of the in-plant system incorporating FRP pipe, consideration of utilizing the same pipe outside was made. There appeared to be several advantages in its use outside also. The corrosion resistance, light weight, strength, and long lengths were all advantages.

Regardless of the type pipe used, the depth of burial, shoring of the trench, and dewatering of the excavation were the same; therefore, the system which could be installed most expeditiously would minimize these installation costs.

The FRP pipe was available in 50 foot lengths, requiring only 60 field joints in the 2,500 feet of pipe required. An alternate piping system using 16 foot sections would have required 166 field joints.

These longer lengths were actually easier to handle since nine foot diameter FRP pipe weighed only 482 lb/ft compared to 3,200 lb/ft for concrete pipe. Therefore, a 50 foot section of FRP pipe

weighs only 21,100 lb. compared to 51,200 lb. for a 16 foot section of concrete pipe. This meant much lighter equipment and easier handling in the field (see Figure No. 2).

The pipe had to cross four-laned U.S. Highway No. 1 twice since the plant is west of the highway and the Indian River is east of the highway. The Florida Department of Transportation, not being familiar with FRP pipe, at first insisted that a sleeve be placed under the highway and the pipe installed therein. After showing them that the FRP pipe was many times stronger than the sleeve proposed, they agreed to our direct burying the FRP pipe under the highway.

Since this is the first installation of its kind in the world (to the knowledge of all involved), an unusually high safety factor and special care has gone into this installation. The design of the pipe itself has been ultra conservative to the extent that the safety factor based on yield strength is a high multiple over and above the 10 to 1 safety factor inherent in the basic design equations.

The actual design requirements for the 108 inch pipe are: (1) hoop ultimate strength, 87,400 psi; (2) hoop yield strength, 33,780 psi; (3) hoop modulus of elasticity, 3.8×10^6 psi; (4) axial ultimate strength, 22,700 psi; (5) axial yield strength, 13,280 psi; (6) compressive ultimate strength, 52,000 psi; (7) compressive yield strength, 31,200 psi; (8) modulus of rupture, 135,400 psi; (9) design load (W_c), 878 psi; (10) horizontal deflection, 4.4 percent; (11) tensile stress at design pressure (45 psi), 1,944 psi; (12) bending stress at 5 psia and design deflection, 1,495 psi. From this data, I am sure you will conclude that the pipe system is very conservatively designed since the design pressure is 5 psia to 45 psig and normal operating pressures will not exceed 10 psig.

To verify the design parameters, the supplier was required to perform standard laboratory stiffness tests on a random sample cut from a piece of the pipe. The ASTM test, "External Loading Properties of Plastic Pipe by Parallel-Plate Loading," was followed to determine the load versus deflection characteristics of the pipe. This particular test generates a pipe stiffness factor which is then used in the Spangler equation for flexible conduit to solve for the permissible earth overburden at a given pipe deflection and with the specified design parameters governing the anticipated trench burial conditions.

The pipe is constructed using a 65 degree filament helix angle over-wind and a dual resin system with Atlat 4010A flexible blend polyester resin for the 100 mil thick inner liner and Reichhold's 33-402 isophthalic resin for the structural wall to give minimum wall thickness of 1-1/8 inches (see Figure No. 3).

A twelve inch section cut from a random length of pipe was selected for testing. It was instrumented with six inch long strain gauges on both the inside and outside of the pipe. The strain gauges are not a part of the ASTM test procedure but were used to obtain additional information.

The testing proceeded by loading the pipe to a scheduled vertical deflection, recording the horizontal deflection and reading each of the eleven strain gauges. Readings were taken at the following deflections: 1, 2, 3, 5, 8, 10, 15, 20, 25, and 30 percent. Even though at 30 percent deflection (32 inches) there was no indication of structural wall damage or internal lining crazing, it was decided not to deflect further since the horizontal deflection had exceeded the framework and could not be measured. There was concern over the safety of the college students used to observe the readings because of the tremendous potential energy now stored in the ring and the chance that it might slip out of the rig (see Figure No. 4). At 30 percent deflection the vertical measurement was down from 9 feet to 6 feet 2 inches and the horizontal extended to more than 11 feet. The strain in the liner exceeded the design strain by tenfold with no evidence of cracking or crazing.

As a matter of interest, when the load was removed, the ring section returned to within 1-3/8 inches of its original shape, and by the next morning the ring had returned to its exact original

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roundness which indicates the ability of the pipe to take an enormous range of deflection without suffering structural damage or exceeding the elastic limit of the material. This assures reliability even if the installer does not achieve the specified degree of compaction around the pipe and consequently overloads the pipe as backfill is being placed over it. At the design deflection of 5 percent the load was 804 lb. and the stiffness factor was calculated to be 229,520 psi.

Once we decided to use FRP pipe for this installation, several unique concepts were incorporated; one being a 108 inch diameter by 50 foot long venturi section which will be a part of the pipe hung in the basement (see Figure No. 5). It was constructed in the classic manner as invented by Clemens Herschel and will follow Bernoulli's theorem where the difference between the pressure at the throat and that upstream is proportional to the square of the velocity of the water. This section will not be calibrated since we know of no facility which can calibrate up to 315,000 gpm. However, we intend to establish base conditions with all of the equipment new and clean and then will be able to tell if any deterioration occurs.

Another interesting piece is the trifurcation at the pumping station where the three pump discharges tie into a single line to the condenser. This piece was made at the factory as a single section, thereby greatly reducing the field labor.

Another innovation incorporated in the buried pipe is the design of the step-tapered joints which are welded from the inside of the pipe. This special joint design helps facilitate the installation by being out of the weather and away from the dirt and debris of the trench. A special rig was provided to hold the splice material in position on the overhead section of the joints (see Figure No. 6).

Even though the installation is not 100 percent complete at this time, it is evident to us that the installed cost of the FRP piping system is less than comparable systems. This is primarily due to the easier handling, longer sections, and the speed of laying which reduces the overall construction time.

This corrosion resistant piping system will be incorporated with a condenser using copper-nickel water boxes, tube sheets, tubes and butterfly valves to provide what we anticipate to be a corrosion free system needing no cathodic protection. Incorporated into the condenser design is the MAN tube cleaning system which utilizes a brush in each tube and a plastic basket on the ends of each tube so that the tubes are automatically cleaned each time the condenser is backflushed. We anticipate that we will eliminate many of the corrosion and erosion problems we have experienced on this salt water application.

This unit is scheduled for operation in the summer of 1973; therefore, we cannot relate any actual operation experience, but we are all confident that this installation will lead the way to the future in the application of FRP pipe to circulating water systems.

REFERENCES:

1. Black & Veatch, Consulting Engineers, "Circulating Water Piping, Specification 5268 ME-8A," 1971.
2. CorBan Industries, "Parallel-Plate Loading Test on 108" Diameter Filament-Wound Pipe," 1972.

T. C. POPE, JR.

Mr. Pope is thirty-nine years old, a native Floridian. Was first employed by Orlando Utilities during summer vacations while a student at the University of Florida. After receiving a BSME degree from U of F, serving three years in the U.S. Army Ordinance Corps at Aberdeen Proving Grounds, and returning to U of F for two years of study for a masters degree in Business Administration and Economics, became fully employed by the Orlando Utilities Commission in 1959 as Results Engineer at its new Indian River Plant. Became Plant Superintendent in 1964, and has held present position since 1967. Is a Registered Professional Engineer and presently is Chairman of the Southeast Region, National Association of Corrosion Engineers.

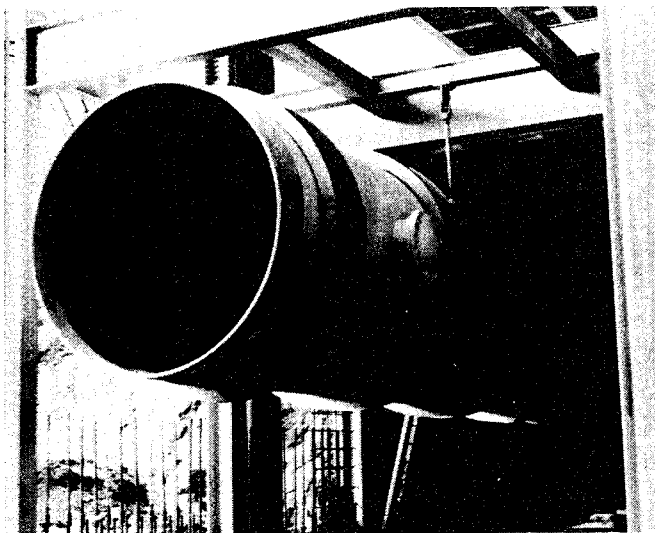


Figure No. 1: Suspended Pipe in Basement Area

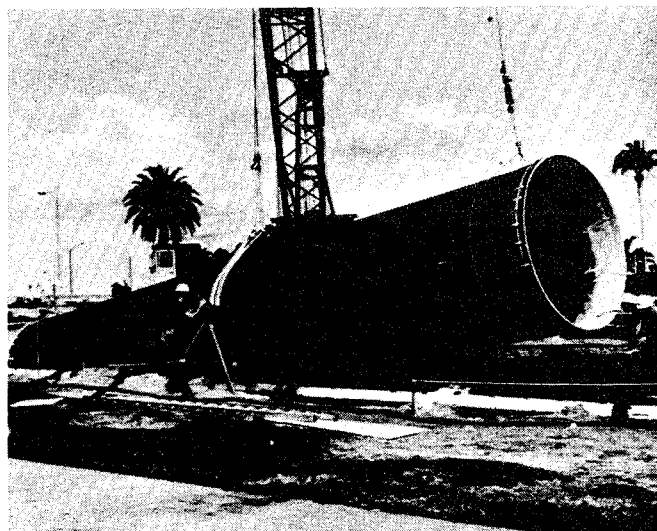


Figure No. 2: Placing 50-foot Sections in Trench

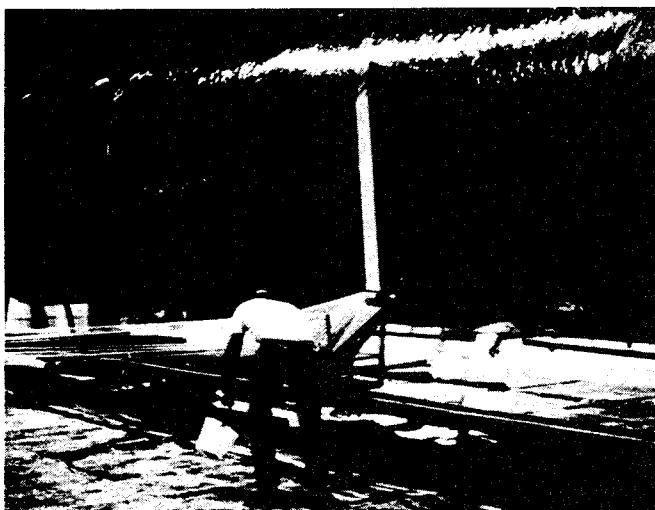


Figure No. 3: 65° Helix Winding Operation

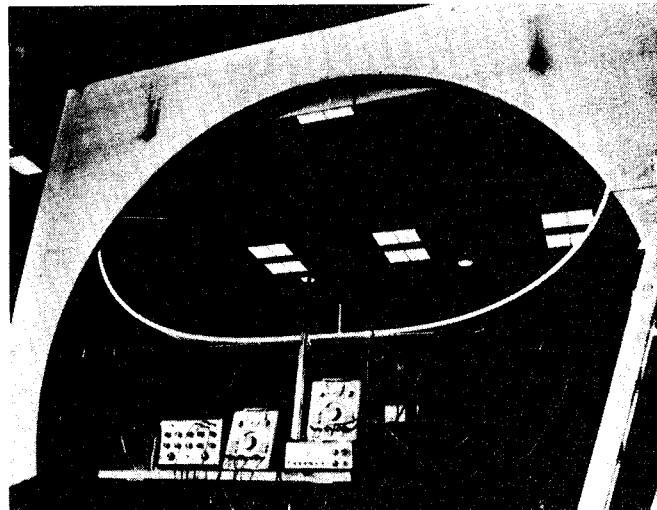


Figure No. 4: 30% Deflection Test

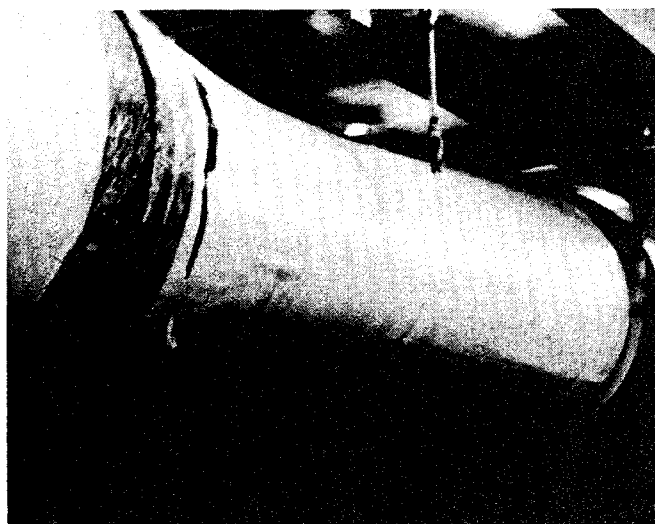


Figure No. 5: Venturi Section

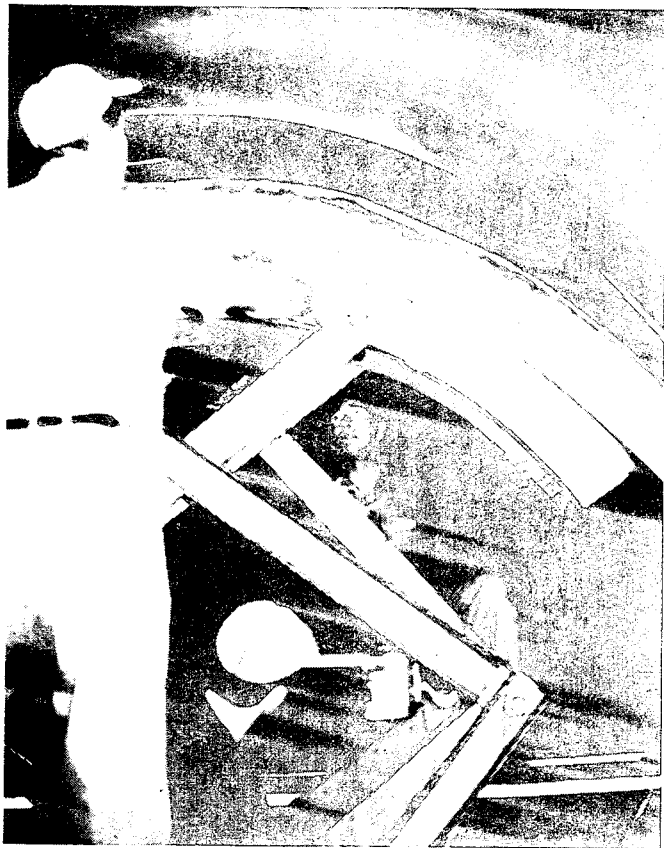


Figure No. 6: Overhead Welded Joint Support Rig

REINFORCED THERMOSETTING RESIN PIPE IN CORROSIVE INDUSTRIAL SERVICE

by

ROYCE A. CURRIEO, P.E.*

ABSTRACT

Historically, the FRP piping designer has been forced to compromise between mechanical, thermal, and corrosion resistance properties in the resin matrix of his piping system. If he chose a resin which had substantially better than average mechanical or thermal properties, he invariably had to sacrifice chemical resistance. By the same token, if the designer specified a resin with excellent corrosion properties, his piping system had serious mechanical or thermal service limitations.

FiberCast Company approached this dilemma from the standpoint of using two completely different thermosetting resin systems in the same pipe. The first resin system was formulated strictly for its chemical service properties, and this material was used for the internal liner. The second resin was designed to maximize mechanical and thermal properties. This material was used to impregnate the glass fiber reinforcement to form a structural "shell" which affords good mechanical strength at both ambient and elevated temperatures.

The resulting pipe was designated FIBERCAST CL-2030, and it is used in a wide variety of severe corrosion services within the CPI. This paper proposes to describe several of these applications, and the manner by which CL-2030 pipe has met the corrosion resistance requirements.

— — — —

The practice of lining piping systems with materials which are designed to resist chemical attack has long been established. Glass lined steel pipe has been commercially available for several years. More recently thermoplastic lined pipe has been introduced, and it has received fairly wide acceptance in the Chemical Process Industry.

Piping systems manufactured from reinforced thermosetting resins lend themselves very readily to the lining concept. Even the use of different resin systems in the liner, as opposed to the resin system used in the reinforced matrix, has gained wide spread acceptance. For example, it is not at all uncommon to find vinyl ester or bis-phenol A polyester corrosion resistant liners in isophthalic polyester reinforced pipes. Moreover, thermoplastic liners in tandem with a reinforced thermosetting resin structural matrix have received a measure of acceptance within the CPI.

The thermoplastic liner within the reinforced thermoset structural body has many advantages in chemical service. Within the thermal limitations of the material, the thermoplastic liner can be tailored to the service. Impact blows which would render most thermosetting resin liners unserviceable are easily absorbed by the thermoplastic liners. Moreover, the thermoplastic liner does not crack upon enlargement when the piping system is subjected to internal pressure.

From a manufacturing standpoint, the thermoplastic liner leaves

much to be desired. It is difficult to achieve a good adhesive bond at the thermoset/thermoplastic interface; the thermoplastic sheet stock is somewhat troublesome to handle, particularly in the heavier gauges; and from FiberCast's standpoint, it would be very difficult to include a thermoplastic liner in a filament wound pipe, and virtually impossible to line a centrifugally cast pipe with thermoplastic sheet or tube stock.

FiberCast Company embarked on an R & D project to develop a resin system based on vinyl ester resin which would incorporate the desirable features of both thermoplastics and the commercially available thermosetting resins commonly used in the manufacturing of Fiberglass Reinforced Plastic pipe. This resin was to be used in the liner of a centrifugally cast pipe whose reinforced structure was to be a mat and woven roving construction in a vinyl ester resin matrix.

The pipewas required to be serviceable in a wide variety of highly corrosive applications. We were particularly concerned that the piping system be serviceable in phosphoric acid, chlorine and chlorine water, strongly caustic liquors, hydrochloric and sulfuric acids, and the various brine liquors commonly used in the CPI.

At this writing, one-half million feet of CL-2030 pipe is installed in services ranging from hydrochloric acid to caustic soda, and sodium hypochlorite to wet chlorine gas.

The CL-2030 liner resin system is a flexible copolymer of vinyl ester. It exhibits 25% elongation at tensile failure, and this property causes the liner to behave similarly to the inner tube in a tire or the bladder in a football when the pipe is subjected to internal pressure. The flexibility of the liner enables the pipe to withstand impact blows which would severely damage a liner manufactured from the conventional thermosetting resin. Moreover, the high degree of pliability of the liner precludes pipe failure by "weeping", and when the ultimate internal pressure is exceeded, the pipe fails structurally.

In the manufacture of CL-2030 pipe, fiberglass woven roving or fabric and chopped strand mat are wrapped about a wrapping mandrel and loaded into the casting tube. The tube is rotated to force the glass reinforcement to assume the configuration of the casting tube I.D., after which the tube is stopped and the mandrel is removed. The casting tube is again rotated and the thermosetting resin is introduced to the mold. The "shell" formulation, which is vinyl ester formulated to give a serviceable temperature of 200° F. is pumped from a central storage tank with a metering pump. The resin is expelled through a nozzle, which the operator uses to distribute the resin evenly throughout the length of the casting tube. After the shell formulation has been charged the liner resin is introduced to the tube, again using a metering pump. The glass/resin charged is subjected to centrifugal forces in the range of 100 g's during the processing cycle. When the cycle has timed out, the tube stops turning, the pipe is removed from the casting tube, trimmed and inspected.

The following Table describes a few interesting corrosion applications in which CL-2030 pipe is presently in service:

Service	Temperature	Pressure	Time in Service
SO ₂ and SO ₃ Vapors	150°-200° F.	6" Water Vacuum	1.5 yrs.
12%-15% HF	180°-220° F.	Atmospheric	1.5 yrs.
Sewage Sludge and Treatment Chemicals	110° F. max.	60 psi	2 yrs.
Alum	120° F. max.	75 psi	1 yr.
37% MgCl	140°-150° F.	100psi	1 yr.
Ammonium Nitrate	120°-160° F.	25 psi	2 yrs.
50% ZnCl	140° F.	50 psi	1 yr.
50% Caustic Soda	150° F.	50 psi	1 yr.

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A truly universal solution to industrial corrosion problems has not been devised, and very likely never will be. It is not surprising that CL-2030 piping systems have their limitations also. Broadly, CL-2030 pipe should not be used to convey chlorinated hydrocarbons and highly concentrated solutions of strongly oxidizing acids as picric acid, nitric acid, and chromic acid. Diluted concentrations of the oxidizing acids at reduced temperatures can be transported successfully in CL-2030 piping systems.

Within the pipe's service limitations, CL-2030 has established itself as an effective solution to many corrosion problems within the CPI. In fact, some of the chemical services in which CL-2030 pipe has been used successfully have been surprising. Nevertheless, it is not good practice to utilize CL-2030, or for that matter, any other FRP piping system in chemical services for which it is not specifically rated. If there is any doubt whatsoever about the application, and in those cases where the chemical service is not specifically listed in the manufacturer's literature, some doubt would have to exist; by all means the manufacturer's Engineering Department should be contacted for specific recommendations.

ROYCE A. CURRIO

Royce A. Currieo is a Registered Professional Engineer in the State of Oklahoma. He graduated from Oklahoma State University in 1959 with a B.S. degree in Chemical Engineering. He has been with Fibercast Company in the R & D group as a Product Development Engineer since 1968. He is a member of Sigma Tau Engineering Honor Society, MENSA, Society of Plastics Engineers, American Institute of Chemical Engineers, Oklahoma Society of Professional Engineers, and the National Society of Professional Engineers.

EPOXY FIBERGLASS PIPE AND ITS APPLICATION

by

D. W. BORDNER*

ABSTRACT

The benefits which epoxy fiberglass pipe offer to the end user are reviewed in detail and typical end use applications discussed. Also included in this presentation is a cost comparison of alternate piping systems based on a present value analysis.

INTRODUCTION

Today epoxy fiberglass pipe is being used as an alternative to steel, stainless steel, and rubber-lined steel pipe in hundreds of industrial applications. Other applications include steam condensate, industrial wastes, fire protection systems and pipelines for the transportation of petroleum products. Installations are both below ground and above ground, in the ocean and on board ship. Epoxy fiberglass pipe can be considered wherever its resistance to interior and exterior corrosion, its light weight, its ease of assembly, its low thermal conductivity, and its non-contaminating properties offer a significant economic advantage over other engineering materials.

METHOD OF MANUFACTURING

Epoxy pipe is produced today using either the centrifugal casting or the filament winding process. In the centrifugal casting process the epoxy resin and glass reinforcement is applied to the interior of a mold which is rotated and heated, subsequently polymerizing the resin system.

Filament-wound pipe is produced by wrapping continuous strands of fiberglass roving or roving tape around the outside of a mandrel in a predetermined pattern, under controlled tension. The roving may be saturated with a liquid epoxy resin or preimpregnated with partially cured resin. Subsequent polymerization of the resin is obtained by the application of heat. In addition to pipe, a complete line of filament-wound fittings made to ANSI dimensions is available.

While these two manufacturing processes produce pipe that is significantly different in construction and physical properties, the benefits which they offer are generally the same. Let's take a closer look at a few of the benefits which fiberglass reinforced epoxy pipe offers the end user.

BENEFITS

Corrosion Resistance

Epoxy Fiberglass Pipe is corrosion resistant both inside and out. It will handle a wide range of corrosive chemicals including a few that even rubber-lined steel cannot. These chemicals include salt solutions, organic acids, inorganic acids, petroleum products, and solvents at varying concentrations and temperatures. In addition, it can be

buried directly in hot soils without the fear of galvanic corrosion. Costly cathodic protection, possibly detrimental to existing piping, is not required.

Light Weight

Epoxy Fiberglass Pipe is light in weight. It weighs approximately one-sixth that of Schedule 40 carbon steel pipe of the same diameter. What does this weight savings mean to the end user? It means lower transportation costs and increased ease of assembly. For example, a 20-foot length of six-inch Bondstrand® pipe weighs approximately 60 pounds and may be easily handled by one man. A 20-foot length of six-inch Schedule 40 steel pipe would weigh 397 pounds and would require mechanical equipment to be moved.

Easy to Install

Fiberglass pipe and fittings can be economically and reliably installed in the field. Only light weight, easy-to-use equipment is required to cut the pipe, prepare the surfaces to be joined, and cure the adhesive bonded joints. Quite often an electric saw with an abrasive wheel, a flapper sander mounted on a drill motor, and a power-driven pipe shaver are all that is needed to prepare the pipe for assembly.

The adhesive bonded joints may be cured either at room temperature or preferably by the application of external heat. When properly assembled and heat cured, the adhesive bonded joints are as strong as the pipe.

Non Contaminating

Fiberglass products are non-contaminating. They are used to prevent contamination by metallic ions wherever high purity chemicals are required. Epoxy Fiberglass Pipe has been installed to handle the high purity water used in nuclear reactors and in the manufacture of electrical components, as well as jet fuel for the military.

Safe for Food Processing

A specialized use of epoxy fiberglass pipe is in the food processing industries, where it often replaces stainless steel products. For these application areas, resin systems which meet current federal regulations for repeated use in transporting food are available.

Low Thermal Conductivity

The thermal conductivity of fiberglass pipe is approximately 2.3 BTU/hr. ft.2°F./in. This means that less heat input is required to maintain a fixed temperature. This is particularly important in the design of steam condensate return or hot water heating systems where the heated medium is being pumped a considerable distance.

For those applications where additional insulation is required, factory-insulated products are available. Because of its excellent thermal properties and its resistance to corrosion inside and out, insulated fiberglass pipe is being widely used today in underground heating systems.

Non-conductive

Epoxy Fiberglass Pipe is non-conductive and may be buried in corrosive soils without the fear of galvanic corrosion. Steel piping systems require additional exterior protection before being used for this application. For this reason, fiberglass pipe is used in many of the underground piping systems being installed today.

Competitively Priced

Fiberglass pipe is competitive with Schedule 40 carbon steel pipe on an installed cost basis and is considerably lower in cost than other engineering materials offering equivalent chemical resistance and service life. When considering a fiberglass pipe system, an economic

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*A proprietary FRP pipe manufactured by the Ameron Corrosion Control Division, Brea, California.

analysis that takes into consideration the initial installed cost, annual maintenance cost and the estimated life should be used to develop the total present value of each alternative.

WHERE EPOXY FIBERGLASS PIPE IS USED

Because of these many benefits which epoxy fiberglass pipe offers, it is today being used in countless industrial applications. Several of these are reviewed below:

Steam Condensate

Epoxy Fiberglass Pipe is being used extensively for the handling of hot water and steam condensate in industrial, commercial, and military applications. Photograph No. 1 shows a buried hot water system being installed at Stanford University. This particular system supplies hot water to a student housing complex. In another application at Stanford University, epoxy filament-wound pipe and fittings are used to return steam condensate to a boiler several thousand yards away. The filament-wound fittings were used because of the high thermal stresses which are commonly encountered in this service. This is a very demanding application for any piping system. Steel pipe, when used for this application, must be wrapped or coated to prevent exterior corrosion and protected on the interior by the addition of corrosion inhibitors to the water. Even with such protection, steel piping systems frequently fail within a period of five years or less in this environment. In several installations, epoxy pipe has been used for over 10 years in steam condensate service without any evidence of interior or exterior corrosion.

In many applications, such as in this central heating system at Stanford University, the fiberglass pipe is insulated with either fiberglass insulation or polyurethane foam housed in a fiberglass or PVC shell to prevent moisture from entering the insulation and to protect the insulation from mechanical abuse.

Jet Fuel

Photograph No. 2 shows fiberglass pipe being installed in a jet fuel storage and transfer system at Hickam Air Force Base in Hawaii. In this installation over 10,000 feet of six- and ten-inch epoxy pipe was installed below ground level. Fiberglass pipe was chosen over stainless steel because of its lower cost, ease of installation, and resistance to corrosion. This particular piping system was assembled alongside the trench and then rolled onto 2 x 4's placed across the trench. To place the pipe in the trench, the line was lifted at one end, the loose 2 x 4's removed, and the pipe lowered into the ditch using light-duty lifting equipment. It required less than three hours to lower 1,000 feet of fiberglass into place.

Photograph No. 3 shows an epoxy fiberglass piping installation on a Navy Fuel Barge. In this particular installation, the fiberglass pipe was prefabricated at the factory and then bolted together at the job site. The fiberglass epoxy pipe was used because of its resistance to salt water corrosion and its light weight.

Fire Water System

Epoxy fiberglass pipe is ideally suited for use in fire service systems. Photograph No. 4 shows such a system installed in a petroleum complex in South America. In this one installation, over 100,000 linear feet of eight-, 10- and 12-inch epoxy pipe was installed. The system carries brackish water and operates at pressures up to 180 psig.

Industrial Wastes

Today thousands of waste products produced by industry are being successfully handled in epoxy fiberglass pipe. Take the waste recovery system shown in Photograph No. 5, for example. This piping system handles salt water with traces of sour crude oil at pressures up to 130 psi and temperatures of 180°F. Schedule 40 carbon steel pipe lasted less than one year in this service. After seven years of continuous use the initial installation of fiberglass pipe is still performing satisfactorily.

ECONOMIC EVALUATION OF ALTERNATE PIPING MATERIALS

With all of the benefits which epoxy fiberglass pipe offers, one wonders why it is not more widely used today. Perhaps it's because our industry has not fully exploited the benefits which our product offers in the terms that a purchaser or specifying engineer can understand. We've been too concerned about the price per foot of our product compared to that of a competitor and not enough about the major benefits which it offers to our customers in the form of a lower installed cost and in many instances a longer service life.

To determine the actual cost of any piping system, consideration must be given to

1. The initial cost of the pipe and fitting.
2. The cost of installing the piping system.
3. The cost of maintaining the system after it has been installed.
4. The effective interest rate. (See below.)
5. The replacement cost of the piping system.
6. The life expectancy of various piping materials in the expected environment.
7. The number of years that the plant is designed to operate.

Once this information is available, it becomes relatively easy to compare the costs of alternate piping systems by using what is called a "Present Value Analysis". Basically, this Analysis determines the amount of money that must be put in the bank today so that enough money is available in the future to replace or maintain the piping system throughout the life of the plant.

The effective interest rate used in the calculations is the prevailing interest rate the company can get for its money if invested now, less the rate of inflation.

To see how this works, let's take a look at Table No. 1. This Table shows the present value costs for a straight 1,000-foot run of buried two-inch diameter pipe using an effective interest rate of four percent and a required service life of the system of 10 years. Column No. 1 lists a number of piping materials. Column No. 2 lists the material cost of each type of pipe being considered. Column No. 3 shows the material costs plus the cost of assembling and burying each type of pipe. Column No. 4 shows the annual maintenance cost. The last five columns show the present cost of each type of pipe, based on the expected life of the pipe.

To see how this works, let's assume that you are designing a central heating system which requires approximately 1,000-feet of two-inch pipe. The line is to be buried in corrosive soils where Schedule 40 galvanized steel pipe lasts only four years. Epoxy fiberglass pipe reportedly lasts 10 years in this service. If the buyer is looking only at the cost of the pipe, he will choose the galvanized steel pipe. But, if he investigates further, he will find that over the life of the system the steel pipe will cost \$40,957 and the fiberglass pipe only \$19,672. Fiberglass pipe, even though it initially costs more per foot, provides a saving of \$21,285 over the 10 year period.

CONCLUSION

With all the benefits which fiberglass piping systems offer to the end user in the terms of long life and ease of installation, you can well understand why the market for fiberglass pipe is so rapidly expanding.

D. W. BORNDER

Received a B.A. degree in chemistry from Pomona College in Claremont, California in 1958. Since graduation, he has worked extensively in the development and use of reinforced plastic products for the corrosion control field. He has been an employee of Ameron Corporation, Corrosion Control Division, for 16 years and is currently Manager of the Process Development and Control Section. He is also a senior member of SPE and an active member of several SPI/ASTM committees involved in the writing of specifications and test methods for fiberglass pipe and fittings.

TABLE I
PRESENT VALUE COST OF A STRAIGHT 1000-FT. BURIED LINE -- NO FITTINGS

PIPE SIZE = 2-INCH
PCT. YEARLY MAINT. RATE = 1.0

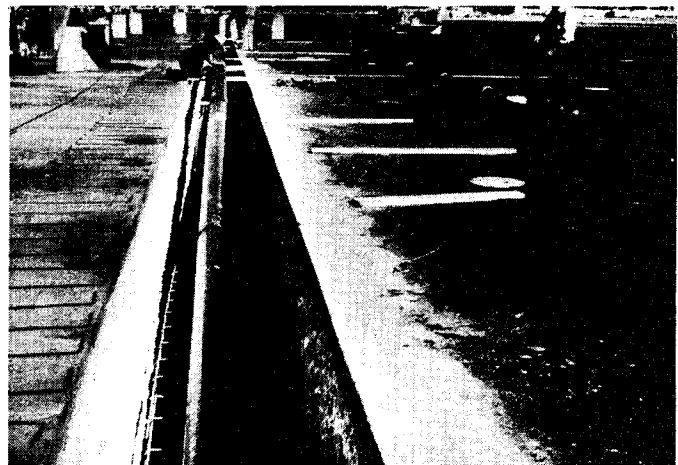
EFFECTIVE INTEREST = 4%
LABOR RATE -- \$15.00/hr.

PIPE TYPE.....	PIPE COST	INSTAL COST	MAINT COST	. . . PRESENT VALUE COST OVER 10 YEARS . .					
				YEARS OF SERVICE					
				2	4	6	8	10	
Fiberglass									
→ Epoxy	- 2000	2/20	18435	184	66832	41441	30429	28894	19672
CS-SCH40	T & C	913	18393	184	66679	41346	30359	28828	19627
→ CS-SCH40	T & C GAL	1200	18220	182	66052	40957	30074	28557	19443
CS-SCH40	WELD PE	860	20360	204	73810	45768	33606	31911	21726
CS-SCH40	PP - LINE	5718	24203	242	87742	54407	39949	37935	25827
CS-SCH40	RB - LINE	8215	26700	267	96794	60020	44071	41848	28942
CS-SCH40	SN - LINE	5504	23989	240	86966	53926	39596	37599	25599
CS-SCH80	WELD PE	1250	23350	233	84650	52489	38541	36598	24917
SS-SCH5	304 WLD	3941	21536	215	78073	48411	35547	33754	22981
SS-SCH5	316 WLD	4821	22416	224	81264	50390	37000	35134	23920
SS-SCH10	304 WLD	4805	25590	256	92770	57525	42239	40108	27307
SS-SCH10	316 WLD	7275	28060	281	101725	63077	46316	43980	29943
SS-SCH40	304 WLD	6580	29120	291	105567	65460	48065	45641	31074
SS-SCH40	316 WLD	9640	32180	322	116661	72338	53116	50437	34339

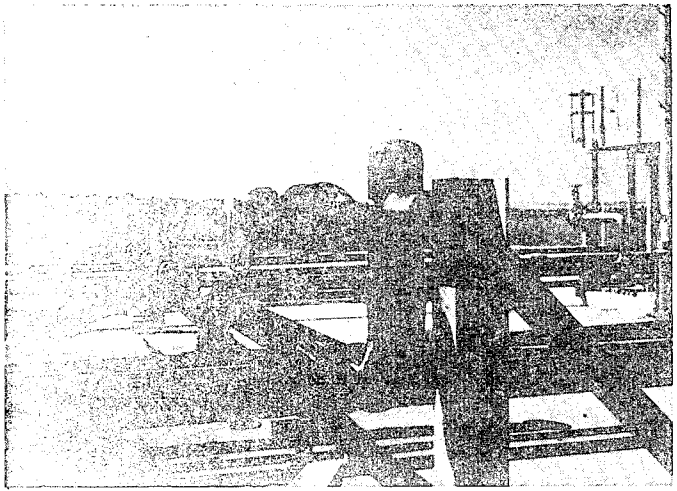
CS = Carbon Steel
SS = Stainless Steel
T & C = Threaded and Coupled



Photograph 1. Buried Central Heating System - Stanford University



Photograph 2. Jet Fuel Handling System being installed at Hickam Air Force Base



Photograph 4. Fire Service System at Major South American Petroleum Refinery

THE BUREAU OF RECLAMATION'S EXPERIENCE WITH FRP AND REINFORCED PLASTIC MORTAR PIPE

by

HENRY JOHNS*

ABSTRACT

The paper covers results of laboratory and field work on RPM pipe completed since the initial evaluation work. Included are final creep tests on 96-inch ID pipe in air; critical strain tests on 12-inch ID pipe in air and water-submergence; sand erosion resistance of linings; evaluation of a newer spigot material; some evaluation of pipe in northern U.S. climate service; effects of bedding on pipe deflections; and some comments on a contract installation. Also included are results of laboratory and field tests on a reinforced thermoplastic resin pipe.

INTRODUCTION

The intent of this paper is to describe some of our experiences with reinforced plastic mortar (RPM) pipe and with one fiber reinforced plastic (FRP) pipe. The RPM pipe is a composite of polyester resin, silica sand, and glass reinforcement. The resin used in RPM is a basic isophthalic polyester which gives the product excellent resistance to a wide variety of chemical solutions. The sand is a clean well-graded, high silica sand; it is used in the pipe wall as a filler to produce a product at a competitive cost by replacing part of the resin with lower-cost sand. The reinforcing filament is a borosilicate E type glass with a special surface treatment to enhance the adhesion of resin to glass. The pipe is built up in layers on a mandrel by a filament winding process modified to incorporate the sand into the pipe wall. The result is a pipe that is flexible and lightweight, but having high hoop tensile strength. The pipe is manufactured in standard 20-foot (6.1 meter) lengths with bell-and-spigot, rubber-gasketed joints. The joint is essentially the USBR R-4 joint design. The bell is fabricated as an integral part of the pipe on the mandrel during the winding process. The spigot is cast or molded on the outside of the pipe wall at the end of the pipe.

Rpm is included as one of our six alternates for line pipe, the others being asbestos cement pressure pipe, steel pipe, and three types of concrete pipe.

The fiber reinforced pipe we have had under study for the past 2-1/2 years consists of a polyvinyl chloride resin compound reinforced with nylon fibers. This pipe is unusual in that it is manufactured in a soft state so that it may be folded or coiled for shipment. By a heat process it is hardened at the jobsite and while still warm is rounded by air pressure.

The pipe achieves its design stiffness on cooling, which is usually only a few minutes, depending on ambient conditions. It is unique in that it can be laid rapidly in extremely long lengths. The limitation on length without joints varies with diameter and is limited by the size of shipping containers and the mode of transport.

Unjointed length is therefore much greater for smaller diameters.

REINFORCED PLASTIC MORTAR PIPE

Our evaluation of RPM pipe began several years ago; this work is well documented in laboratory reports. 1/, 2/* It is only necessary here to describe work done following the evaluation period and to cover some of the problems involved in handling and installing the pipe. Laboratory work done since the completion of the reports consists of completion of creep tests on the 96-inch ID pipe, critical strain tests on 12-inch ID pipe, evaluation of a newer spigot material, and some further considerations on erosion resistance.

CREEP TESTS

Creep tests were run on 96-inch (2.44 meter) inside-diameter pipe. The tests were made in air beginning at initial deflections of 5 and 10 percent with external sustained loads of 985 and 1,840 pounds (447.2 and 835.4 kg) being applied to produce the deflections. After nearly 4 years' continuous loading and is as shown in Figure 1, the 5 percent deflection increased to 6.6 percent; and the pipe deflected ten percent increased to 13.7 percent. This is probably not serious since the tests are conducted in air, with no side support for the pipe section. If proper side support were provided, the increase in deflection would, no doubt, have been less.

CRITICAL STRAIN TESTS

This test series was run to evaluate the effect of fairly long-term strain on 12-inch (.305 M) diameter pipe. Two sets of pipe were used, one set submerged in tap water for the 2-year exposure period, the other set in air at ambient room temperature. Five pipe sections comprised each set, one pipe at zero vertical deflection, the other four at 2-1/2, 5, 7-1/2, and 10 percent deflection, respectively. Evaluation of changes in the pipe was made by conducting parallel plate pipe stiffness tests at the conclusion of the 2-year period. The pipe stiffness tests were run according to ASTM method D2412. The pipes were also inspected visually for delamination or other obvious distress. Only one pipe, the one deflected 7-1/2 percent and submerged in water for the 2-year period, had any noticeable delamination. This delamination was first observed after the test had been in progress for 3 months, and apparently did not become appreciably more severe during the remainder of the test period. Following are the stiffness factors determined from the stiffness tests.

The minimum stiffness factor required for 12-inch ID RPM pipe under USBR specifications is 1200 in.²lb/in at 5 percent deflection, so that it may be seen from the above tabulation that even after 2 years' continuous strain in the minimum requirement is still exceeded. The anomaly in this display is the behavior of pipes 1 and 6 which were unstressed during the test period. Apparently the stressed pipes developed a set, recovery from the deflected condition being at least 98 percent of the original diameter. As would be anticipated, however, the general trend in stressed pipe is one of decreasing stiffness with increasing deflection. This is portrayed graphically in Figure 2. Also as might be expected water submergence is shown to have a diminishing effect on pipe stiffness.

THE LOWER YELLOWSTONE TEST

This is a 1200-foot-long, 39-inch ID test section installed as a replacement for an existing canal in the Lower Yellowstone Irrigation District near Sidney, Montana. The installation was made in April 1968 to evaluate the performance of RPM in a severe climate. Cover is 3 to 5 feet of backfill. After 6 years there is no indication of damage from freeze-thaw effects; settlement of one 20-foot section has caused an 1/8-inch-wide circumferential crack in the pipe

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*Numbers refer to references in bibliography.

invert. Vertical deflection at this point is 4 percent. Soils for bedding are clayey sand and silty sand.

EROSION RESISTANCE OF RPM PIPE

Erosion in pipe linings is a problem, but in most cases, not a significant one. It is encountered most frequently in pipe downstream from earth-lined canals, where a bed load of sand and gravel may be carried along the invert causing scouring. In our line pipe scouring is an unusual situation; we still, however, require that the interior surface be erosion resistant and in response to suppliers' requests, erosion resistance has been quantified and a test developed for its determination for specifications purposes.

During the evaluation tests run several years ago we found that a straight polyester resin liner had only moderate erosion resistance. The addition of fine sand to make a resin rich mortar improved the lining hardness sufficiently that we could consider it to be "erosion resistant." With increased hardness came increased brittleness and increased damage risk. Manufacturers found that impacts barely noticeable on the exterior surfaces would result in serious damage on the interior surfaces, apparently because of the brittleness of the lining. The addition of a fine filler to the resin in place of the sand (aluminum silicate was found to be satisfactory) rendered a sufficiently elastic and a suitably erosion resistant compromise.

By way of comparison here are some of the materials tested, in decreasing order of erosion resistance:

- Steel pipe
- Type 304 stainless steel sheet
- Neoprene paint
- RTRP
- Cement mortar
- Vinyl resin paint & sand
- Asbestos cement pipe
- Coal-tar enamel
- RPM (resin rich mortar lining)
- RPM (resin & fine filler lining)
- RPM (polyester resin lining)
- Vinyl resin paint

THE YUMA PROJECT FIELD TEST³

This is a test to evaluate the effectiveness of types of bedding and methods of compaction on the deflection of RPM pipe under field conditions. In this case 1200 feet of 30-inch ID RPM pipe were installed to replace two deteriorated open laterals on the Yuma Project near Yuma, Arizona. Table 2 shows the results of these tests.

Because of the granular nature of sand it is generally considered to be a better bedding material than cohesive material. It was not found to be true in this case because the sand was not compacted to specifications requirements while the natural earth was.

Backfill was 4.5 (1.37 m) feet over the pipe

INSTALLATION OF RPM UNDER USBR SPECIFICATIONS

One of the advantages of RPM pipe is that it is lighter in weight than our other five line pipes. The lighter weight is also a disadvantage: the pipe tends to float out of its bedding during compaction of the side backfill. Another of the drawbacks: backfill must be selected and must be compacted to a depth of 0.7 D, since RPM is a flexible pipe. Further, it is a more delicate pipe than those our contractors are accustomed to, and therefore more susceptible to damage during handling, shipping, and installation.

RPM has not so far seen a large usage under our contracts: 15,000 feet on the Manson Unit of the Chief Joseph Project in the State of Washington; about the same amount on the Minot Extension in North Dakota. For the near future, about 20 miles in the Westlands of central California is due to begin installation in March of this year.

Some of the experience of our contractors on the Manson Unit may be of interest here. About 6 percent of the 750 pipe units, 44 to be precise, were damaged either in shipping or handling at the jobsite and were rejected by our inspectors. The pipe was installed in a variety of terrain and soil type conditions. Pipe grades ranged from 77 percent to 0.1 percent. Trench conditions included solid rock, silts interspersed with cobbles up to 1 cubic yard in size, gravels, silts, clays, and even short reaches of almost pure pumice. These various soil conditions reflect a typical geological condition resulting from glacial deposits.

Grade control fell short of that required for proper installation. At the recommendation of the supplier a change order was issued requiring backfill within 6 inches of the pipe be not larger than 1 inch. No excessive deflections were found in the pipe after installation, but four leaks occurred: 2 caused by damage after installation, and the other seemed to have been damaged during installation.

At the conclusion of the job the contractors stated that under the same conditions they would install RPM pipe again. They felt they had learned a lot and that some of their methods and procedures would be modified. More care would be taken in shipping and handling the pipe and closer survey control would be used to speed installation. More fittings would be ordered since even small angular changes are difficult to make due to joint opening restrictions.

I should point out here that our construction specifications have been modified to require that backfill closer to the pipe than 6 inches be not larger than 1 inch. We still have the joint opening problem under study and expect some change will be made in this area.

TESTS ON RPM SPIGOT MATERIAL

This consists of a series of tests on cylinders 2 inches in diameter, 4 inches long, composed of the resin used for forming spigots. There were two series of tests; one on material previously used, the second on the material now in use. Evaluation consisted of changes in hardness, in moisture absorption, and in modulus. After a 1-year evaluation it was found that moisture absorption in the newer spigot material was about twice as great as that for the older material (0.9 percent vs. 1.2 percent); the newer material is somewhat softer than the older material (measured by Shore D), and that it softens at a greater rate (76 to 68 for the newer material, 84 to 80 for the older material); and the newer material is lower in modulus than the older material (see Figure 3).

The manufacturer changed to the lower modulus material because it was less brittle and therefore less susceptible to damage. As far as we know, the newer spigot material has not created any problems; our experience is not yet sufficiently great to indicate whether lesser spigot damage has occurred.

FIBER REINFORCED THERMOPLASTIC RESIN PIPE

Most of the evaluation work on this pipe was done in the field; only pipe stiffness, erosion tests, and hardness determinations were done in the laboratory.

Table 3 shows a comparison of the stiffness of this pipe with other materials we have used or considered.

Erosion resistance of the fiber reinforced thermoplastic resin pipe was found to be good. The only visual change was a slight dulling of the surface. There were no detectable thickness losses and the weight loss was quite small, compared say, to our standard pipe lining for steel, which is coal-tar enamel.

We probably did not obtain a true measure of the hardness of the pipe since it had the reinforcing fibers embedded in it. The readings were about 40 for the soft or uncured material and about 60 for the hardened pipe, using the Shore D apparatus.

FIELD TEST NO. 1, MITCHELL IRRIGATION DISTRICT, MITCHELL, NEBRASKA

The test section was 2,900 feet long, 16-inch inside diameter, laid in one section, without joints. The pipe was processed and laid in the trench at the rate of 20 feet per minute, although the manufacturer stated it could be done at 45 to 50 feet per minute. This installation was made in November 1972; unfortunately, and at the manufacturer's insistence, no compaction of backfill or bedding was done. There now remains only about 1,800 feet of the pipe in service, separated into two sections about 900 feet long. Our plan here was that we would be able to run a television camera through the shorter reaches and thereby be able to monitor deflections. The remainder of the pipe, about 1,140 feet, was vertically deflected for much of the length to near collapse. The excessive deflection was induced by an overzealous farmer who wished to assure himself of a nonsettling corn field. In this he was eminently successful, to our dismay. In November 1974 we tried to run the television camera through one of our good sections; the 2 inches of silt in the bottom of the pipe quickly built up to 4 inches then to 6 inches covering the camera lens. The effort was abandoned. Our impression before the picture was obscured, was that some further deflection of the pipe has occurred, greater than that found on previous inspections.

FIELD TEST NO. 2, SOLANO IRRIGATION DISTRICT, DIXON, CALIFORNIA

This test section was 40-inch inside-diameter, and originally intended to be 2,300 feet long. Only 400 feet of pipe was actually installed in April 1973. There were problems in quality control of pipe manufacture and in the converting equipment at the jobsite. Our present understanding is that all 400 feet of the test section have now been removed because of collapses occurring during the summer of 1973. The manufacturer plans to redo the test section in the spring of 1976.

There were, therefore, stability problems with both of the test installations. Ring stiffness tests show this pipe to be even more flexible than our other flexible pipe; and ring stiffness has been found to be a reliable indicator of the behavior to be expected from pipe subject to external forces, in this case, backfill pressure.

CONCLUSIONS

It appears the decision to include RPM as one of our line pipe options is justified. Laboratory work done since that time and reports on field test installations are favorable. Contract installa-

tions have not been in place long enough to provide data. Also, in the meantime both the cost and the availability of steel have had an effect both on steel pipe and on reinforced concrete pipe.

The situation with the fiber reinforced thermosetting resin pipe is somewhat obscure. It was the intent originally that this pipe also might eventually be included in our pipe options. There will probably be changes in both pipe design and in manufacturing techniques to overcome what seems to be a creep tendency. Changed in laying methods and in backfilling procedures also will be needed, to compensate for the fact that this is, indeed, a more flexible pipe than any of those in current usage.

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He has worked in materials testing and product evaluation since 1949, specializing in plastic pipe for the past three years. He is a 1955 graduate of the University of Colorado with a degree in Civil Engineering (BS). He is a registered professional engineer in the State of Colorado, a member of ASTM and the National Association of Corrosion Engineers; he is also a member of the Bureau's Open and Closed Conduit Systems (OCCS) Committee.

TABLE 1. STIFFNESS FACTORS AFTER 2-YEAR DEFLECTION

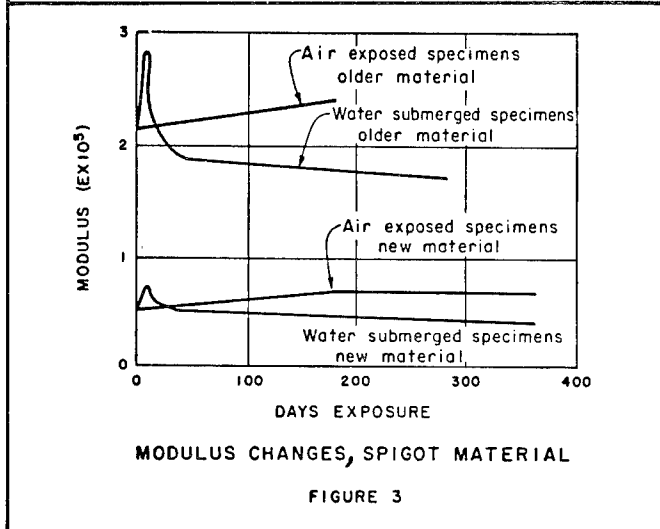
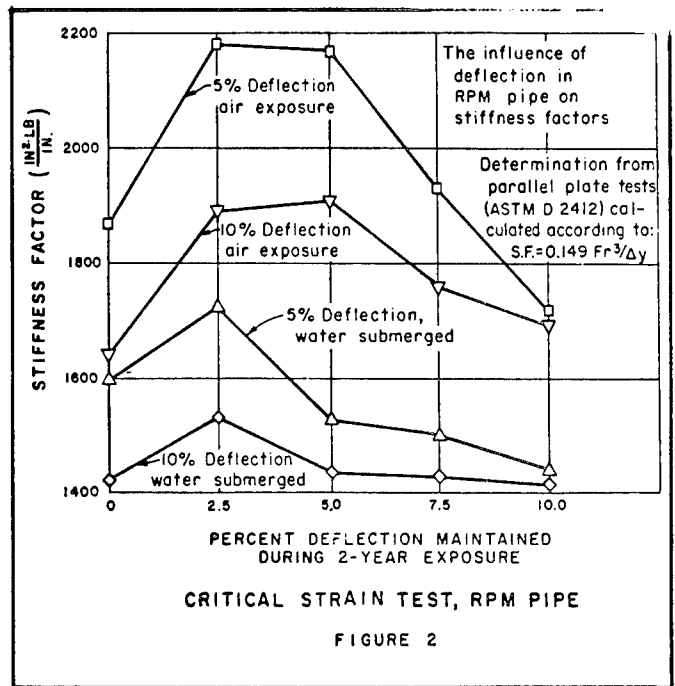
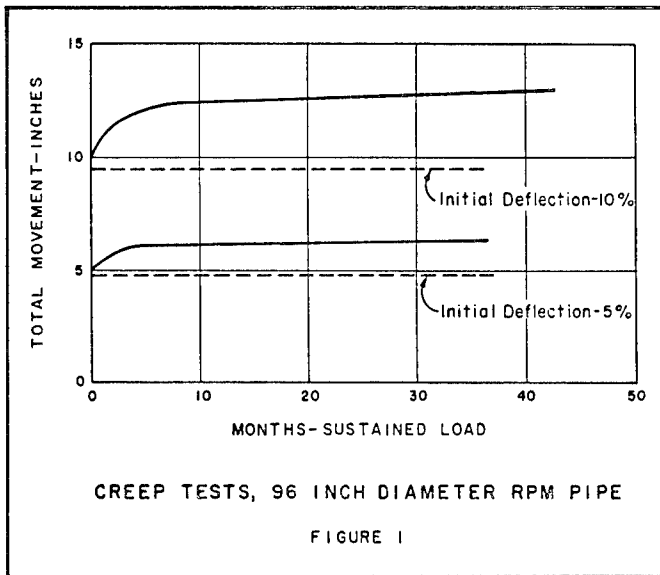
PIPE NO.	EXPOSURE CONDITION	DEFLECTION MAINTAINED DURING TWO YEAR TEST, %	STIFFNESS FACTOR ($\frac{\text{in.}^2 \cdot \text{lb.}}{\text{in.}}$)	
			5 PERCENT DEFLECTION	10 PERCENT DEFLECTION
1	AIR	0	1860	1623
2	AIR	2-1/2	2175	1875
3	AIR	5	2160	1890
4	AIR	7-1/2	1916	1755
5	AIR	10	1704	1677
6	WATER	0	1578	1401
7	WATER	2-1/2	1704	1522
8	WATER	5	1516	1429
9	WATER	7-1/2	1486	1417
10	WATER	10	1424	1405

TABLE 2

Bedding type	Percent vertical deflection
Compacted natural earth	0
Compacted sand	1
Puddled natural earth	4
Loose sand (flooded)	6
Loose natural earth (flooded)	8

TABLE 3

Pipe Material	Ring stiffness factor psi	Stiffness factor $\frac{\text{in.}^2 \cdot \text{lb.}}{\text{in.}}$
PVC, unreinforced, 15-inch ID	9.0	5300
RPM, 18-inch ID	3.0 - 4.0	2300 - 3000
Steel, 14 gage, 18-inch ID	1.8	1300
Steel, 10 gage, 18-inch ID	9.5	7100
Polyester RTRP, 18-inch ID	2.0 - 4.0	1500 - 3000
Epoxy RTRP, 18-inch ID	4.0	3000
Fiber reinforced PVC, 16-inch ID	0.8	435



REINFORCED PLASTIC MORTAR PIPE BREAKTHROUGH IN SEWER AND IRRIGATION APPLICATIONS

by

B. JAY SCHROCK and G. RANGEL*

ABSTRACT

Reinforced Plastic Mortar Pipe (RPMP) is a composite structure of polyester resin mortar (sand filled) with continuous fiberglass filaments. The pipe combines these materials in a properly engineered structure to produce a flexible, high strength, lightweight pipe product.

RPM pipe is the first Reinforced Thermoset Resin Pipe (RTRP) that has an ASTM Specification for Sewer Pipe. The chemical resistance requirements listed in this specification are very stringent defining strain acid testing. The ring stiffness, joint, beam strength and dimensional tolerances and testing are clearly defined in this specification. Also, the U.S. Bureau of Reclamation, following a three year testing program, has issued a specification for RPM pressure pipe.

The pressure, strength, hydraulics, durability, versatility and excellent joint capabilities lend RPM pipe to sound engineering design and construction practices. The paper will discuss these aspects and present a number of installation situations to illustrate performance and application.

INTRODUCTION AND BACKGROUND

The sewer and water distribution pipe market traditionally utilized vitrified clay pipe, epoxy lined and unlined asbestos cement pipe, plastic lined and unlined reinforced concrete pipe, lined and coated steel pipe and protected and unprotected ductile iron pipe. Each of these pipe products had their advantages and disadvantages. Reinforced Plastic Mortar Pipe emerged as a possible solution for combining many of the advantages provided in the other pipe products into one pipe. This has been done before, but not with a product that was competitive. However, since RPM was a unique product requiring slightly different installation techniques, additional advantages and minor disadvantages materialized. These advantages and disadvantages will be discussed in this paper. As the design and construction education continues, the advantages continue to grow and the disadvantages continue to disappear.

TECHITE® Reinforced Plastic Mortar Pipe is a composite structure of layers of fiberglass, resin and sand[†]. The incorporation of sand in the pipe wall is used primarily as a filler to build up the section modulus permitting deep trench burial. An interesting aspect of the pipe wall design is that the wall thickness for a given diameter remains virtually the same for all pressure ranges. This applies to all classes ranging from gravity to 250 psi. The wall thickness was established for structural reasons to provide a certain ring stiffness to transfer the overburden load into the pipe zone material as per flexible pipe design theory. The maintaining of a set wall thickness has been established in that as the pressure range goes higher, glass and resin are substituted for sand giving a similar ring stiffness strength. Also, in that the glass and resin has a lower specific gravity, the weight of the pipe lowers as the pressure class increases.

A significant difference between filament wound RPMP and helically wound fiberglass pipe is the angle at which the glass is applied to the mandrel or mold. The helix angle is less on RPMP. This provides greater

hoop strength but lower axial strength. The necessary axial strength is obtained by additional fiberglass applied in the longitudinal direction to handle normal bending and axial stresses. Also, the ability to increase the amount of longitudinal reinforcement provides the capability of handling longitudinal thrust for applications where thrust blocks are not permitted.

It is not economically feasible to design a structure to overcome all potential problems. However, it is necessary, if you want to market a product, to isolate those problems into groups and attempt to eliminate them. Some examples of these are: 1) shear failures at rigid structures such as concrete manholes, reinforced concrete structures, thrust block, etc., necessitated joint articulation immediately adjacent and outside of these rigid structures; 2) the use of a flexible pipe in a poor in situ soil condition can be overcome by using a wider trench with a coarse granular backfill material in the pipe zone area; 3) the addition of a highly flexibilized resin formulation on the inner pipe surface has minimized the problems once associated with shipping and handling impact and installation damage; 4) casting the spigots in fixed molds with flexibilized resin has significantly improved dimensional tolerances and resistance to impact damage.

R.P.M. APPLICATIONS

The real breakthrough in RPM applications are:

SEWER APPLICATIONS

In late 1973 ASTM issued the specification D3262 for RPM sewer pipe. This culminated more than five years of intensive research and testing by many people resulting in what is considered to be the best all around sewer pipe specification to date. It is probably the most stringent pipe specification ever issued by ASTM. This is understandable in that the piping industry including those with competitive materials contributed heavily to writing and approving this specification.

Normally, plastics and fiberglass reinforced plastics are tested in accordance with ASTM Specification D-543 (Resistance of Plastics to Chemical Reagents). The corrosion resistance of the material is based on simple immersion of the specimen in various reagents. The mechanical properties loss is measured by comparing control specimens to exposed specimens and noting the percentage loss in properties. In most applications, this test method is adequate.

In composite structures, such as RPM pipe, these tests showed insignificant changes in the mechanical properties. It was discovered, however, that if some of the same materials were immersed in the same reagents in a fixed stressed condition, loss in mechanical properties or corrosive attack could occur more rapidly.

This condition can be related to actual installations of RP products. Buried pipelines for instance, are subject to deflection from earth loads, and localized deflection from uneven or rocky bedding. Above ground piping and vessels are also subject to localized loads from improperly designed supports. These conditions to name a few can cause excessive strains in the structure. These strains coupled with a corrosive media may accelerate the breakdown of the material.

A strain corrosion failure is characterized by a fracture in the structure which resembles broken concrete as opposed to a normal RP fracture which has many exposed fibers visible. The corrosion fracture line usually follows the line of highest strain in the structure. For instance, a pipe which has been subjected to ring deflection will fail in the longitudinal direction, whereas, a pipe subject to axial loads suffers a radial fracture.

Some materials are less susceptible to this problem than others but this does not mean the problem can be ignored. All installations of RP products should be scrutinized for possible danger areas. Piping installations subject to corrosive media should be designed so that the minimum of strains are applied to the pipe.

As pollution control requirements become more stringent, more and more industries require piping systems capable of handling the aggressive wastes. The piping in these areas must be reliable.

Specifications such as ASTM D3262 are a good example of joint efforts to provide the users with a reliable product. The specification not only specifies minimum physical requirements, it specifies a very critical corrosion resistance test. (See Figure 1). The specification calls for Reinforced

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† Patented Process.

Thermosetting Resin Pipe (RTRP) to be capable of being deflected to a level defined as 0.5% strain for at least 100,000 hours while exposed to 1.0 normal sulfuric acid without failure. A minimum of 18 points are required on a log/log plot, strain versus time, 10 to 10,000 hours. A lower confidence level (LCL) calculation using the least squares method (Method D2992) is the basis for the requirement.

During the years of developing the ASTM specifications, RPM pipe continued to be improved upon to exceed these stringent requirements. Some of the latest developments in corrosion resistant and test methods were introduced in this specification. This test method will become a standard ASTM test method for testing the corrosion resistance of all fiberglass pipe that will probably become the more accepted method. In other words, the corrosion resistance of RPM pipe verified in the ASTM specification assures minimum standards of acceptance. What this means to the installer and the owner of the pipeline is that he will be getting the best all around sewer pipeline on the market today. The pipe can be installed with the assurance that corrosion resistance will not be a concern even in situations of very high sulfides. This does not mean that the pipe can be installed without any regard to provide a good side support to prevent excessive deflections. Deflections should be controlled to under 5%. This conforms to long established engineering practices and provides additional margin of safety leading to longer life.

Since RPM is a flexible pipe the strength of the pipe is dependent upon the passive strength of the backfill material. RPM pipe being a flexible pipe with good bending strengths is an excellent pipe for poor native soil conditions provided that trench controls and joint articulation outside rigid structures are included in the design considerations. Remember that RPM pipe has easy to install and tight bell and spigot joints.

GRAVITY SEWER

RPM is truly the only product that approaches the corrosion resistance capability of vitrified clay pipe. Noteworthy of mention is that clay pipe cannot be used for anything other than gravity applications. RPM also has the additional capabilities of:

- 1) Watertight joints.
- 2) A gasket under enough compression that root penetration is virtually impossible. Also, not enough compression to crack the bell.
- 3) Ease of installation.
- 4) Ease of making sewer service connections.
- 5) Excellent hydraulic characteristics (Mannings $n = 0.009$ to 0.010 See Figure 2), and the anticipated perpetual maintenance thereof.
- 6) Ability to be utilized as a manhole providing an entire corrosion resistance system.
- 7) Can be repaired in place in case damage to the pipe wall occurs.

Pressure Sewer

RPM gravity sewer pipe can be used for 50 psi service if so specified. The corrosion resistant inner surface permitting long life for gravity sewer applications as per ASTM D3262 is also utilized in the pressure sewer pipe. The answer to a significant design problem is the use of RPM sewer which has superior hydraulics, excellent corrosion resistance, and the built-in capability of conversion to a low pressure sewer system when greater flows are developed. Therefore, any surcharging of flows will not affect public health in that the pipe joints have the necessary pressure capabilities.

RPM pressure sewer pipe is the only competitive large diameter pipe available today that does not require protective linings, coatings or filaments of molecularly dissimilar materials protecting the structural integrity of the pipe from internal and external corrosive attack.

Liner Sewer

No single use of RPM pipe has been more innovative than its use as a liner for rehabilitation of failing water and sewer pipe lines.

An owner rightfully expects his pipe system to operate effectively and efficiently for its design life. However, due to unforeseen or changing conditions, corrosion and/or structural failure sometimes occurs. Experience over the past several years has shown that many apparently "lost" pipelines can be salvaged by inserting RPM liner pipe inside the existing pipeline.

When compared to the alternative of replacing a failing pipeline with a new one, rehabilitation of the existing line with RPM liner pipe offers very substantial benefits to the user.

The cost of lining pipe is only 25% to 70% of the cost of replacement.

New rights-of-way, easements, and permits normally required for construction of a replacement pipeline are not needed when the existing pipeline is lined with RPM liner pipe.

Although the time required to line a pipeline is dependent on job conditions, it is many times less than that for construction of a replacement pipeline. Lining eliminates the need for extensive trenching in developed areas and thus avoids traffic disruption, danger to pedestrians, dirt, and noise nuisance to property owners and also can normally be accomplished while the existing line maintains service.

IRRIGATION APPLICATIONS

The U. S. Bureau of Reclamation culminated a three year study entitled "Valuation of Reinforced Plastic Mortar Pipe Between the Bureau of Reclamation and Industry". It was published in 1972. This study conducted over a three year period evaluated reinforced plastic mortar pipe for water resources application and was comprised of laboratory and field programs. Preparation of specification and design data results indicate that RPM pipe will perform satisfactorily as pressure pipe for irrigation distribution and water conveyance systems. Changes in physical properties resulting from environmental exposures of solutions of sulphuric acid, sodium hydroxide, synthetic soil extract, and to tap water and distilled waters are an acceptable magnitude; the major fact being attributed to wetting action rather than chemical action. Laboratory buried pipe tests show that RPM pipe deflects more than steel pipe with similar stiffness under external load. However, field tests indicate that the recommended maximum deflection of 5% of pipe diameter will not be exceeded when the pipe is properly installed. Disadvantages of RPM pipe are: adverse changes in physical properties in service age (See Figure 3) and less deformation resistance than some other pipe. Advantages are: high corrosion resistance, good chemical resistance, no inherent cracking and light-weight greatly facilitating handling and installation operations. In addition to this the ASTM Pressure Pipe Specification is in the final process of being approved.

R.P.M. PRODUCT ADVANTAGES

CONTROLLING INFILTRATION/INFLOW

The joint used for RPM pipe remains the same since its inception in 1966. However, in addition to utilizing the U. S. Bureau of Reclamation R-4 design concept, the method of making it and the resin used has changed. During 1971 the cast-on spigot in lieu of molded spigot method was perfected. This method was greatly aided by going to a more resilient resin formulation than had previously been used. The new resin provides excellent tolerance control and impact resistance. The tolerance control is usually in the range of plus or minus 0.015 to 0.025 inches in diameter which equals or betters any other pipe product.

The R-4 joint concept is a self centering joint which places the pipe load on the back shoulder of the spigot rather than on the gasket.

The gasket itself is 20 to 40% compressed when the joint is in place. When the properly installed joint pull is not exceeded, the infiltration inflow is zero and the amount of internal pressure to cause leakage is in excess of 450 psi. The O-ring gasket provides joint articulation outside of rigid structures which is a must with any pipe product.

INSTALLATION COST SAVINGS WITH RPM PIPE

One of the questions often asked by engineers and contractors concerns the cost of installing RPM pipe in comparison with other pipe materials. Naturally, there is no one answer that will cover all sizes, classes, trench depth, soil conditions, etc. Experience has shown that installation cost savings from \$0.50 to \$4.00 per lin. ft. have been reflected by many contractors bidding RPM pipe. It may be helpful to evaluate the various installation conditions encountered on a typical pipeline project and to point out the potential savings for each condition that may be realized using RPM pipe.

Excavating

RPM pipe usually requires less excavation than other type of sewer and water pipe, the chief reason being the thin wall and slim profile of RPM pipe.

Handling

RPM is a lightweight, tough material which can be easily handled with lighter, less costly equipment. Up to 21" RPM in 10 ft. lengths and 14" in 20 ft. lengths can be manhandled, as the total weight is approximately 200 pounds. Concrete and clay sewer pipe weighs approximately ten times per foot more than RPM pipe. Large diameter asbestos cement and cement mortar lined and coated steel water pipe weighs about eight times more.

Joining

An important difference between laying RPM pipe and other types of pipe material is in the joining. RPM is manufactured in longer lengths than most other types of pipe. For instance, compared to a 20 ft. long RPM joint, concrete and asbestos cement require two times as many joints and clay pipe requires four times as many joints. RPM having no lining or coating needs no painting, mortaring or wrapping of the joints for corrosion protection as does conventional metal pipe.

Backfill

If less excavation is required for RPM piping because of its slim profile then less backfill must be placed as well. Where imported bedding and backfill is specified, considerable cost savings may be realized.

Pavement

When working in pavement a wider trench requires more pavement removal and more pavement replacement.

Casing

When passing beneath highways and railroad tracks water and sewer pipelines are often installed in casing pipes. Again the slim profile and lightweight of RPM contributes substantially to cost savings.

Breakage

Although difficult to evaluate in dollars and cents savings, on the job breakage due to accidents or mishandling is minimal with resilient material like RPM. In comparison the breakage factor for more brittle materials is higher and protective linings and coatings on any type of pipe is subject to abrasion, cracking or chipping.

CORROSION CONTROL AND INSTALLATION

Most buried metal pipe systems require that certain corrosion control activities be accomplished during pipeline installation. If coated with a dielectric coating that is, coat tar, etc., it is customarily required that the contractor test the entire pipeline with a holiday or spark tester. Rubber gasket joints on steel pipe should be bonded to assure electrical continuity in the joint area, and the joint areas painted, wrapped or mortared after laying. Remember, RPM needs no protective lining and coating. Another interesting feature is the continual annual maintenance on a cathodic protected system. In recent irrigation jobs, design engineers have protected reinforced concrete pipe in the more corrosive type soil conditions. This requires that the steel reinforcing cage be provided to the surface at the joint in order to permit bonding jumpers for electrical continuity of the metal.

Another interesting cost savings is the feature of off loading trucks unloading bundles of banded RPM pipe en masse. RPM pipe can be handled by helicopter, side boom on a truck, or even highline cable in areas where other pipe cannot even be installed. Large diameter RPM pipe can be installed in a trench and the joint pushed together by use of lightweight equipment. Up through 24" diameters can be installed using a bar manually pushing the joint together. Pipe joints 27" and up can be made up utilizing a come-along or heavier weight equipment, or a combination of pulling on the cable and barring in. In some cases installers have found that utilizing motorized equipment in the trench, such as a small tractor, provides excellent results.

TYPICAL R.P.M. INSTALLATIONS

SEWER PROJECTS

In the Cucamonga industrial interceptor, 8,200 ft. of 42" and 3,000 ft. of 27 TECHITE pipe meeting ASTM D3262 Specification was installed for Chino Basin Municipal Water District. Utilizing TECHITE pipe and manholes, the entire job was completed in eighty-two working days in spite of burial depths to 30 feet.

The City of Oceanside had over 6,500 ft. of 42" and 3,600 ft. of 24" to 36" meeting ASTM D3262 Specification installed in the San Luis Rey Treatment Plant. An interesting feature about this application was that the road used to bring in all the heavy construction materials passed over a 42" TECHITE pipe with 5 ft. of cover, maximum deflection in six months $\frac{1}{4}$ of 1%. Later on in the project 42" TECHITE was buried with 38 ft. of cover; again maximum deflection $\frac{1}{4}$ of 1%.

In 1955 South Laguna Sanitary District has 10,000 ft. of 21" VCP installed in a tunnel running through the cliff behind South Laguna Beach. Seven adits were constructed in the face of the cliff to facilitate getting the pipe into the tunnel. Since flows were extremely low, the sewage was extremely septic and the sulfuric acid attack caused numerous failures. The raw sewage flowing from the adits down the face of the cliff on to the beach became increasingly intolerable and in 1974 a contract was placed to install 24" bottletight TECHITE through the tunnel. The contractor is crushing the VCP in place with a small mine type jaw crusher. The VCP is proving to be an excellent bedding material in this application.

SEWER LINE PRODUCTS

The City of Modesto, California was involved in the first rehabilitation of a failing sewer pipeline utilizing RPM pipe as a liner. The operation involved the jacking of 5,500 lineal feet of 18 inch pipe from one pit through the near 60 year old 24 inch sewer line. The old line had tremendous infiltration and was in danger of complete failure due to severe hydrogen sulfide corrosion.

During 1969 a 27 inch RPM liner pipe was installed for East Bay M.U.D. in an existing 20 year old 30 inch pipeline. This installation was accomplished from one jacking pit in first one direction and then the other, with a closure being made within the jacking pit. The work was done on the heavily travelled Seventh Street in Oakland, California. The pit was located near the newly constructed BART overhead. The existing pipeline was 25% corroded from sulfuric acid, the end product of generated hydrogen sulfide gas.

During 1969 the City of Stockton, California experienced a serious street cave-in. After much consternation, it was discovered the then five year old 36 inch pipeline had failed and undermined the street. This five year old pipeline had experienced some of the worst known active corrosion in municipal piping history. RPM liner pipe came to the rescue. Since that date the city has had an annual relining program to rehabilitate that system and others.

In Sacramento, California a troublesome pipeline was relined with 42 inch RPM. This is believed to be the largest diameter ever used for complete relining with pipe. The original pipeline was installed with 48 inch and 51 inch diameter pipe. During the years after a number of failures, 44 inch, 45 inch and 46 inch short sections of pipe had been installed as sleeves and the annular spaces were grouted. There were also several places where repair bands 12 inches wide were utilized at the leaking areas. RPM with a 43.75 inch maximum outside diameter negotiated the alignment when the distance was over 1200 feet away from the jacking pit.

The Corps of Engineers was assigned the job of replacing a pipeline that had been subjected to very infrequent spillages of a corrosive fluid. RPM was utilized in this Army Ordnance Depot Project near Charlestown, Indiana.

IRRIGATION PROJECTS

Nevada Irrigation District, Nevada County, California had installed over 20 miles of RPM pipe in this rugged Sierra Mountain terrain. About 20,000 feet of it is 48 inch diameter pipe having operating pressures up to 150 psi. This first 48 inch was installed in 1968 in this constantly shifting mountain terrain. It was estimated that the initial 14,000 feet was installed

with a savings of a quarter million dollars over the use of conventional materials. This was due primarily to the fact that longer lengths and/or heavier pipe would have required wider swaths of rights-of-way, hence, additional costs and damages to the wooded areas.

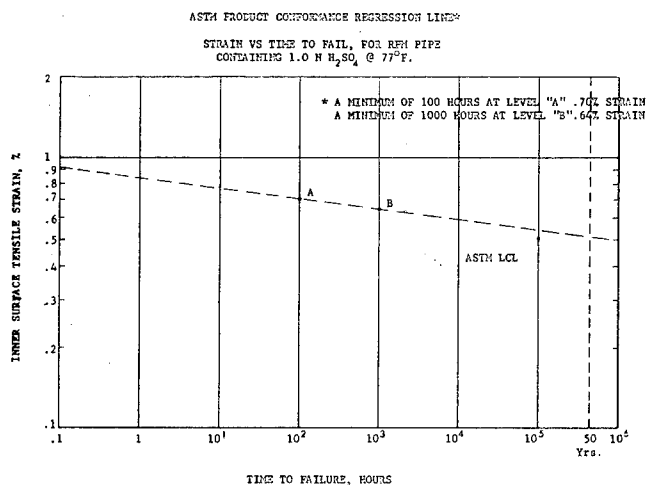
Superior Farming Company of Bakersfield, California, selected RPM pipe as their mainline transport line to supply water to their crops. They required a long life, corrosion free pipe that was unaffected by a corrosive soil and resistant to internal abrasion and chemical attack by fertilizers, insecticides, and herbicides which were to be introduced into the system. The company installed in excess of 300,000 feet of 8 inch through 16 inch RPM pressure pipe during 1969-70.

El Dorado Irrigation of California installed some 600 feet of 24 inch RPM pressure pipe utilizing helicopter transport. This line to be used to siphon water across a canyon was a replacement of a metal line that had previously been replaced. The RPM pipe was installed during 1966 and has been performing quite well since that date. When last investigated at the site, there was no sign of internal or external corrosion or internal erosion. Samples taken out of the pipe have revealed the actual strength retention is over 10% in excess of that which was projected on the stress aging curve (See Figure 3). With this continued performance the line should last in excess of the 100 year projected life.

The Wheeler Ridge Maricopa Water Storage District and the Semi-Tropic Water District have seen 200,000 feet of RPM installed in these areas near Bakersfield, California. Water deliveries from the 444 mile long California Aqueduct have water turnouts some of which passes through 54 inch RPM pipe. This area has a long history of shallow subsiding soils and deep subsidence from excessive ground water draughts. These Districts, due to excellent Engineering design and the use of RPM have installed pipe at approximately 10% below estimates.

During 1973, the U.S. Soil Conservation Service job in Minersville, Utah utilized 50,000 feet of RPM in the local Water District. This job went in without a hitch and tested without one pipe leak.

During the past eight years the U. S. Bureau of Reclamation has been involved in RPM design, review of design and installations in most of the seventeen western states. We have all learned from these projects; some were not perfect or ideal, others were. In the final analysis, it is believed that the track record is in the forward direction. The product has been improved upon, i.e., pipe design changes, quality control adjustments, and installation methods developed. The Bureau has been instrumental in improving other types of pipe over the years and it appears that RPM irrigation pipe development has also been keyed to them.



IRRIGATION LINER PRODUCTS

Solano Irrigation District, Solano County, California has since 1966 installed approximately 100,000 feet of RPM liner in their existing system. This work was accomplished under the U. S. Bureau of Reclamation's Rehabilitation and Betterment funding program which updates existing or failing irrigation systems.

B. J. SCHROCK

Jay Schrock is Marketing Manager, Amoco Reinforced Plastics Company, Riverside, California. In his present position, Mr. Schrock is responsible for marketing and sales of Amoco's Techite RPM pipe.

Prior to joining Amoco, Mr. Schrock was Sales Manager of United Technology Center, who developed Techite pipe. Mr. Schrock has had 18 years of diversified experience in the pipe industry including design, construction and sales of conventional pipe materials.

Mr. Schrock is a graduate Civil Engineer, California State College and is a registered Professional Civil Engineer in California and Nevada.

G. RANGEL

Gabe Rangel is Engineering Services Manager, Amoco Reinforced Plastics Company, Riverside, California. In his present position, Mr. Rangel is responsible for all pipeline layout engineering and field technical service related to Amoco's Techite RPM pipe.

Mr. Rangel has had 20 years of diversified experience in equipment design, tooling design, pipeline engineering, and pipe development. Before joining Amoco, he held various positions with United Technology Center, Aerojet General, and Food Machinery Corp. in the aforementioned areas.

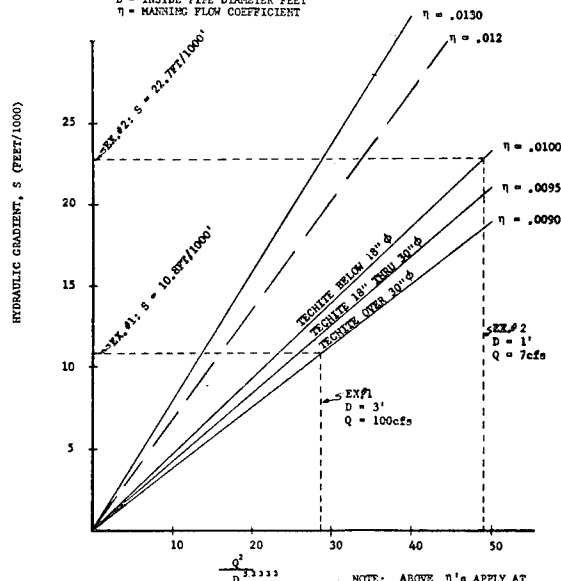
MANNING FORMULA

NORMAL FORM: $V = \frac{1.486}{n} R^{2/3} S^{1/2}$
NOTING: $Q = AV = \frac{\pi}{4} D^2 V$ and $R = \frac{D}{4}$ FOR CIRCULAR PIPES

FLOWING FULL, S REVERSES
 $S = \left(\frac{n}{.4629} \right)^3 \frac{Q^2}{D^{5.333}}$

S vs $\frac{Q^2}{D^{5.333}}$ IS PLOTTED BELOW FOR VARIOUS n VALUES.

WHERE:
 S = HEAD LOSS, FEET PER FOOT OF PIPE
 Q = FLOW RATE, CUBIC FEET PER SECOND
 D = INSIDE PIPE DIAMETER FEET
 n = MANNING FLOW COEFFICIENT



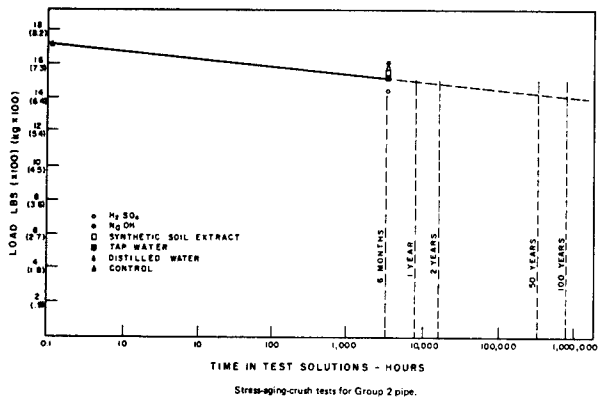
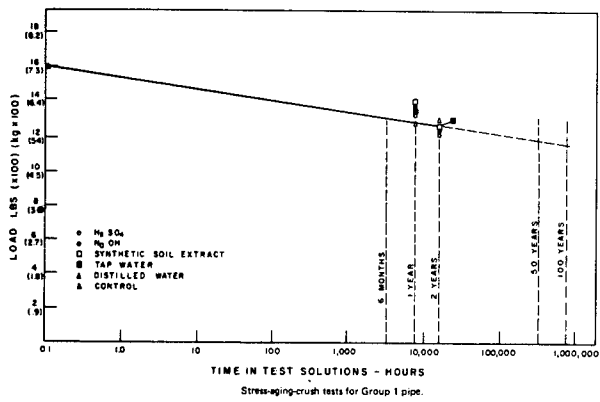


FIG. 3



Photo 1. Cucamonga Interceptor Sewer—42" Installation



Photo 2. Cucamonga Interceptor Sewer—RPM Manhole in Fore-ground

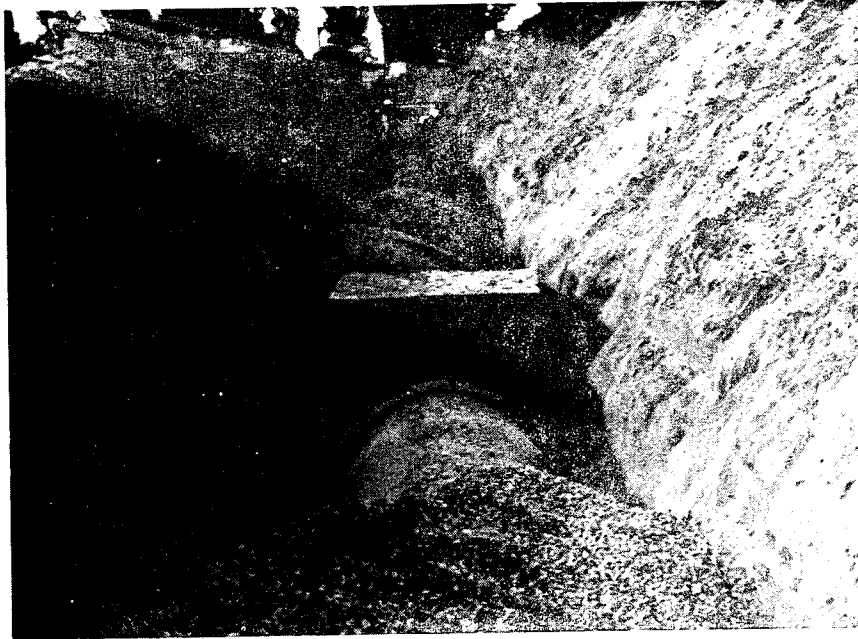


Photo 3. Cucamonga Interceptor Sewer— $\frac{3}{4}$ " and Minus Graded
Rock in Pipe Zone Area

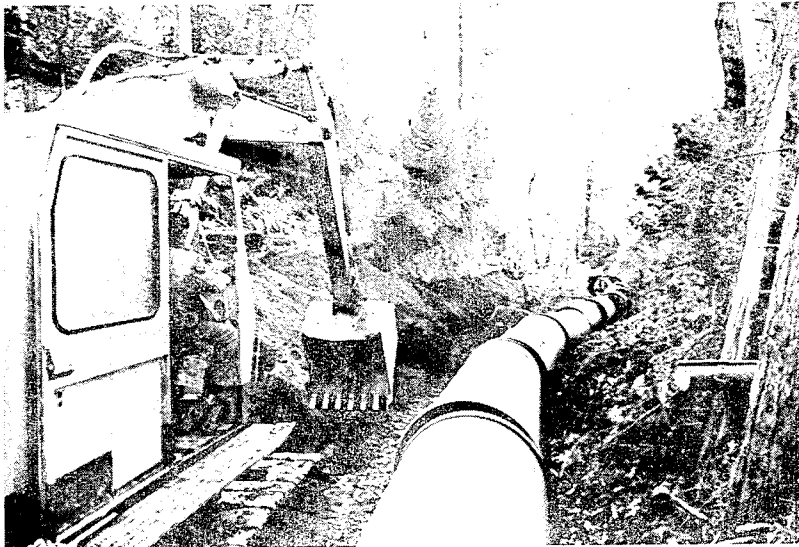


Photo 4. Nevada Irrigation District—48 Inch Pressure in Tree Area
and Mountain Terrain. Narrow Rights-of-Way.

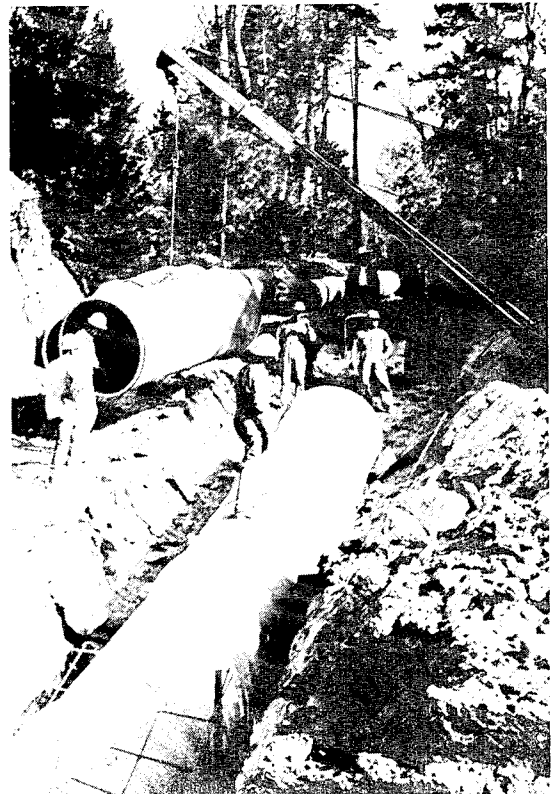


Photo 5. Nevada Irrigation District—Unique Installation Methods
with Large Diameter Lightweight RPM Pipe.

SECTION FIVE

SOURCES FOR FURTHER INFORMATION

Much admired as a comprehensive survey article for chemical engineers is "Using Reinforced Plastics for Process Equipment," by J. S. Dorsey, Consulting Engineer, Whittier, California, *Chemical Engineering*, September 15, 1975 (11 pp, Order No. 236, to Chemical Engineering Reprints, 43 floor, 1221 Avenue of the Americas, New York, N.Y. 10020, \$2.50 per copy).

For the last several years the SPI Reinforced Plastics/Composites Institute Annual Conference, the first week of February, has included ten or twelve papers on chemical-resistant materials or applications. Some specific uses, and certain detailed research papers have been omitted from this selection. Readers should also be alert to the papers on this subject which will be presented at the 1976 and subsequent Annual Conferences. In recent years the Conference Proceedings Book has been available for \$35.00 per volume, orders to Publications Sales, SPI, 355 Lexington Avenue, New York, N. Y. 10017.

SPI has also been active in sponsorship of joint Conferences with the National Association of Corrosion Engineers and other organizations. Papers presented at NACE symposia April 13-15, 1971 (St. Louis) and November, 1975 (San Antonio) are available from NACE, 2400 West Loop South, Houston, Texas 77027. The Corrosion Data Survey, Nonmetals Section, fifth edition, is available from NACE at P.O. Box 1499, Houston, Texas 77001.

Readers may also be interested in the reprint of "Economy in Reinforced Plastic," a major technical conference for engineers and end-users of corrosion-resistant structures, to be held April 28-30, 1976 in Las Vegas, Nevada. More than twenty papers are being prepared by fabricators exclusively, the intention being to specifically assist product users. Reprints will be available after May 1, 1976 from SPI Publications Sales in New York, address as above.

Finally, material suppliers, manufacturers, and users very active with these applications should be aware of American Society of Testing and Materials Committee D-20.23, "Reinforced Thermoset Resin Piping Systems and Process Equipment," which at the time of publication has fourteen different specifications and/or methods of test in the course of development. Qualified plastics industry members may also belong to the SPI Corrosion-Resistant Structures Committee, which has liaison with the technical standards activity of ASTM (above) and extensive programs in the area of codes, conferences, market promotion, statistics, and various other trade association functions.



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