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"VINYL PLASTICS IN THE HOUSEHOLD"

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November 15, 1961

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"VINYL PLASTICS IN THE HOUSEHOLD"

Regional Technical Conference of the Society of Plastics Engineers, Inc.

sponsored by

NEW YORK SECTION

New York, New York

November 15,1961

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INTRODUCING PLASTICS INTO RESIDENTIAL BUILDING

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ANALYZING THE PRODUCT AND ITS MARKET

A distinguished lawyer once remarked that had he time to study only one side of a case, he would spend that time researching his opponents case. While seemingly paradoxial, this modus operandi is analogous to the problem of gaining acception of plastics building products; knowledge of the market and product requirements is of paramount importance in developing acceptable building products. The massive market potential offered by the building industry has attracted many product innovators into the market, only to lead them into failure due to lack of product acceptance. Other good products pass through abortive sales programs due to lack of product testing, product standards and field experience so necessary to developing customer acceptance. In many cases, the success or failure of a building product is determined before the product actually "hits the market" and subsequent commercialization is inevitably disastrous.

Thus, rather than review the merits of plastics for building, [This paper ~~will~~] [discusses problems which were faced in developing plastics for the building markets and how development efforts can lead to more successful product sales. No engineering design data are provided but the need for product standards, product uniformity, and quality controls is pointed out.]

With increasing costs of construction and the demand for better performance and lower upkeep of residential buildings, construction methods and materials are becoming subject to intensive study. One result is that the building industry has adopted many industrial engineering practices to improve efficiency of site construction operations. These new construction methods, such as prefabrication, preassembly and mass construction apply proven cost reducing principles to the handling of traditional building materials. Therein lies an anomaly. Building materials dictate the method for their application and, thus, place a restriction on the extent to which method and material innovations can be employed. Add this to the comparative lack of research and development effort in the building industry and you can readily see why this industry needs help. This provides a great opportunity for you as plastics manufacturers to participate in the building market.

Recognizing that the market potential for building products provides adequate justification for development effort, analyze the industry from the standpoint of factors that govern acceptance of building products and product requirements which are necessary to fulfill functions of the application.

A. Factors Governing Acceptance of Building Products

The building industry is difficult to define in that it lacks many of the criteria normally used to identify an industry. For purposes of this discussion, confine the analysis to the residential building market. Initially, it is necessary to distinguish between production and regularity elements which combine to govern residential construction. The production of housing units involves designers, material manufacturers, distributors and builders. To this group add the home owner who in turn influences the designer and the cycle of primary influence is completed. Each of these five stations in the cycle represents various specialized operations in planning and creating housing. Designers involve architects, engineers, land planners and interior decorators who plan the physical and environmental concepts of the house. Material manufacturers represent producers of basic materials, components and equipment; these groups have the largest investment in production plants and materials and are thus most concerned about obsolescence of products through design or product change. Distributors provide a vital link to the widely dispersed residential building market. Depending on the product and geographical coverage, marketing channels may involve distributors, jobbers, wholesalers, manufacturers' agents, dealers, building supply houses and retailers. These factors, while essential to getting a product into the house, do not exert much original influence on product design; however, projected product prices must provide sufficient incentive for their distribution services. Builders represented by general contractors, subcontractors, homebuilders, prefabricators and labor perform the final assembly operations. They utilize services of these other groups to construct a house which must meet the approval of the fifth group - building owners and operators. While the buyer makes the ultimate decision on the house, he is losing influence in the selection of building products with the trend away from custom built houses. However, the selection of those products which add comfort and ease of living to the house will still be strongly influenced by the building owner. Finally, to close the cycle, the buyer influences trends in residential styling, thus governing the work of designers.

Regulatory groups, though considered as secondary, serve equally important functions of financing, insuring and safety. Financing of new buildings is so important to their creation that a major segment of the banking institution - both private and public - is devoted to the needs of the building industry. When providing long term funds for construction and purchase of housing, financing agencies require assurance that construction methods and materials will be adequate to maintain property value during the term of their mortgage; yet, regulations cannot restrict the introduction of new, though relatively inexperienced, products that may lower cost or improve performance of housing. The Federal Housing Administration has been instrumental in providing housing to an income class not otherwise able to afford adequate shelter. In so doing, FHA has developed a set of Minimum Property Standards for residential building materials and products which have become almost universally accepted by the housing industry. While FHA maintains that their MPSs are not a code, few builders will use products which are not approved by FHA and thus acceptable for their financing.

Building codes are of vital importance to the entire industry. By establishing minimum standards for construction methods and product performance, building codes provide protection for the owner and occupant. Recognizing the public responsibility of building codes, it is important to consult with these groups during planning, developing and testing of new building products. Code groups - especially the performance codes - are designed to serve the building industry and can be most helpful to you in directing and conducting building product development activities.

B. Analyzing Building Product Requirements

A preliminary review of the building industry will provide background knowledge necessary to making proper evaluation of and planning for plastics building products. Unfortunately, many plastic companies undertake market potential studies and, on their basis, move directly into product development and production activities; this road to success is paved with many, many failures.

Product analysis of the building industry will reveal those areas that offer the best opportunities and will, if properly evaluated, prevent you from undertaking futile development projects. It is axiomatic that the greatest opportunity exists in those areas of greatest need; however, many people forget this simple truth in selecting products for development.

Building products and their application should be evaluated from both cost and performance. The builder will look more towards cost while the owner will evaluate individual products and materials more on their performance.

The cost of building construction has been increasing largely due to increased costs of labor. The division of total costs for residential construction is estimated to be:

Component	Per Cent of Total Cost
Foundation	10
Frame and Exterior Finish	15
Masonry	10
Plumbing, Heating, Wiring, Appliances	30
Interior Finishing	25
Decorating	10
Total	100

It should be noted that interior finishing and installation of facilities represents 55% of the building cost, over half of which is labor expense.

Cost reductions in building may be achieved in several ways; these include:

1. Lower priced materials
2. Lower installation costs
3. Preassembly of components
4. Combination of functions in a product
5. Elimination of building operations
6. Mechanizing building operations

Improving performance and durability of building products increases the utility value of these products to the consumer; his savings will be gained from:

1. Lower maintenance and repair expense
2. Improved appearance and environment
3. Less frequent replacement
4. Additional safety
5. Lower operating expense
6. Added leisure time

Introduction of new building products, which provide better quality, has always been a successful commercial approach. Witness such notable examples as vinyl flooring, melamine laminates and vinyl electrical insulation.

After selecting those building product areas which justify further study, determine the functional and performance properties of existing products and compare this data with optimum performance requirements for their application.

You may wish to establish a master list of building product requirements and rate materials accordingly. Be sure to give adequate consideration to tangible as well as environmental criteria, to initial as well as maintenance and replacement costs, to product as well as installation cost and to performance and comfort as well as safety.

A similar evaluation should be made of plastics materials, including their properties, processing and application methods. Look for those materials which offer the best optimum balance of properties and processing methods and which most closely fulfill building industry regulations for safety, performance and durability.

A careful evaluation of these product analyses will provide the right areas, the right products and the right material with which to initiate your building product development program. At the same time you have developed a better understanding of the building industry's organization, operation, regulations and applications and are now ready to begin the development of plastics building products.

DEVELOPMENT OF THE PLASTICS BUILDING PRODUCT

The development of plastics building products involves important new considerations that may not be associated with your present product structure. You will be concerned with long term performance, safety of the occupants and contingent product liability, rigid performance requirements and product standards, satisfactory demonstration of operation under extremes of climatic conditions, methods of product application as well as operation and responsibility to your company to develop building products which will assure a future role in this growing market.

A. Designing the Product

With reference to building products, design may be defined as the fashioning of suitable materials into a form required for effective performance and easy installation and an appearance that is attractive and complimentary to the structure. Implicit in any definition of design is the relationship between materials and ultimate shape. Plastics building products must be designed to take advantage of the inherently good properties in these materials and, of course, to overcome their weaknesses.

The criteria important to good design should include full exploitation of the inherent properties of the materials, engineered product performance, modular dimensions, coordination with other building components and integration of components. With the gap existing between the plastics and building industry, it is imperative that plastics producers and architects and design engineers work together. Too often the good properties of plastics in emulating the design of existing products are not exploited; thus, incurring criticism from engineers and architects. For example, when rigid plastics pipe was developed, plastics pipe manufacturers adopted I.P.S. dimensional standards, which in turn were based on the burst pressure of the steel pipe with adequate allowance for corrosion and fitting assembly. The lack of correlation is obvious. Industry efforts are now being directed towards establishing a more meaningful system of plastics pipe dimensions.

The responsibility for engineering product performance requires: determination of engineering data required for application, uniform standards of measurement, accurate measuring of product performance, interpretation of results into meaningful engineering data and extrapolation of results into long-term performance.. Architects and engineers have not yet learned to separate plastics by chemical classifications, much less to associate plastics with their specific properties. Referring once again to pipe, the initial burst pressure established for the several plastics products were determined by different test procedures, thus preventing any meaningful correlation of operating pressure and safety factors. To assist the plastics industry in designing and reporting building product data, the Building Research Institute has prepared a format outlining information requirements for selection of plastics for use in building. Copies of the format are available from BRI headquarters in Washington, D. C.

With the flexibility inherent in plastics products, it is easy to observe good modular practice in designing of building products. This same versatility also enables closer coordination of plastics with other building products; the synergism which are achieved in chemical products can also be achieved in building products. The prefabrication of building products and integration of discrete components into complete assemblies is becoming a popular approach to reducing building costs. It will be to your advantage to design plastics building products which facilitate this trend.

The need for prototypes of plastics building products is evident by the inability to predict operating and climatic performance of plastics products. Prototypes, while being important to the design engineer, also provide a means to evaluate the production problems incident to their ultimate manufacture. Finally, these pilot models will inform you of the relationship between adequate product design and product costs.

All building products have minimum performance standards to meet, though acutal industry standards may infer these properties through design or specification controls. Thus, it is not sufficient to reproduce the image of conventional building products in designing plastics components; actual performance must be used as a criteria.

Plastics, being non-metallic, have provided many confusing and fearful conditions to the design engineers, which required evaluation of prototypes to resolve. For example, while the coefficient of thermal expansion of rigid vinyl is greater than that of aluminum its insulation value protects rigid vinyl sash from extremes of temperature, thus reducing actual dimensional changes to less than would be expected. Though two types of hot water plastics piping may have similar short term burst pressures, their relative sensitivity to creep and to stress crazing will have significant influence on long term performance. The inherent resilience of plastics to bending and denting provides resistance to this type of abuse where metal must depend on adequate thickness for dent resistance. Fatigue strength under vibration loading will vary between reinforced plastics and homogeneous materials. Some plastics suffer more from weather erosion than from sunlight, thus, limiting their serviceable life. These and many other criteria can only be evaluated through actual performance tests.

FIELD TESTING

Of great importance to the building industry and especially to the regulatory agencies is the performance of new building products under field tests. Many vital performance criteria cannot be properly or meaningfully evaluated in the laboratory; special factors requiring field tests may include resistance of product to handling during shipping and installation, factory and field assembly operations, exposure to effect of extremes of climatic and atmospheric environments, acceptance of labor to the product, acceptance of building codes and government regulatory agencies and consumer acceptance. Many times, extensive field tests will reveal a need for additional laboratory work on specific performance properties.

The builders and code groups provide an impasse to the product development man by requiring product installation experience before buying but being unwilling to become guinea pigs for new products. Fortunately, efforts to resolve this dilemma are bearing fruit. Recent changes in the Housing Law now provide for testing of promising new products in FHA insured construction. The National Association of Home Builders has erected a series of research houses to evaluate new building products; after construction, the houses are occupied under provisions for routine observation of product performance.

Often large builders are willing to test new products which offer promise of improving their housing construction. In many cases, field testing of building products is expensive; however, being mindful of contingent liability for product performance and occupant safety, the cost is good insurance.

COMMERCIAL DEVELOPMENT

Development of building products cannot be confined to product and field testing, since ultimate acceptance still must be obtained from the secondary regulatory agencies that govern the quality and performance of materials and their installation. Planning and preparation for obtaining approval should become an elemental part of your commercial development program.

The preparation for commercial presentation of plastics building products should include development of product quality and performance standards and identifying governing regulatory agencies, determining their product tests and providing adequate information for product appraisal.

A. Product Standards

The performance and durability of building products is of great importance to the welfare and safety of the occupants. Thus, the product manufacturer has direct responsibility for product performance and contingent liability for damage resulting from its failure. Cost of contingent liability could easily bankrupt small companies. In addition, product failure could result in complete prohibition of the product in future construction, thus, destroying the market potential which was to have paid for the product investment. Plastics building products are most suspect, because of their association with other plastics products - especially consumer items - which have failed because of improper design or materials selection.

Product standards, product uniformity and quality controls are necessarily related. The product controls for plastics building products will usually involve three factors - raw materials, processing and/or conversion and fabrication and assembly. You as plastics converters, will be held directly accountable for product performance - and failure. Yet, as a converter of plastics, you must rely on your supplier for quality control and uniformity of raw materials and on the fabricator or installer who accepts little if any responsibility for product performance. The raw material suppliers should provide evidence, based on laboratory and field testing, of his products performance in the specific building product applications. Proper caution here can pay big dividends. The variance in materials and their performance in such properties as brittleness, weathering, creep, structure, corrosion resistance and appearance may not be evident until years after installation. Remember, that the cost of replacing products may be far more expensive than initial costs.

Remember too, that many important functional and performance requirements lack reliable accelerated tests. The classic argument on correlation of accelerated weathering equipment with actual exposure is but one example. Plastics pipe provides another good case study. European rigid vinyl pipe producers have used experience gained from twenty years of service to develop reliable production controls which correlate with performance expectancy. Another example is window sash. How do you predict the life expectancy of rigid vinyl sash without actual field experience on sash materials; realistic quality standards and product controls can only be determined after careful and extensive observation of extended installations.

There is no real substitute for actual field testing where plastics building materials and products are subjected to all extremes of temperature and sunlight exposure, handling and installation abuses, atmospheric conditions including industrial and coastal, and types of operation. Furthermore, the performance of a material in one application does not imply that the material is satisfactory for other building products. Obviously, the specific performance environment indigenous to pipe products differs from window sash or glazing and dangerous inferences can be made by relying on unrelated product experiences.

B. Regulatory Agencies

Regulatory agencies for controlling quality and application of building products are necessary to protect the safety of occupants and the financial investment of owners and mortgagors. The regulating agencies will differ with geographic areas, types of construction; e.g. residential, commercial or industrial types of ownership, products and functions of products and type of financing. Knowing the product and specific building markets toward which your commercial development program will be directed, you can - and should - determine which code groups and other regulatory agencies govern use of your product. Indeed, identification of these agencies, their product standards and acceptance procedures should be an important part of the initial market analysis. A building product has no market value for primary construction without building code approval.

It is estimated that there are about 5,000 regulating agencies controlling building products. If one recalls the various types of product and governmental codes, this figure does not seem excessive. Recognizing the importance of code groups in gaining acceptance of plastic building products the Manufacturing Chemists Association, in conjunction with the Society of the Plastics Industry, is preparing a primer on where and how to obtain building code approval.

Residential construction is becoming increasingly governed by the "Minimum Property Standard" issued by FHA. While not operating as a code group, the extent of FHA financing places a strong influence on the use of building products for house construction. Since most mortgages extend for a minimum of twenty years, FHA and other similar financing groups require assurance in the form of test data and performance experience that the product will last that long without failure. In addition, product standards are required to insure conformance of commercial products to performance requirements.

You will find it helpful to discuss new products with the proper code groups during the development period. Their guidance on performance tests and quality measurements will be helpful in your product evaluation. It is self-evident that gaining the confidence of the building code groups will be helpful in gaining their ultimate acceptance of the product.

CONCLUSION

The plastics industry has a real challenge to face in developing new and better building products. If we are to be successful, we must approach these developments with a well organized plan and a profound and demonstrated sense of responsibility to the industry and to our customers. We must become better acquainted with the building organization, operations and needs. Then too, we must proffer only those products which have been thoroughly tested and proven to meet the needs in both performance and durability.

The opportunity is great, and with proper planning and development, you can enjoy a real exciting future in this the building industry.

Plastic Ref # 167

EFFECTS OF PROCESSING CONDITIONS AND PLASTICIZER CHOICE ON PHYSICAL PROPERTIES OF POLYVINYL CHLORIDE

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INTRODUCTION

The study of the effect of plasticizer choice on the solvation and processing characteristics of polyvinyl chloride resin formulations has been widely reviewed in recent years. This is justly so. The selection of a proper plasticizer, involving economic and quality considerations offers a wide range of problems, as every vinyl formulator well knows.

This paper ~~will~~ classif~~y~~ies plasticizers in broad terms by their solvating effect on PVC resin and compares their relative effects on processing conditions and physical properties. The information presented represents a plasticizer-application-laboratory viewpoint so that it might be of as wide-spread interest as possible.

CLASSIFICATION

The 1961 "Modern Plastics Encyclopedia" lists 375 commercial plasticizers. There are probably others. To bring the number of products within the scope of one paper, these will be divided into three general classes (each typified by a specific compound) selected according to fusion characteristics in polyvinyl chloride.

Table I shows a list of recent articles dealing with this problem of resin solvation by the plasticizer. The majority of these papers covered different methods of measurements, but all categorize plasticizers into three major groups - rapidly, moderately and slowly solvating. All seem to agree on the examples selected as typical of each class. The defining limits set are more arbitrary.

The suggested classes then are as shown in Table II. The last class has two examples to indicate a range of values, but DIDP will be used primarily.

Table III shows how this classification compares with data presented previously. The pattern is established. All agree within acceptable limits.

COMPARISON

With three ranges of solvating rates established, it is natural to assume that each product performs differently under identical test conditions. This is exactly the case. These variations should be studied that they might be better used to each formulator's advantage.

All vinyl compounders, whether formulating for garden hose, toys, or vinyl coated fabrics, are concerned with the curing rate and conditions optimum for their product. Plasticizers have important influences on these. In Figure 1 note the difference in percentage of ultimate elongation developed by the three plasticizers at identical fusion times. Figures 2 and 3 continue to support these differences. The rapid solvating plasticizer shows faster fusion at lower temperatures and more rapid development of usable physical properties. This is of great importance where available processing temperatures are marginal or where faster production rates would be advantageous.

Today, a short "dry-blending" cycle is an advantage to many extruders. The relative solvency of the plasticizer is of obvious importance here. Table IV compares the dry-blending of these plasticizers. The rapid solvating plasticizer tends to speed the dry-blending cycle, allowing less heat history on the formulation and permitting more blending cycles per shift. This is an inexpensive way to gain greater output. Park of Firestone Plastics also studied this variation in plasticizer activity in formulations mixed in a Day Mixer (Table V). His findings confirmed that the slower solvating DIDP requires longer time cycles or high heat imput than BBP.

The effect of plasticizers on Banbury cycle times was studied as early as 1951 by Bergen and Darby. The advantages they found for butyl benzyl phthalate have been supported by more recent work (Table VI). Data indicates that Banbury mixes used to feed calenders or extruders could be dropped more quickly if rapid solvating plasticizers are used.

The tear strength of vinyl films can be increased by the use of rapid solvating plasticizers without exceeding normal fusion temperatures. This is true in both calendering and plastisol applications as Figures 4 and 5 demonstrate.

Processing conditions for both vinyl-asbestos and homogenous vinyl floor tile formulations may be influenced by the choice of plasticizers. Rapid solvating plasticizers are widely favored in these applications as insurance against processing difficulties. Tables VII, VIII and IX show evaluations of vinyl asbestos and flexible vinyl floor tile comparing the three types of plasticizers.

Most recent studies on effect of plasticizers on fusion characteristics of vinyl formulations has been made on plastisols. Many comparisons exist among butyl benzyl phthalate, dioctyl phthalate, and diisodecyl phthalate. All agree in essence. This field most clearly illustrates the "compromise" considerations necessary for proper vinyl compounding. Rapidly solvating plasticizers offer fast cure cycles, rapid tensile and tear strength development and prompt gel formation, as well as build-up viscosity more easily during prolonged shelf life or during storage at accelerated temperatures. Slowly solvating plasticizers as DIDP offer superior long-term viscosity stability with small viscosity increases but require higher temperature cures or longer oven cycles. It is up to the skill of the formulator to balance these two extremes. Table X shows a comparison of several sets of data backing up this thinking.

Many companies consider that point in the curing cycle of a plastisol where maximum elongation is achieved as the optimum end point. Table XI compares cure cycles and elongation results for the three plasticizers re-emphasizing the advantages of the rapid solvating plasticizer in this application.

CONCLUSIONS

Plasticizers may be grouped in three broad categories according to their relative rate of solvation for polyvinyl chloride resins. The following classification ~~was~~ suggested:

Rapidly solvating plasticizers	Butyl benzyl phthalate
Moderately solvating plasticizers	Di-2-ethylhexyl phthalate
Slowly solvating plasticizers	Diisodecyl phthalate

The unique advantages of each group to the vinyl formulator ~~was~~ discussed under several processing conditions. It is trite but true to say that these differential variations, considered with each plasticizer's performance characteristics, offers an almost endless challenge to the vinyl compounder. The skillful formulator realizes this and uses these variances to his best advantage.

The effect of plasticizer choice on fusion time, maximum elongation, and tensile strength.

TABLE I

SUMMARY OF RECENT ARTICLES ON RESIN SOLVATION BY PLASTICIZER

C. E. Anagnostopoulos A. Y. Coran H. R. Gamrath	"Polymer-Diluent Interactions A New Micromethod of Determining Polyvinyl chloride-Diluent Interactions", Journal of Applied Polymer Science, Vol IV, No. 11 Pages 181-192, (1960).
W. G. Bauer	"Plastisol Gelation - A New Instrument and Formulating Technique", SPE Journal Page 174, February, 1961.
David H. Bechtold	"Effects of Processing Conditions and Plasticizer Choice on Physical Properties of Polyvinyl Chloride" Paper presented at Philadelphia Section of SPE, March 28, 1961.
H. S. Bergen J. R. Darby	"Vinyl Plasticizers - Effect on Processing Polyvinyl Chloride in Banbury Mixers", Industrial and Engineering Chemistry, Vol 43, Page 2404, October, 1951.
A. W. M. Coaker M. W. Williams J. R. Darby P. R. Graham J. A. Greenhoe	"Plasticizer Absorption Rate of Polyvinyl Chloride", Modern Plastics, October 1955. "Viscosity Stability of Plastisols", Modern Plastics, June 1955. "The Mechanics and Testing of Plastisol Gelation and Fusion", paper presented at SPE 17th Annual Technical Conference in Washington, D. C. January, 1961.
P. R. Graham J. R. Darby Arthur C. Hicker Norman L. Perry	"Effect of Plasticizers on Plastisol Fusion", SPE Journal, Vol. 17, No. 1, January 1961 "Determination of Plasticizer Compatibility by Swelling Measurements". Paper presented at SPE 16th Annual Technical Conference in Chicago, Ill., January, 1960
L. A. McKenna	"Effects of Plasticizers on the Fusion of Vinyl Plastisols", Modern Plastics, Page 142, June 1958.
D. S. Newton ARIC J. A. Cronin Russell A. Park	"Plasticizers for PVC Plastisols" British Plastics, Page 426, October 1958. "Effects of Plasticizers upon Dry Blending Polyvinyl Chloride Resins", publication of Firestone Plastics Co.

TABLE II

PROPOSED CLASSIFICATION OF PLASTICIZER BY SOLUENCY FOR PVC RESIN

Classification	Example	Range
Rapidly solvating	Butyl benzyl phthalate	Most rapid solvating down to diphenyl phthalate
Moderately solvating	di-2-ethylhexyl phthalate	From butyl octyl phthalate types to diisodecyl phthalate
Slowly solvating	diisodecyl phthalate (DIDP) or diisodecyl adipate (DIDA)	From diisodecyl phthalate to slowest solvating type adipates and polymerics

TABLE III

COMPARISON OF PLASTICIZER SOLVATION RATES BY VARIOUS METHODS

Method	Reference	BBP	DOP	DIDP	DIDA
Fusion points, °C.	1	89	127	138	156
Plast. absorbed, lbs./hr.	2	155	290	130	25
Plasticizer absorption time, mins.	3	2	3	4.2	-
Fusion temperature, °C.	4	76	110	130	156
Setting temp. °C.	5	80	70	105	95
Gelation temp. °C.		145	160	160	165
Fusion temp. °C.		160	170	170	170
Banbury fusion time, Sec.	6	47	71	-	-
Fusion time, sec.	7	47	71	86	-
Day mixer time, mins.	8	4	8	90	-

References

1. P. R. Graham, J. R. Darby from Table I
2. Arthur C. Hicker, Norman L. Perry, from Table I
3. A. W. M. Coaker, M. W. Williams from Table I
4. L. A. McKenna from Table I
5. D. S. Newton ARIC, J. A. Cronin from Table I
6. H. S. Bergen, J. R. Darby from Table I
7. David H. Bechtold from Table I
8. Russell A. Park from Table I

TABLE IV

RELATIVE DRY BLENDING TIMES

BBP	2 minutes
DOP	3 minutes
DIDP	4.2 minutes

FORMULATION

Opalon 300 FM	100	Temperature 100°C
Plasticizer	50	

SOURCE

A. W. M. Coaker
M. W. Williams
From Table I

TABLE V

ABSORPTIVITY CHARACTERISTICS OF VARIOUS COMMERCIALLY AVAILABLE PLASTICIZERS

Plasticizer	Day Mixer Absorptivity Time, Minutes
Butyl benzyl phthalate	4
Dioctyl phthalate	12
Diisodecyl phthalate	90+

Formulation

Exon 500	100
Plasticizer	50
Co-ppt Ba Cd Laurate	2
Chelating Agent	1

SOURCE

Russell A. Park Fire Stone Plastics Co.
"Effect of Plasticizers upon Dry Blending Polyvinyl Chloride Resins", 12/3/58

TABLE VI

FORMULATIONS AND BANBURY TEST DATA

	Fusion Time, Sec.	Temp. at Fusion, °F.	Time to Reach Uniform Temperature, Sec.
Butyl benzyl phthalate	47	240	190
Dioctyl Phthalate	71	245	265
Diisodecyl phthalate	Not then commercially available		

Formulation

Opalon 300	100
Plasticizer	50
Pos B	2
Fused Lead St.	1

SOURCE
H. S. Bergen and J. R. Darby
"Vinyl Plasticizers on Processing Polyvinyl chloride in Banbury Mixers"
Industrial & Engineering Chemistry 10/51

TABLE VII

PLASTICIZER FOR VINYL ASBESTOS TILE

Formula

Opalon 506	100
Asbestos 7R	160
Limestone	290
TiO_2	20
Normasol	5
Plasticizer	As Indicated

			Staining			Processing		
	PHR	MBIH	Brown	Yellow	Asphalt	Banbury	Plasticity	Tack
Dioctyl Phthalate	32.0	8.9	F	F	F	2:35	VG	G
Diisodecyl Phthalate	34.0	9.5	P	P	P	2:35	G	F
Santicizer 160	36.0	8.7	G	G	G	2:03	E	E

TABLE VIII

FLEXIBLE VINYL TILE STUDY

Formulation	
Opalon 306B	100
Atomite	120
Snowbrite Clay	60
Paraplex G-62	5
Metasap 635	4
Aristowax	0.5
Stearic Acid	0.5
TiO_2	5
Plasticizer	Varied

Processing Conditions

Banbury: 30# Steam on Jacket
15# Air Pressure on Ram
No water or steam on rotors
#2 Speed
Drop Temperature 320°F.
Mill: Front Roll - 320°F.
Back Roll - 300°F.
Time - 1:30
Calender: Front Roll - 300°F.
Back Roll - 255°F.

Plasticizer	Concentration, lbs/hr.	Fusion Time Sec.	Fusion Temperature °F.	Time to Reach Banbury Drop Temperature of 300°F.	320°F.	Plasticity	Tack to Rolls in Calendering
Santicizer 160	36	:30	225	1:20	2:33	Good	Good
Diisodecyl phthalate	32	1:25	260	2:25	3:20	Fair	Fair
Dioctyl phthalate	32	1:02	245	2:05	3:00	Fair	Fair

TABLE IX

FLEXIBLE VINYL TILE STUDY

Formulation	
Opalon 306B	100
Atomite	66
Snowbrite Clay	200
Paraplex G-62	5
Metasap 635	4
Aristowax	0.5
Stearic Acid	0.5
TiO_2	10
Plasticizer	Varied

Processing Conditions

Banbury: 30# Steam on Jacket
15# Air Pressure on Ram
No water or steam on rotors
#2 Speed
Drop Temperature 320° F.
Mill: Front Roll - 305°F.
Back Roll - 285°F.
Time - 1:30
Calender: Front Roll - 295°F.
Back Roll - 255°F. 2 passes

Plasticizer	Concentration lbs/hr.	Fusion Time Sec.	Fusion Temperature, °F.	Time to Reach Banbury Drop Temperature of 300°F.	310°F.	320°F.	Plasticity	Tack to Rolls in Calendering
Santicizer 160	54	:30	225	1:40	2:05	2:20	Excellent	Excellent
Diisodecyl phthalate	50	:55	270	1:15	1:20	1:55	Fair	Fair-Good
Dioctyl phthalate	51	:49	260	1:14	1:52	2:18	Fair	Fair

TABLE X

COMPARISON OF PLASTICIZER SOLVATION DATA IN PLASTISOLS

Test	Butyl Benzyl Phthalate	Dioctyl Phthalate	Diisodecyl Phthalate	Source
65 lbs/hr Fischer Johns)Fusion clear point test)Point, °C.	89	127	138	Monsanto Laboratories
Minimum fusion temp @ 90 lbs/hr., °C.	76	112	130	L. A. McKenna Effect of Plasticizers on the Fusion of Vinyl Plastisols
Gelation temp @ 75 lbs/hr., °C.	55	63	70	Todd WD. Easgrove D & Smith M D Mod Plastics 34,159, Sept. 56
Setting temp, °C.	80	70	105)	D.S.Newton, Aric, J.A.Cronin "Plasticizer for PVC Plastisols" British Plastics Oct. 58
Gelation temp, °C. @ 67 lbs/hr.	145	160	160)	
Complete fusion temp, °C.	160	170	170)	

Plastisol Viscosity @ 80 phr (in poises)

Brookfield 25°C LUF	Initial (4hr)	35	36	45	
#4 spindle	28 days	164	132	80	
12 rpm 40°C	Initial(4hr)	37	37	31	Monsanto Laboratories
	28 days	gel in 7 days	426	120	
50°C	Initial(4hr)	gel	66	50	
	28 days	gel	gel in 1 day	300	

TABLE XI

TIME AT WHICH 60 PHR PLASTISOLS
REACH HIGHEST ELONGATION

	150°C		170°C		200°C	
Butyl benzyl phthalate	25 min.	(400%)	10 min.	(420%)	5 min.	(460%)
Dioctyl phthalate	240 min.	(330%)	15 min.	(400%)	10 min.	(400%)
Diisodecyl phthalate	-----		35 min.	(430%)	5 min.	(460%)

EFFECT OF PLASTICIZER CHOICE ON FUSION TIME & ELONGATION DEVELOPMENT

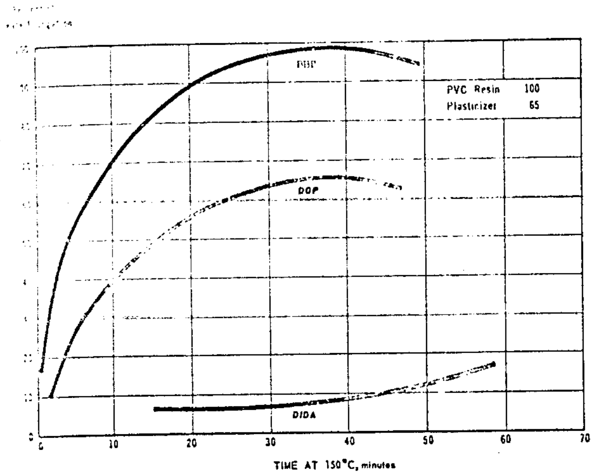


FIGURE 1

EFFECT OF PLASTICIZER CHOICE ON FUSION TIME & TEMPERATURE

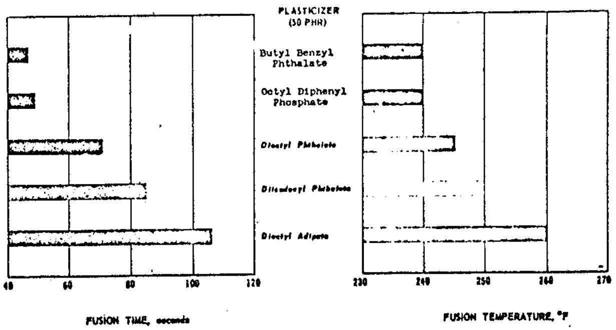


FIGURE 2

EFFECT OF PLASTICIZER CHOICE ON TIME TO DEVELOP 75% OF ULTIMATE ELONGATION

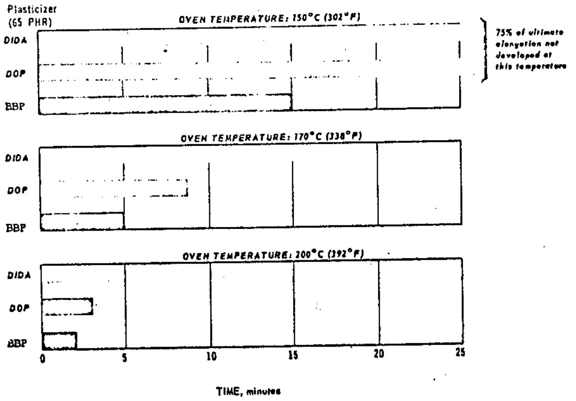


FIGURE 3

EFFECT OF PLASTICIZER CHOICE ON TEAR STRENGTH

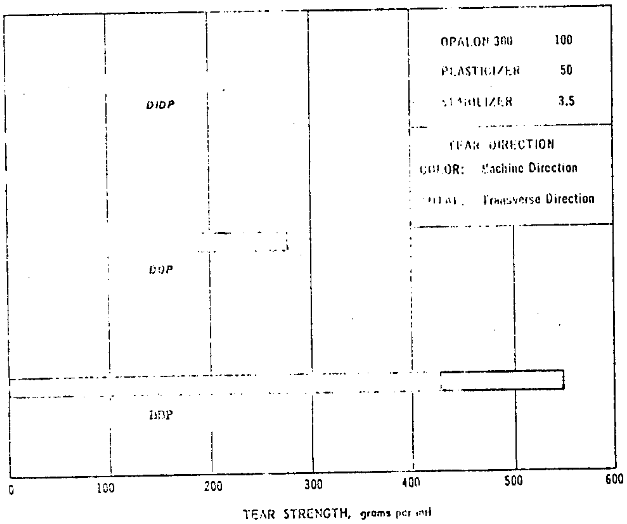
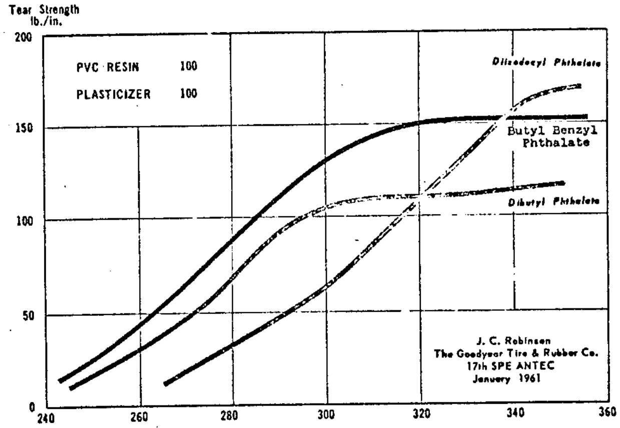


FIGURE 4

EFFECT OF PLASTICIZER CHOICE ON FUSION TEMPERATURE & TEAR STRENGTH



J. C. Robinsen
The Goodyear Tire & Rubber Co.
17th SPE ANTEC
January 1961

FIGURE 5

Plastic Ref.
1673

STUDY OF THE EFFECTS OF FILLERS IN COMPOUNDING PLASTICS FLOORING

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BACKGROUND

This study was originally undertaken to enlarge the fund of information available regarding compounding vinyl flooring. In this paper "vinyl" refers to compositons based on copolymers of vinyl chloride and vinyl acetate. Very little information has been published regarding the effects of various components, in vinyl flooring compositions. One paper of interest was published by Perloff[1], who developed a compounding table and method for formulating vinyl plastics to a constant hardness and pound volume cost. The majority of available information is that which has been translated from the compounding of rubber. This study was designed to prepare samples under a controlled system, and to study the effects of different fillers at different levels of loading on the physical properties of vinyl flooring.

EXPERIMENTAL DESIGN

A basic flooring composition was selected and no changes other than the fillers to be studied were made. Compounding was done on a volume loading basis to eliminate the effect of different specific gravities on the various fillers studied. To minimize small errors of compounding, all ingredients, with the exception of the fillers to be studied, were first blended into a master batch, and samples from this taken for the mixing and sheeting operations. The master batch was checked from time to time to be sure it was uniform throughout. As each new master batch was prepared it was checked for properties against those of the original.

PROPERTIES EVALUATED

The following physical properties were considered: [illegible] elongation, [illegible] strength, [illegible] stability, [illegible] 3 [illegible] addition. [illegible] fillers [illegible] ed (3 Tables and 12 figures).

to pg

A. Flexibility as Measured by the Olsen Stiffness Test.[2]

This test differs from the more common test of flexibility, mandrel bend, in that it is a direct measurement of the flexibility of the material under an applied force. It indicates the handling characteristics of the composition in its final form.

B. Tensile Strength and Percentage Elongation[3]

The tensile strength measurements were made at 70°F., 50% R.H. on a sample 4" x 1/2" using a 2" jaw distance and a pull of 6" per minute.

C. Moisture Absorption[4] and Growth[5]

The test was performed by immersing a 1" x 9" sample in a 9.6 pH buffered solution for 72 hours at 158°F. and measuring both the percentage change in length of the sample and its percentage change in weight. The test indicates how a composition might be affected under moist alkaline conditions such as are found on some damp concrete subfloors.

D. Dimensional Stability[6]

Samples were accurately measured and then exposed to a temperature of 250°F. in an oven for 24 hours. After exposure and cooling, they were remeasured and any change reported. Since some strains are most always incorporated into a vinyl sheet during its manufacture, its ability to resist dimensional change afterward must be known. This test is one accelerated means of estimating how well a vinyl flooring composition will retain its original dimensions at ambient temperatures.

E. Indentation Resistance[7]

Indentation resistance is measured in two ways - first, with 150 lb. load on a .178" tip for 30 seconds and second, with a 60 lb. load on the same tip for 30 seconds. Recovery from indentations as the result of both the 150 lb. and 60 lb. loading was measured after 15 minutes. Indentation resistance is a measure of the resistance of the floor covering to deformation by loads placed on it, and residual indentation is a measure of the ability of such a floor to recover from indentation.

F. Resistance to Abrasion as Measured by the Armstrong Sandpaper Abrader[8]

This test, while it is not a direct measure of the life of the material, does give an indication of how materials relate to each other in their resistance to abrasion.

G. Plasticizer Absorption

The plasticizer absorption test was developed as a modification of the standard rub-out oil absorption test for pigments. As used in this study, a 10 gram sample was weighed to the nearest hundredth of a gram. The sample was placed on a clean glass plate under a burette containing plasticizer, tricresyl phosphate (Figure 1). The plasticizer was added drop-wise to the filler while the sample was constantly mixed using a spatula (Figure 2). The end point was determined when the mixture was first formed into a curl using the tip of the spatula (Figure 3). Three check determinations were required. An experienced operator could reproduce his own results quite readily. Determinations between different operators were less reproducible. All the results of this study were done by a single operator. The test shows to what degree each filler may be competing with the resin for the plasticizer in the compounded sheet, and the values obtained are undoubtedly related to the filler surface area.

TYPES OF FILLER

The fillers examined were as listed in Table I.

SAMPLE PREPARATION

Samples were prepared by premixing the filler to be studied with a predetermined amount of master batch and these were introduced into a laboratory size Banbury mixer for mixing. Since all Banbury batches had the same volume, equal and complete filling of the mixing cavity was assured. The master batch used had the formulation shown in TABLE II.

The batches were mixed to 310°F., dropped from the Banbury and milled on a small laboratory two-roll mill. The roll temperatures were adjusted to find the best conditions for processing each composition. The loading levels for the study were: 15, 30, 45 and 60% by volume. With some fillers it was impossible to form a satisfactory sheet at the 60% level.

The milled sheets were then press polished between chrome-plated steel platens in a hydraulic press with platen temperatures of 320°F., cooled under pressure and released cold. Press polishing provided a uniform, smooth surface for performing physical testing. The press polished samples were conditioned for at least one week at 70°F. and 50% relative humidity, before testing.

EXPERIMENTAL RESULTS AND DISCUSSION

Table III is a tabulation of the data collected from this study. These results were first plotted against percent volume loading for each filler studied. As is often the case in experiments such as this, variables and errors cannot be completely controlled and the data showed considerable scatter.

It was observed that the properties of the fillers with similar plasticizer absorptions were, for the most part, grouped together. A new plot of the data was then made. The best visual curve was then selected for each group of fillers having similar plasticizer absorptions. The resulting plot was like Figure 4. This was an improvement, but it did suggest that a mathematical analysis of the data might prove more meaningful.

Accordingly, a least squares regression analysis was performed, using an IBM 1620 computer, to determine if a functional relationship existed between the independent variables and the various responses. An arbitrary model containing linear, quadratic, and cross product terms of the form:

$$y = b_o + b_1x_1 + b_2x_2 + b_{11} x_1^2 + b_{22} x_2^2 + b_{12} x_1x_2$$

was chosen, where the y represents the response, x_1 the volume loading and x_2 the plasticizer absorption. It was assumed for this analysis that all other variables were contributing nothing to the system.

At this point a technique called stepwise regression was employed to develop a function containing only the statistically significant terms from the chosen model.

Using this method the coefficients were determined in order of relative importance. The order in which these coefficients are introduced indicate the relative relationship between the variables, but not the reason for the relationship. Any coefficient which could have occurred more than n times in 100 by chance alone, would not be included. (n being an arbitrary significance level, which in these cases was 5).

In order to compare these various functions to the observed data, each function was evaluated for volume loading and plasticizer absorption. The values selected for volume loading were 15, 30, 45 and 60%. The plasticizer absorption levels selected were, 6.66, 4.17, 2.36 and 1.76. These values were arbitrarily selected as being the best representatives for all the fillers in each group. In each case they were close to the actual value for at least one member of the group, so that correlation between actual values and computed values could be evaluated. Plotting these points produced the curves shown in Figure 5. All of the data will be presented using these mathematically selected curves. Where no sheet could be formed at 60% loading, the value shown is a computed one. The curves are extended slightly beyond the 15% and 60% loading levels since it is felt the data are sufficiently valid for these areas. None of the curves are extended to the 0% level since there may well be trends in the area between 0% and 15% loadings which were not found due to our arbitrary selection of levels.

For each plot a percentage fit of the curves to the data has been calculated. This figure indicates what part of all the data is explained by the curves shown. That portion of the data not explained may be due to errors in the experiment or to other factors not considered in the analysis.

In addition to selecting the best curves, the computer was programmed to analyze the data and determine whether volume loading, plasticizer absorption, or a function of either was the predominant factor in the results. Actual values cannot be assigned to the degree of dominance of one over the other based on this work, but this may be possible with future work.

A. Flexibility (Figure 5)

Flexibility in all cases decreases with increased loading of the stock. In fact, the analysis shows the square of volume loading to be the most important variable. This is shown on the curves by the increasing force required to bend the sample through an angle of 20°. Plasticizer absorption also is a contributing factor since the greater the absorption, the greater the reduction in flexibility. The fit of this curve is 75%.

B. Tensile Strength (Figure 6)

The curves show that finer particle size fillers, or fillers with high plasticizer absorption tend to develop more tensile strength than do those with lower plasticizer absorption. An interesting note is that there may be higher tensile strengths in sheets filled beyond 60% loading. The function exhibiting the most effect is volume loading. The fit of these curves to the data is 66%.

C. Percent Elongation (Figure 7)

Again, volume loading is the controlling factor. The coarser limestones for their low absorption coefficients tend to permit greater elongation of the sheet. Here, the analysis indicates negative numbers for 60% loading with fillers of higher plasticizer absorption. At first this was puzzling, but on reviewing it was found that satisfactory sheets could not be produced at 60% volume loading for the higher plasticizer absorption fillers. The fit of this curve was quite high, 83%.

D. Moisture Absorption (Figure 8)

The trend is for decreased moisture absorption with increased loading and the calculations confirm this as the most significant variable. At higher volume loadings, the fillers with higher plasticizer absorption exhibit less tendency towards moisture absorption. It is felt since the fit of this curve is low, 50%, that factors other than those considered contributed to the results. This does not mean that volume loading and plasticizer absorption are not significant factors, but that they do not explain all the data. It is possible that moisture absorption is an equilibrium phenomenon and that this test measures only a section of a rate curve. The data for this property and the following, moisture growth, both exhibited a wide scattering of values indicating there were probably other factors than those considered which contributed to the results. The fit of this curve is low, 50%.

E. Moisture Growth (Figure 9)

As with moisture absorption, the moisture growth curves tend to decrease with increased loading and the same conclusions can be drawn. Again the fit is low, 42%.

F. Dimensional Stability (Figure 10)

In all cases the resultant dimensional stability measurements were negative, indicating a shrinkage of the material. The vertical scale of this plot, therefore, begins with -0.5 at the top of the scale and the values are negative numbers. Volume loading is the most significant variable, with those fillers having high plasticizer absorption contributing most towards dimensional stability. The fit of this curve is low, 42%.

G. Indentation Resistance (Figure 11)

The curves shown are for 150 lb. loading since both the 150 and 60 lb. curves are essentially parallel. Resistance to indentation in all cases increases with increased loading. The finer precipitated calcium carbonates and the clays having higher plasticizer absorption tend to offer more resistance to indentation at the same volume loading levels, than do the coarse dry ground calcium carbonates. The fit of this curve is very good, 94%.

H. Sandpaper Abrasion (Figure 12)

Loss due to sandpaper abrasion increases in all cases with increased loading. The finer materials offer the best abrasion resistance. The coarser materials are less resistant, probably due to their larger particles being less firmly bound into the sheet. The fit of this curve is very good, 89%.

CONCLUSIONS

The study has shown that both volume loading and particle size of the fillers as measured by plasticizer absorption had definite effects on the properties of vinyl flooring compositions. In the area examined by this study volume loading appears to be the predominant factor. In addition, the fit of the mathematically computed curves to the experimental data further strongly suggests that regardless of filler chemical composition, filled vinyl compositions can be largely tailored to meet physical property requirements at a given loading provided the plasticizer absorption of the filler is known and its value is within the range reported here. That compositions can be tailored to provide required physical properties is in agreement with the earlier work of Perloff[1].

ACKNOWLEDGEMENT

The author wishes to thank Mr. D. C. Messersmith of the Armstrong Research and Development Center for his large contribution to this paper in performing the mathematical analysis of the data and its interpretation.

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2. Armstrong Cork Company, Research & Development Center, T.M. 79
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4. Armstrong Cork Company, Research & Development Center, T.M. 41
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6. Armstrong Cork Company, Research & Development Center, M.E.P. 128
7. Armstrong Cork Company, Research & Development Center, M.E.P. 86 R-1
8. ASTM #D-1242 - Procedure B

TABLE I

FILLER TYPES AND SIZES

Filler Type	Maximum Particle Size,Microns
I. Calcium carbonate	
A. Natural limestone	
1. Coarse, dry ground	300
2. Fine, dry ground	43
3. Fine, wet ground	30
B. Precipated calcium carbonate	
1. Fine	1
2. Ultra-fine	0.1
II. Clay	
A. Uncalcined	10
B. Calcined	1

TABLE II

MASTERBATCH FORMULATION

Ingredient	% by Weight
Vinyl resin (Copolymer of vinyl chloride 97.5% and vinyl acetate)	44.07
Vinyl resin (Copolymer of vinyl chloride 86.0% and vinyl acetate)	11.87
Ceresin wax	.85
Stabilizer	3.33
Epoxidized soya bean oil	2.57
Tricresyl phosphate	25.46
Rutile titanium dioxide pigment	11.85

Filler	Volume Loading %	Plasticizer Absorption Ml./10 Gms.	Flexibility In. Lbs. @ 20°	Tensile Strength PSI	Elongation %	Moisture Absorption % Change in Wt.	Moisture Growth % Change in Length	Dimensional Stability % Change in Length	Indentation Resistance (150#) Inches	Sandpaper Abrasion Loss c.c.
Dry Ground Limestone, Coarse (A)	15	1.74	0.20	1810	199	6.34	1.84	-1.67	.040	0.64
	30		0.37	1173	154	11.18	4.32	-1.36	.028	0.80
	45		0.47	720	109	7.28	2.97	-1.23	.024	1.03
	60		0.89	493	33	2.66	0.83	-1.01	.011	1.33
Dry Ground Limestone, Coarse (B)	15	1.74	0.21	1815	213	7.54	1.65	-1.98	.037	0.63
	30		0.41	1350	180	3.76	0.51	-1.08	.022	0.86
	45		1.00	1155	120	2.90	0.39	-1.26	.016	0.75
	60		1.90	1126	3	3.47	0.95	-0.70	.008	1.65
Dry Ground Limestone, Coarse (C)	15	1.82	0.16	1807	228	8.82	1.30	-1.62	.040	0.70
	30		0.45	1276	190	2.81	0.27	-1.18	.025	0.94
	45		0.82	944	137	2.60	0.21	-1.12	.016	1.36
	60		2.08	1033	2	3.91	1.18	-0.35	.007	1.67
Dry Ground Limestone, Coarse (D)	15	1.71	0.19	1813	208	9.20	2.19	-1.60	.034	0.66
	30		0.49	1218	180	3.02	0.30	-1.30	.026	0.92
	45		1.10	879	130	2.92	0.45	-0.99	.017	1.27
	60		2.49	783	2	8.40	2.18	-0.77	.007	1.86
Dry Ground Limestone, Fine	15	2.60	0.25	1810	177	5.04	0.98	-1.50	.031	0.67
	30		0.49	1393	150	4.50	1.41	-0.94	.028	0.88
	45		0.76	824	111	3.12	0.32	-1.06	.017	1.16
	60		1.75	913	1	3.46	0.67	-0.74	.009	1.44
Wet Ground Limestone, Fine (A)	15	2.39	0.28	2065	164	8.29	1.91	-1.93	.036	0.66
	30		0.47	1467	96	6.06	0.68	-1.77	.026	0.90
	45		0.69	1027	73	5.25	0.14	-1.76	.019	1.17
	60		1.44	1250	2	3.51	0.05	-1.00	.009	1.44
Wet Ground Limestone, Fine (B)	15	2.32	0.30	1857	235	8.75	2.85	-1.10	.032	0.60
	30		0.53	1325	178	6.05	1.32	-1.01	.025	0.77
	45		0.89	1515	10	4.07	0.37	-0.93	.015	1.00
	60		1.73	1132	2	1.80	0.32	-0.78	.008	1.25
Uncalcined Clay	15	4.17	0.34	1940	255	5.54	0.15	-0.96	.036	0.74
	30		0.93	2797	192	5.20	0.36	-0.95	.017	0.93
	45		2.45	3397	30	6.29	0.27	-0.36	.007	1.12
	60						UNABLE TO FORM A SHEET			
Precipitated Calcium Carbonate, Fine	15	6.66	0.23	1902	200	9.57	2.97	-0.37	.032	0.59
	30		0.35	1387	193	6.62	1.69	-0.99	.022	0.75
	45		0.80	1583	13	3.69	0.66	-1.20	.012	0.96
	60		2.47	1338	2	1.94	0.35	-0.58	.005	1.04
Precipitated Calcium Carbonate, Ultra Fine	15	7.29	0.39	1630	101	8.68	2.94	-0.62	.029	0.60
	30		0.73	1357	93	5.00	1.30	-0.34	.015	0.72
	45		1.62	2113	3	2.70	0.37	-0.43	.008	0.90
	60						UNABLE TO FORM A SHEET			
Calcined Clay (A)	15	6.49	0.23	2020	197	8.43	2.03	-0.97	.028	0.58
	30		0.60	1982	70	4.55	0.88	-1.41	.015	0.71
	45		2.03	2542	7	1.76	0.26	-0.81	.003	0.82
	60						UNABLE TO FORM A SHEET			
Calcined Clay (B)	15	6.50	0.20	2117	215	7.80	0.83	-2.66	.032	0.60
	30		0.57	2000	90	3.01	0.51	-1.30	.018	0.75
	45		1.81	2610	7	1.71	0.39	-0.74	.008	0.83
	60						UNABLE TO FORM A SHEET			

TABLE 3

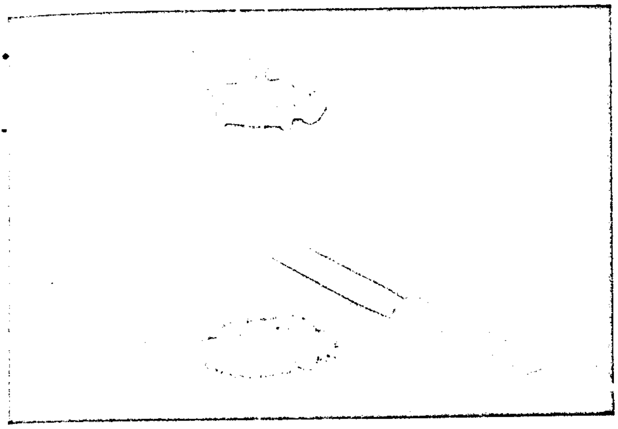

FIGURE 1

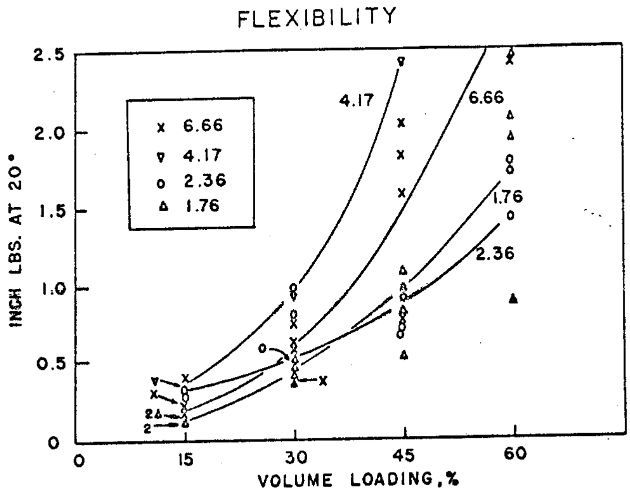

FIGURE 4

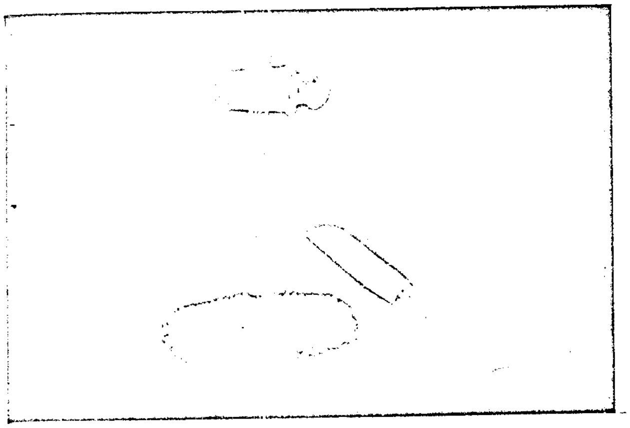

FIGURE 2

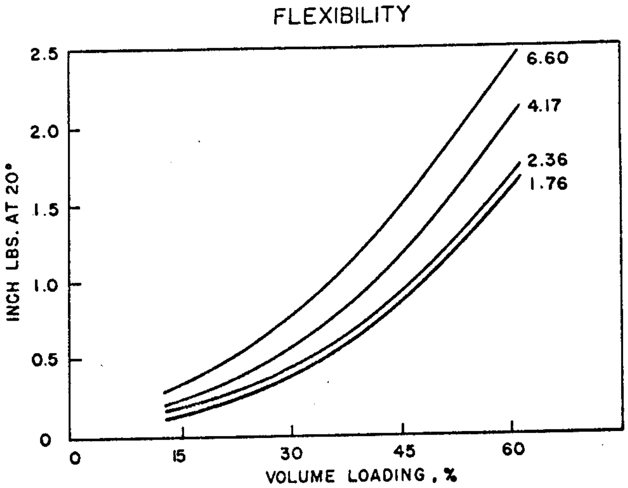

FIGURE 5

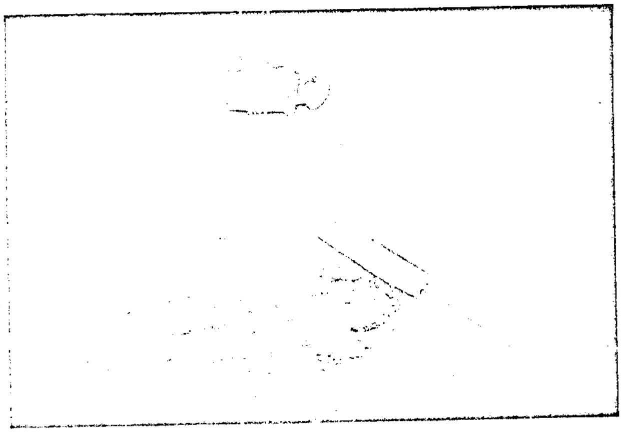

FIGURE 3

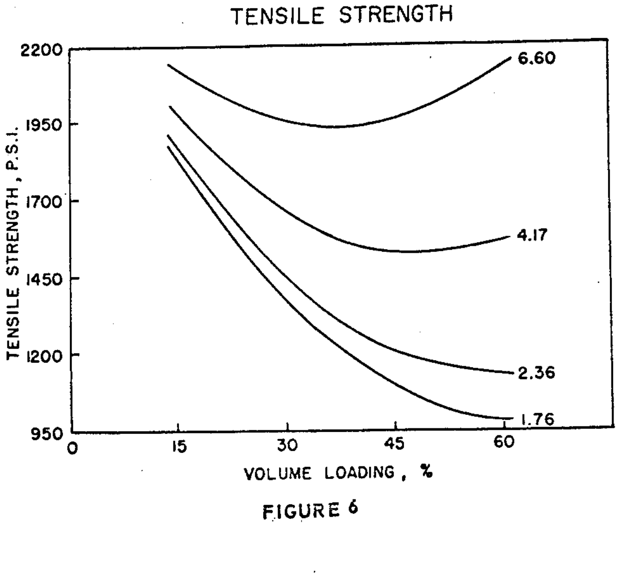

FIGURE 6

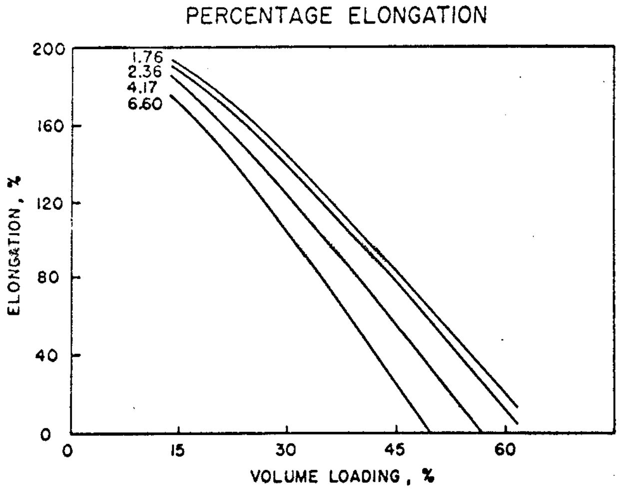

FIGURE 7

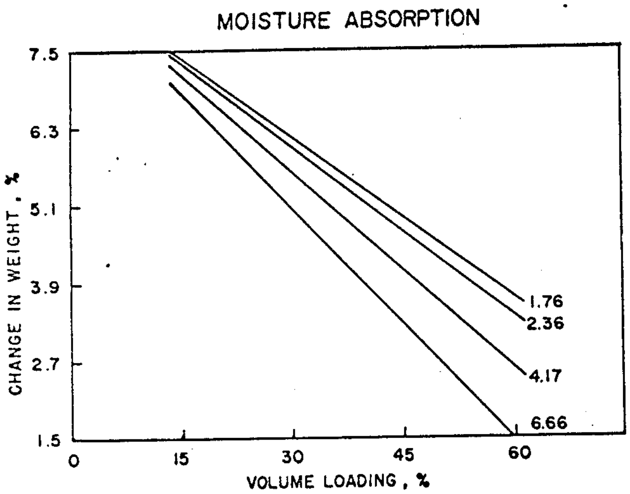

FIGURE 8

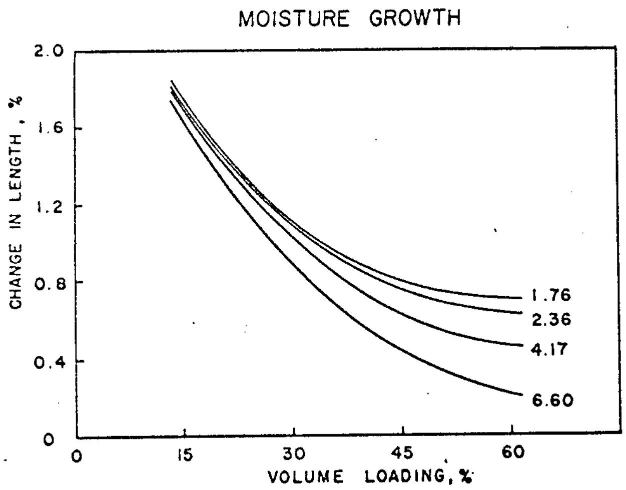

FIGURE 9

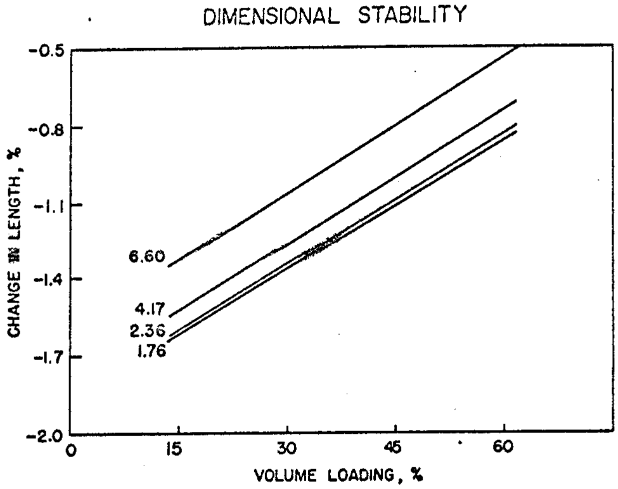

FIGURE 10

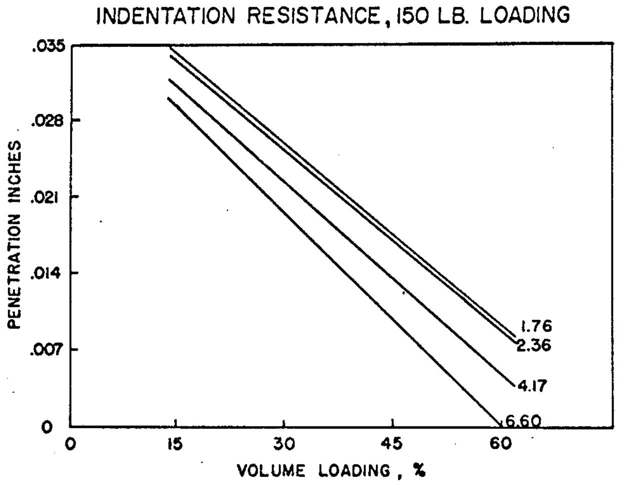

FIGURE 11

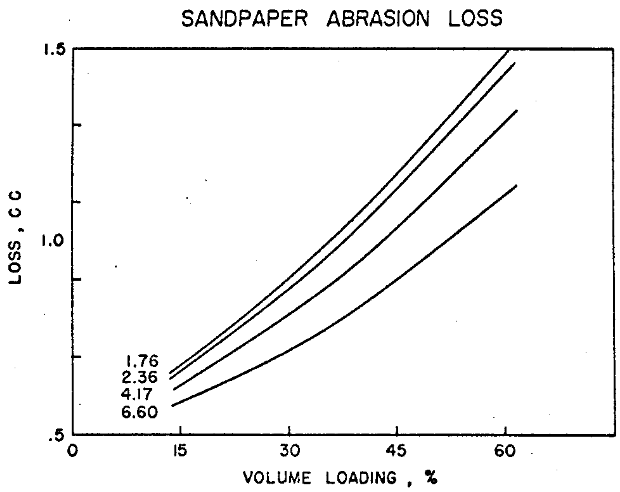

FIGURE 12

Plastic Ref# 1674

THE ROLE OF PLASTICIZERS IN THE FORMULATION OF LOW STAINING VINYL FLOORING COMPOSITIONS

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INTRODUCTION

The use of polyvinyl chloride in the manufacture of flooring compositions has represented one of the most rapidly growing segments of the vinyl industry. Thus, whereas in 1956 -- only a few years ago -- approximately 65 million lbs. of PVC resins were converted to flooring, in 1960 the flooring industry consumed approximately 156 million lbs. Translated into square feet of flooring area, it is quite evident that literally, a lot of ground has been covered in such a short span of years.

DIFFERENT TYPES OF VINYL FLOORING

PVC may be used in various ways to produce flooring by fundamentally different methods. A short demonstration of these types will indicate these differences.

The largest volumes of flooring produced today fall into the following categories:

A. Homogenous,

This type is usually produced with straight PVC homopolymers of medium to low molecular weight using plasticizers and varying amounts of fillers and pigments to produce different design effects. These products are available both as tiles and as sheet goods in varying thicknesses and different patterns.

B. Vinyl Asbestos, and

This product is usually made from 13-15% chloride - vinyl acetate copolymer using high solvating plasticizers and large amounts of fillers such as asbestos and limestone. A copolymer is required to impart the necessary binding power and to permit adequate wetting of the relatively large amount of filler by the smaller quantity of resinous binder. The sample products shown in the slide are usually sold as 9" x 9" tiles.

C. Rotogravure Vinyl Type Flooring,

These products consist of s saturated felt base covered by a heavy printed paper which in turn has been coated with a tough resilient PVC dispersion, usually from an organosol medium. The wearing surface here is a clear film under which a wide variety of printed patterns may be used. Products produced by this technique are usually available in sheet form.

It should be noted that various combinations of these approaches also exist in the form of laminates. However, for purposes of this discussion, the surfaces involved are usually produced by one of the above methods.

It is evident that these different types of flooring are produced by entirely different processes. Thus, processing problems vary greatly with respect to color, color drift, heat and light stability, hardness or indentation characteristics, surface conditions, volatility, abrasion resistance, water absorption, shrinkage, adhesion and migration into mastic.

A problem common to each of these types of flooring, however, has been that of staining.

THE STAINING PROBLEM AND ITS DEFINITION

What is staining? Staining may be regarded as the transfer of color bodies from an external medium to the flooring composition. In contrast to surface dirt, the color bodies penetrate the surface of the floor and permanently discolor the vinyl compound. No amount of cleaning, short of severe abrasion of the surface, will remove the stain since the color of the vinyl compound itself has been changed. In essence, it has been dyed or perhaps even pigmented.

Staining is caused by traffic across the floor, food spillage, inferior waxing compounds or grease deposits. It may be caused either by transfer of the color bodies to the surface directly or by abrasion, softening or destruction of the surface followed by color penetration.

Staining results in consumer complaints about appearance or wear properties of the floor and frequently obligates the producer, who stands behind his product, to replace flooring and reinstall more suitable compositions. Staining frequently is the result of a misapplied installation in areas where present day vinyl compounds, when supplied in stain sensitive designs and colors, can simply not withstand the amount of wear and tear to which they are subjected. Staining is, therefore, an additional expense to the flooring producer aside from the poor impression of the industry as a whole which it may leave with the consumer.

Because of the widely varying causes of staining and the different transfer media containing color bodies, it has been extremely difficult to define the criteria necessary to provide adequate stain resistance. In other words, with present-day technology, it is difficult to formulate against all staining unless an ideal composition can be found which is impervious to all staining vehicles. For example, a kitchen floor resistant to grease stains may not necessarily be resistant to an asphalt stain caused by macadam residues brought into the house on the shoes of children playing in the driveway.

A. Laboratory Stain Test Methods

In order to attack the problem of floor stain from the raw material point of view, it is necessary to examine short term laboratory tests which adequately simulate a long term stain-producing condition. Because of the different stain producing media mentioned above, the Thompson laboratory, in cooperation with members of the flooring industry, has examined various such tests. They are described and results are demonstrated as follows:

In order to evaluate the various stain criteria, the following staining media were chosen:

1. Kerosene - representing aliphatic solvents which may be present in cleaning compounds, extended bituminous mixtures, extended shoe soling and heel compounds and frequently simulating the transfer properties of aliphatic rubber polymers.
2. Liquid Asphalt - representing aromatic solvents, the most severe type of transfer medium which simulates road tars, oils and soft paved surfaces generally.
3. Cottonseed Oil - representing fatty acid triglycerides and simulating oils, greases and shortenings found in kitchens, cooking areas and restaurants, etc.

While the liquid asphalt contains highly colored staining components and is essentially black in color, it was necessary to impart color to the kerosene and cottonseed oil. A maroon dye, duPont oil brown, was chosen and 1% dye concentrates of these solvents were prepared.

Using these media, a number of test variations are possible. Milled and molded homogenous and vinyl asbestos compounds or cast organosol films are suspended in the stain media, either at ambient or at elevated temperatures for a given period of time, removed and rinsed quickly with petroleum ether or other suitable solvent, dried off and examined. In the case of clear films, light transmission can be measured although visual inspection is usually adequate.

Specific tests along with results showing high and low degrees of staining obtained respectively are described below.

B. The Asphalt Stain Test

In this test, 1½" dia. disks cut from 0.075" molded sheets of a filled homogenous compound were half immersed in a liquid asphalt for 16 hours at 50°C. Specimens were removed, rinsed off quickly with hexane and dried. The differences between a high and a low degree of staining are readily apparent.

C. Kerosene Stain Test

In this test, 1" x 6" specimens of a 7 mil organosol type film, were immersed in a jar of kerosene dyed with 1% of duPont oil brown at room temperature.

The specimens were removed periodically - for instance, at 1 hr, 1 day, 3 days and 7 days respectively - and 1" x 3/4" samples were dried out for mounting on a record card. Again, low and high staining systems are clearly differentiated.

D. Cottonseed Oil Stain Test

In this test, disk samples of a clear formulation were half immersed into a 1% duPont oil brown dyed cottonseed oil for 16 hours at room temperature. They were removed, wiped thoroughly, and examined for color intensity. Results show a good degree of differentiation between low and high staining systems.

The tests shown here are modifications and composites of a number of methods developed in the laboratory as well as proposed and used by members of the flooring industry. They have served as screening tests to evaluate candidate components for a low staining flooring composition. All tests should be backed up, however, by actual traffic panels for reliable results under actual use conditions.

The tests are not necessarily limited to the formulations in which they were shown; i.e. any of the three tests proposed may be run on any of the formulations shown.

E. Test Variations

Industry accepted variations of these tests do not depart from basic idea of contact with color bodies and their transfer to the vinyl surface. For example, in a variation of the kerosene stain test, a square of filter paper soaked with dyed kerosene is placed on the vinyl coated surface for one hour and then removed for examination.

A solution of shoe heel rubber compound dissolved in extender oil has also been proposed. Repeated abrasion of the surface with sandpaper followed by application of a staining solution has been investigated. Softening of the surface with a cooking oil followed by an asphalt stain test has been suggested to simulate conditioning of the vinyl surface for stain acceptance.

STAINING FACTORS

What are the major factors responsible for staining in a PVC flooring composition? First, they may be divided into mechanical and chemical or raw material factors. The mechanical aspect of the flooring, that is, the quality of its surface as well as its design, color and pattern, are obviously significant to stain sensitivity. These will not be discussed here.

The raw materials used in the manufacture of vinyl flooring, as in other vinyl compounds, are composed of plasticizers, fillers, pigments and stabilizers. The present discussion is limited to plasticizers.

A. Effect of Plasticizers on Staining

Unplasticized resin compositions do not stain to nearly the same degree as do plasticized compounds. The amount of plasticizer used is usually directly proportional to the amount of staining obtained.

Flooring must be formulated, however, to given hardnesses to meet identation specifications. In order to use minimal amounts, it is therefore desirable to use as efficient a plasticizer as possible.

B. Low Staining Plasticizer

Recent plasticizer research by the Thompson laboratory in conjunction with members of the flooring industry has elucidated novel structures which have yielded low staining flooring compositions. Research has been directed toward development of low staining plasticizers for rotogravure vinyl flooring, homogenous compounds and vinyl asbestor flooring.

It was found that the same plasticizer was not optimum in these three systems. In addition to stain resistance, other requirements must also be met which are different for each system. For example, for organosol coated vinyl, low viscosity development is essential. For vinyl asbestos, good efficiency, high solvation, and rapid wetting and low cost are required. For homogenous vinyl, the optimum in stain resistance and heat stability is required since such flooring is often produced in the most sensitive designs. Such systems are also richer in plasticizer than is vinyl asbestos, and are pigmented which aggravates staining.

This development effort has resulted to date in two new plasticizers whose performance is shown in Table I. The first of these is TRUFLEX 310. This plasticizer is particularly well suited to organosol formulation since it does not develop excessive viscosities at room temperature but is highly solvating and causes rapid fusion at elevated temperatures. Because of its high solvation, it is also usable in homogenous vinyl and vinyl asbestos. It is a primary plasticizer and fully compatible with PVC at all practical levels.

The second is TRUFLEX 315, developed especially for vinyl asbestos tile. This novel plasticizer is of the high solvating type and has excellent wetting properties when used in conjunction with vinyl acetate-vinyl chloride copolymers, as for example, TRULON 761. The plasticizer has good heat and light stability as well as good resistance to migration into the mastics used in flooring installations. It has a lower water solubility and greater resistance to saponification than other plasticizers used for vinyl asbestos compounds. In plastisol applications, lower viscosities are obtained at high shear rates suggesting its use for fast fusing compounds.

The staining properties of both TRUFLEX 310 and 315 vs. DOP are considerably less than a comparable DOP based formulation. In Fig. 1, viscosity development in a plastisol formulation was measured when exposed in a constant temperature bath at 200°F. When compared to DOP, a much faster fusion rate is indicated by the rapid rise in the curves. The relatively low viscosity in the flat part of the curves showing viscosity before the plastisol has reached equilibrium at 200°F., indicates that workable viscosities can be obtained at ambient temperatures.

C. Resistance to Extraction by Hydrocarbons vs. Stain Resistance

In an attempt to relate extraction resistance to stain resistance, the extraction of these plasticizers has been measured when exposed to hydrocarbon solvents of varying aromaticity. Aromaticity of hydrocarbons can be expressed in terms of Aniline Point. The Aniline Point of a solvent, as per ASTM D-1012-51, is the temperature at which a mixture of the solvent and aniline first shows clouding or immiscibility.

Table II shows extraction figures of DOP, TRUFLEX 310 and 315 in solvents of different aniline points. These data are represented graphically in Figure 2 by plotting percent extraction vs. Aniline Point. The curves indicate that it is more difficult to provide extraction resistance to highly aromatic solvents than toward the more aliphatic types. Another way to demonstrate this point is to expose the vinyl films to dyed solutions of solvents having different Aniline Points. Preventing transfer of color bodies from aromatic tars can therefore be expected to be more difficult than providing resistance toward mineral spirits and kerosene.

Correlation of extraction resistance to stain resistance has been found to be limited to monomeric plasticizers which do not contain long chain fatty radicals. Thus, fatty derived epoxy plasticizers generally detract from providing stain resistance. Poor results are obtained when exposing various epoxies to a liquid asphalt system. However, in a kerosene stain test, the butyl esters of the monomerics - such as the epoxystearate and polyepoxystearate or tallate - perform better than either the soya bean oil or the octyl esters. Polymeric plasticizers, although good on extraction resistance, do not ordinarily show good stain resistance. This is explained perhaps by the fact that they frequently contain long chain fatty end groups for efficiency and low temperature properties.

It has also been noted that fillers and pigments can have a marked influence on stain resistance - conceivably due to absorption characteristics. Their effects, however, are not at issue in the present discussion.

SUMMARY

In summary, traffic staining of flooring compositions has been a problem, costly to segments of the flooring industry. Short term laboratory test methods have been reviewed and proposed as screening tests for evaluation of raw materials. Plasticizers, amount and type, are of prime significance in formulating low stain flooring. TRUFLEX 310 and 315 are examples of plasticizers which can provide stain reduction at low cost.

Since staining is regarded as a transfer of color bodies, stain resistance is relative to the transfer properties of the staining medium in contact with the vinyl compound. It is the object of continuing raw material research therefore, to find compositions impervious to as broad a spectrum of transfer media as possible.

Supplier of both resins and plasticizers are carrying on an active program of this type in the laboratory and are constantly seeking to field-test improved products. The above test procedures are only suggested starting points and do not obviate the need for actual traffic testing. Laboratories of both the raw material and flooring producers would welcome development of better short term stain tests that would eliminate the need for lengthy traffic tests and reduce the risks of costly flooring failures.

TABLE I

PHYSICAL & PERFORMANCE PROPERTIES OF VARIOUS PLASTICIZERS

Physical Properties

	TRUFLEX 310	TRUFLEX 315	TRUFLEX DOP
Appearance	Clear, amber	Clear, straw	Clear
Color	4 Gardner	60 APHA	10 APHA
Specific gravity @ 25°C.	1.095	1.060	0.981
Refractive Index @ 25°C.	1.523	1.510	1.484
Acid value	0.1	0.06	0.03
Lbs./gallon	9.25	8.85	8.20
Viscosity @ 25°C., cps	220	180	75

Performance Properties

	TRUFLEX 310	TRUFLEX 315	TRUFLEX DOP
Parts plasticizer	58	52	50
Tensile strength, psi	2850	2965	2710
Modulus @ 100% Elongation psi	1440	1485	1455
Ultimate elongation, %	360	350	355
Hardness shore "A"	85	84	85
Brittle point, °C.	-2	-11	-26
% Carbon volatility @ 90°C.	6.6	7.3	5.0

FORMULATION:
TRULON 500 - 100
Plasticizer - as indicated
Ba-Cd Stab. - 2
Lubricant - 0.25

TABLE II

EXTRACTION RESISTANCE OF TRUFLEX DOP, 310 AND 315 TO VARIOUS SOLVENTS

Solvent	Boiling Range (IBP to End Point °F. ASTM)	Aniline Point	Percent Weight Loss		
			DOP	310	315
Odorless mineral spirits	352-390	184.5	16.8	0.4	1.0
Amsco 140 solvent	364-403	150	8.0	0.4	0.0
Mineral spirits	313-389	132	10.9	1.2	4.2
Amsco lactol spirits	200-225	121	14.3	6.3	10.8
Amsco lactol spirits 45	203-232	110	18.3	12.6	17.8
Amsco solv A	205-268	60	22.9	19.7	22.9

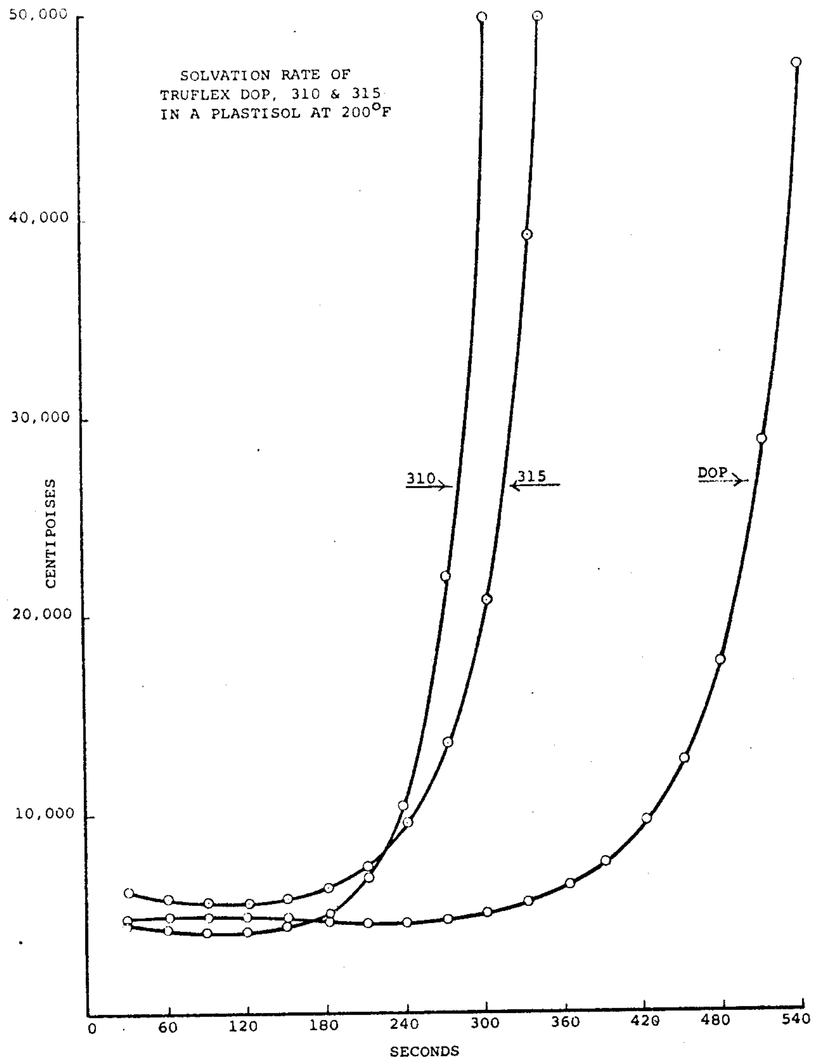
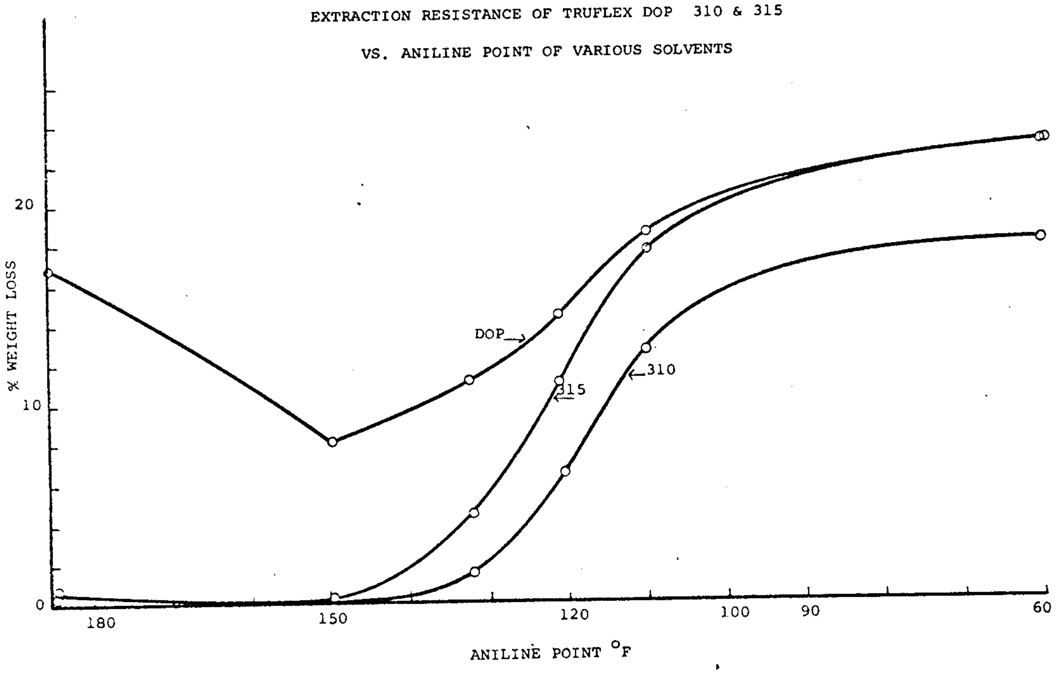


FIGURE 1


EXTRACTION RESISTANCE OF TRUFLEX DOP 310 & 315

VS. ANILINE POINT OF VARIOUS SOLVENTS

FIGURE 2

THE I. C. I. SYSTEM OF COLOR MEASUREMENT

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Perceived color is a psychological sensation. It is produced through the stimulation of the nerves of the eye by light energy. This is not unlike the sensation which enables one to distinguish between hot and cold (temperature), or between high notes and low notes (sound). Each person's response to a particular sensation is associated with his past experience. It is only because one has experienced the sensation of hot and cold that he can put a hand in a pan of water and report its temperature. Likewise, his ability to describe the color of a red object requires first that he has seen red before, and, as a matter of fact, a sufficient number of other colors; and second that he has a language to describe the effects of the sensation.

In many instances descriptions based on previous experience are sufficient. For instance, it is enough to say, "Wear a coat, it's cold outside". All have some crude idea of how cold it has to be before putting on a coat, but when it is necessary to decide how much antifreeze to put in a car radiator, it requires much more information about just how cold is cold. Since both of the above sensations are produced by reaction to energy and since energy content is a physical property which can be measured, all that is necessary is to become familiar with the scales used and results of the measurement in terms of sensations produced.

The scales used to measure temperature are based on the freezing and boiling points of water. Between these points, the scale is divided into one hundred divisions (Centigrade) or one hundred eighty divisions (Fahrenheit). These scales enable specific temperature measurement within the limits of the precision of the measuring device. It is possible to convert from one scale to the other by means of a simple equation - $^{o}F = {}^{o}C\ 9/5 + 32$. This is a transformation equation about which more will be said later.

There have also been scales developed to specify color, but unlike the temperature scale, which is one-dimensional, at least three scales must be used simultaneously for color. In other words, color is three-dimensional. Analogous to the temperature problem, one can say "That hat is red". To most this means something, again based on experience. If, however, a manufacturer of a colored object wishes to reproduce a color, he must have a more refined description. This is where the trouble begins. There have been so many scales developed, each serving more or less successfully for a particular problem, that the average person is more confused than helped when he first encounters them. Add to this the complexity of the measuring devices used to measure color and the unwieldy equations necessary to convert from one system of scales to the other.

It may not be any more necessary for the average person to understand the complexity of color measurement and specification to enjoy color than it is for him to understand electron emmission to enjoy the Ed Sullivan Show, but in a world becoming more and more color conscious, the producers of colorants or colored materials are finding themselves handicapped by insufficient knowledge about the science of color. Unfortunately, many of these people do not know that there are precise instruments for measuring color, that there are three-dimensional scales for tying these measurements to what is seen, that there are mathematical relations enabling one to compute what must be done to reproduce a color, and that there are even computers available to perform the latter calculations.

Begin first with the scales needed for the physical measurement of color. The first scale enables one to distinguish between the various hues. Consider something which all recognize as containing many colors - the rainbow. Scientists have a more sophisticated name for the rainbow - visible spectrum. It is that small portion of the radiant energy scale for which the eye is a detector. This scale also has two convenient reference points which are, in fact, the extremes of the visible range. Temperature scale was marked off in degrees (degrees F or degrees C), the spectrum was divided by units called wavelengths, (Millimicrons). For the Fahrenheit thermometer, reference points were 32° and 212°. For the spectrum these are 400 and 700 mu. Just as the average energy of the material being measured is used to specify temperature, the dominant wavelength will be used to specify the hue of color. Starting with one wavelength of light, (for example, green - 530 mu) it is found that there are two other ways in which the color can be altered and 530 retained as the dominant wavelength. First the color can be made brighter or darker. This parameter, or scale will be called "lightness", and allowed to vary from 0 to 100%. Second, keeping the lightness constant, increasing amounts of other wavelengths can be added while still retaining a DWL of 530. As these other wavelengths are added, color will become diluted, or less pure, until a point of no hue, or neutral (achromatic) color is reached. Depending on the lightness level, the result will be something between white through gray to black for reflected light, dazzling to no light for self-luminous objects, and clear to opaque for transmitted light. This third will be called purity, and will range from 0 to 100. This three dimensional nature therefore applies to self-luminous colors, reflected and transmitted light. The instruments which produce the required information necessary to specify color in terms of all three scales are called colorimeters and spectrophotometers. Colorimeters can give the information directly, while spectrophotometers give this information indirectly.

Consider now a colorimeter and how the scales can be used to specify a color in terms of what is seen. First, a white screen is masked off so that an observer sees only a limited portion. Then one-half of this portion is illuminated with light of some arbitrary color. On the other half of the screen light of three widely different colors - red, green and blue - is superimposed. Further add controls with numbered dials on the sources of these three primary lights so that the amounts of these three lights necessary to match the other half of the screen can be varied and recorded. If the three purest lights available (red, green and blue) are chosen, it will be found that this combination will allow matching of a very wide gamut of colors. The amounts of three primaries necessary to match any color are called <u>tristimulus values</u> and they give three numbers necessary to specify any color within the gamut. The information accumulated from such experiments are summarized by three laws proposed by Grassman in 1853:

A. The eye can distinguish only three kinds of differences, or variations. (Expressible as dominant wavelength, purity and lightness.)

B. If of a two-component mixture, one component is steadily changed, (while the other remains constant) the color of the mixture is steadily changing.

C. Lights of the same color (same dominant wavelength, lightness and purity) produce identical effects in mixtures, regardless of their spectral composition.

Two of the three scales (the purity and the cominant wavelength scale) together specify what is called the <u>chromaticity</u> of a color, and Grassman showed that this chromaticity could be represented by a plane diagram using as coordinates scales indicating the amounts of the three primary colors required to match the chromaticity. Such a diagram is called a chromaticity diagram. The chromaticities of primaries are the three corners of the triangle, and the chromaticities of all colors obtainable with mixtures of these three fall within the triangle. Mixtures of just two fall on the line joining them, and mixtures of all three fall in the area bounded by the sides.

Experiments by Newton, Helmholtz, Maxwell, Wright and others have shown that not all colors fall within any gamut obtainable with any one choice of three spectrum lights. This can be seen if the chromaticity of all the spectrum colors is plotted using as primaries the spectrum colors used by Wright, i.e., 650 mu for red, 530 mu for green and 460 mu for blue.

It will be noticed that a considerable number of spectrum and near spectrum colors fall outside the gamut. What this means is that, for wavelength 500, it would be necessary to use G amounts of 530, B amounts of 460 and take out negative amounts of 650. In other words, blue and green primaries are too red at the start.

It is important to stop here and consider how the negative numbers are derived with a colorimeter. Examine the following problem. The weight of a large stone is to be determined using a balance. The stone is placed on one side of the balance, and on the other side, known weights. To add to the difficulty, only two weights are available, one weighing twenty pounds and one weighing five pounds. It is impossible to obtain a balance with just the twenty pounds of weight, because it is too heavy. Similarly a balance cannot be obtained with the five pound weight, because it is too light. If, however, the five pound weight is placed on the side with the stone, and the twenty pound weight on the other side, a balance is obtained. The stone, plus five pounds, exactly balances the twenty pound weight. Or, 20# - 5# = the weight of the stone (15#). With the colorimeter, the procedure is the same. If a match cannot be obtained with green and blue lights because they are too red, red primary is added to the other side of the screen, (to the unknown) and the amount added is exactly the amount of red that would have to be subtracted from green and blue primaries to obtain the match. The International Commission on Illumination (I.C.I.), in 1931, eliminated the necessity of working with negative tristimulus values by adopting three new primaries which do not exist. These imaginary primaries were so chosen to let all of the spectrum colors fall within their gamut. The device used to change the scales were transformation equations, and they are no more difficult than the transformation equations we use to convert from °C to °F.

$$X = k_1R + k_2B + k_3G$$

$$Y = k_4R + k_5B + k_6G$$

$$Z = k_7R + k_8B + k_9G$$

These tell simply that, by using k_1, k_2, k_3 amounts of our original primaries, R,B,G, respectively, a new primary X could be made. New tristimulus values tell the amounts of these three primaries that would be used <u>if they existed</u> to match <u>any</u> chromaticity.

The chromaticity of a color, as mentioned before, incorporates just two of the three scales necessary to completely specify any color, i.e., purity and dominate wavelength. The I.C.I. had the foresight, however, to adopt one of the new primaries, Y, as a measure of lightness. As a matter of fact, the constants chosen for the transformations were such as to make the Y value correspond to the sensitivity curve, or visibility curve, of the eye.

Unfortunately, from the inspection of the tristimulus values of two colors, it is not always clear whether they differ only in chromaticity, only in brightness, or both. For example, two colors with the same tristimulus values have the same chromaticity, and differ only in brightness,

$X = .2711$ $X^1 = .3462$
$Y = .2565$ $Y^1 = .3275$
$Z = .3028$ $Z^1 = .3865$

but this is not obvious from the above numbers. Chromaticity of a color is determined by the ratio of the three primaries necessary to match the color. Specify the chromaticity with the new numbers which give the ratios more explicitly. Again, simple transformation equations will be used.

$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z}$$

Since $x+y+z$ must always equal one, only two need be calculated. The other is found by subtracting any two from one: $z = 1 - (x+y)$ In the case of the two colors whose tristimulus values were given above:

$$x = \frac{.2711}{.2711+.2565+.3028} = .3265$$

$$x^1 = \frac{.3462}{.3462+.3275+.3865} = .3265$$

$$y = \frac{.2565}{.2711+.2565+.3028} = .3089$$

$$y^1 = \frac{.3275}{.3462+.3275+.3865} = .3089$$

Therefore, $x = x^1$ and $y = y^1$, and the colors have the same chromaticity. The brightness difference is $.3275-.2565 = .0710$, or 7.1%.

These new numbers are called "trichromatic coefficients" and if these ratios are used as coordiantes, chromaticity diagram is obtained in which all real colors can be plotted.

The smooth curve (spectrum locus) represents the chromaticities of the spectrum colors from 400 mu to 700 mu. The chromaticities of several important light sources are also plotted. Point A is the standard light, Illuminant A representative of gas-filled incandescent lamps, Point C is standard light, Illuminant C, representative of average daylight, and Point E is that of the "equal energy spectrum" or what would be seen if there were equal amounts of all wavelengths of light. The dominant wavelength of a color is obtained from this diagram by drawing a line from the light source through the sample point to the spectrum locus. The wavelength at the point of intersection with the spectrum locus is the DWL. The purity is that obtained by taking the ratio of the distance from the light source to the sample point, to the distance from the light source, to the intersection of the spectrum locus.

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This paper is only intended to present a general approach to the understanding of Color Specification by the C. I. E. System. It is recommended that the following supplemental references be used for more detailed explanations.

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Plastic Ref
#1675

PREDICTION OF THE WEATHERING LIFE OF VINYL PLASTICS

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During the past fifteen years, which have seen vinyl plastics become fixtures in the household, knowledge of factors affecting their performance in use has been enlarged tremendously. The producer of such familiar vinyl items as garden hose, upholstery sheeting, film and electrical insulation undoubtedly leads a complicated life with respect to costs and marketing problems today. But from a purely technical standpoint, he now has well established standards of testing, as well as tightly controlled raw materials, to enable him to turn out high-performance vinyls without undue difficulty. This is quite a different situation from that of earlier days, and the change is due principally to sincere and cooperative efforts, by professional plastics workers in many sectors of the industry. Standard tests on heat stability, tensile strength, elongation, electrical properties, low temperature performance, volatility, flammability, cracking, plating, burst strength, impact resistance and others have reached the stage of substantial agreement in the industry, and in most cases official standards have been adopted.

Light and weathering stability of vinyl plastics has received more attention, in terms of total work time by individual laboratories and cooperative group efforts, than any of the other vinyl tests. A number of standards, based on sunlamps and electric arc machines, have been chosen to provide controlled artificial test conditions, intended to predict weathering life of vinyl plastics. While these methods are capable of indicating trends, where comparison with known controls is standard practice, the fundamental weakness remains that correlation with natural weathering ranges from fair to poor. There is a definite element of uncertainty until machine results are supported by natural weathering information.

The problem confronting the vinyl processor who must estimate weathering life on an accelerated basis is, therefore, the choice of operating conditions with a particular artificial weathering apparatus which will come closest to the truth of natural weathering. The state of knowledge in this respect has been greatly enlarged during the past decade. It will be instructive to examine in some detail the most exhaustive study which has been made to date in this area, in which natural and artificial methods of testing light and weather resistance of vinyl plastics were evaluated, and to comment on some of these findings.

The Group III Committee of The Society of the Plastics Industry on Exposure Test Methods for Artificial Weathering, began an ambitious program of round-robin testing ten years ago. In a monumental effort, about 25 committee members selected 19 test compounds; mixed and calendered 8 mil film stock; conducted outdoor exposures on 15 sets of samples at six locations; exposed all 19 test compounds in 22 different arc and lamp machine conditions; compiled data on stiffness, spew, discoloration, spotting, tack, embrittlement and reflectance; and evaluated the comparative data on more than 6000 test pieces.

All of this work was carried out on base compounds which were not pigmented, except for the opacity imparted to some test compounds by pigment type stabilizers.

A second series of similar studies, using colored vinyl films, was carried out by a special subcommittee of Group III. In this work, four colored vinyl film stocks were weathered at five outdoor locations, and aged artificially in three types of arc machines; seven additional pasted colored vinyl film stocks were weathered outdoors to help establish performance standards.

The basic philosophy followed in all of this test work, spanning about eight years, was to start with an agreed standard of weathering performance on simple, unpigmented vinyl stocks. The factors involved in weathering degradation are quite complex, considering exposure location, type of mounting, effect of rainfall, contamination by solid or gaseous industrial products and agreement on evaluation methods. Confinement of these variables to a base system of resin, plasticizer and stabilizer, was considered necessary for the first and major phase of the study. The later project on colored vinyl stocks confirmed this decision, since failures of colorants themselves, exclusive of the vinyl base, led into a complicated problem of isolating specific colorant degradation effects with different outdoor locations; the variations among Florida, Arizona, New Jersey and Long Island exposures were great enough to make artificial machine correlation virtually impossible.

Since definitive conclusions were obtained from the non-colored vinyl compound study, and they point up specific artificial test apparatus and procedures, only this work will be discussed in this paper; space does not permit taking up the colored vinyl film subject, in spite of its great importance to the industry.

SUMMARIZED COMMITTEE PROCEDURE

Nineteen test compounds were selected and processed into eight mil film. Eleven of these stocks were clear, based on barium-cadmium and organotin stabilizers; eight compounds had varying degrees of opacity, ranging from highly translucent Plumb-O-Sil combinations with dibutyl tin dilaurate to relatively opaque Dyphos formulations. Outdoor tests were conducted at 45° south at six locations - Miami, Phoenix, St. Louis, Kingsport (Tenn.), Bound Brook (N. J.) and Sayville (L.I.). Samples were exposed both directly to the weather and under glass; various backing materials were included and compared. Exposure was measured in several ways simultaneously where possible. Artificial tests were conducted with sunlamps (6), Fade-Ometers (4), Twin-Arc Weather-Ometers (7), and Single Arc Weather-Ometers (6), operated at various temperatures, water spray cycles and special conditions. Periodic samples were taken for each exposure condition for central testing, and each was rated for spotting, tack, spew, and color change. Detailed data was kept, graphed and analyzed for more than 6,000 samples. Test results were evaluated by the order and types of failure obtained with the test machines, compared with averaged results obtained with direct and under glass exposures out of doors.

COMPARISON OF DIRECT OUTDOOR TESTS AT DIFFERENT LOCATIONS

The working base, necessary as a yardstick for machine testing on the test compounds, had to be a satisfactory standard of outdoor weathering performance. This was obtained by analyzing fifteen sets of exposures from 6 locations. At this point, basic agreement had been reached on uniform estimation of spotting, discoloration, tack and spew; stiffening was judged with the Dexter Constant Strain Stiffness Apparatus.

The similarity in order of failure of the speciments at different locations was gratifying. The mean average deviation in numerical order for all locations was 0.3, as shown in Table I.

The types of failure corresponded quite well; these data are also shown in Table I.

The Miami order of failure was taken as the reference point. Generally, agreement on order of failure was excellent. Sayville exposures differed from the others in that Sayville samples were exposed on painted wood; the others were free films. Since the white backing increases degradation in clear stocks by reflection, one would expect the higher deviation in order of failure. Phoenix may have shown slightly greater deviation than average because of its lower humidity and rainfall.

Frequency of spotting correlated well among the different locations. It might be mentioned here that these tests were summer exposures; in a separate set exposed at Sayville in winter, spotting frequency was below the summer normal.

The frequency of stiffening and discoloration failures stayed within narrow limits, except that Kingsport was somewhat below average in both. Winter exposure increased the frequency of stiffening as a failure type.

Tack formations as an initial failure varied from three (Miami) to ten (Kingsport). Winter exposure produced a sharp reduction in tack at Sayville.

RATES OF FAILURE AT DIFFERENT OUTDOOR LOCATIONS

A surprising change of relative rates of failure between direct and under glass exposures at various locations showed up. Typical figures given in Table II show the average number of days exposure for a median stock to exhibit initial change at each location.

The rate of failure on direct exposure tests was greatest in Phoenix, lowest in Miami; it was almost identically intermediate in three other locations.

Under glass, Miami's rate of failure was identical with Miami direct exposure. Phoenix and Sayville under glass rates were intermediate and identical, while Bound Brook was slower. It was interesting to see that Phoenix is twice as fast as Miami on direct exposure, but substantially slower under glass; the writer is not aware of any reasonable explanation.

EFFECT OF SAMPLE BACKING

The standard test samples in this work were supported as free film, but a number of backings were evaluated in simultaneous exposures. The use of white pine, red oak, cloth, aluminum, painted wood and cloth over painted wood backers increased the rate of failure substantially.

Aluminum is not satisfactory, showing poor order of correlation with free film; it appears to subject clear films to greater radiation by reflection.

Unpainted white pine and red oak gave reasonably good alignment with free film failures; they varied somewhat in order of failure and tack development.

Painted wood also gave reasonable correlation, and may be satisfactory. Careful preparation is obviously essential, and severe paint lifting may occur in some instances.

The use of cloth (unbleached muslin) over painted wood prevented paint lifting and minimized wind loss with good correlation on type and order of failure.

Cloth backing (unbleached muslin) maintained proper order of failures as well as free film, and perhaps slightly better; it showed slightly higher tack development, but otherwise would be highly satisfactory for reducing wind losses of free film.

EVALUATION OF SUNLAMPS VERSUS DIRECT WEATHERING

The data shown in Table III were used to rate six lamp machines against direct weathering. The results speak very clearly for themselves in Table III. All of the machines for which data were obtained gave completely unsatisfactory order of failure and type of failure. They were very low in spotting and very high in stiffening and discoloration; correlation with outdoors was poorest in this group of machines.

EVALUATION OF FADE-OMETERS VERSUS DIRECT WEATHERING

The Model FDA-R Fade-Ometer was operated in four tests, using the three black panel temperatures as shown in Table IV.

The most significant feature in these data is the pronounced effect of black panel temperature. Note the progressively greater deviation in order of failure and in discoloration type of failure as the black panel temperature rises. From the late 1940's through the mid-1950's, it is important to remember that a major segment of the vinyl industry was using 200°F. black panel Fade-Ometer tests as a criterion of light stability. Later partial re-evaluations of data by the committee chairman would lower the A.D. for 1250 B.P. Fade-Ometer from the 2.3 shown to 1.9, a good correlation rating.

EVALUATION OF TWIN-ARC WEATHER-OMETER VERSUS DIRECT WEATHERING

Table V shows six variations in operating conditions of the Twin-Arc Weather-Ometer. The operation of this machine without any water spray gave the best correlation on order of failure with outdoor weathering of any machine tested. Agreement on type of failure was also very good, high tack being the only deficiency. The other tests in this group show that in general, spotting is weighted in the proper range in the Twin-Arc machine; stiffening is too high with most water cycles; and where stiffening is kept down, tack is high. In most cases, good performance on order of failure is characteristic. This work suggests the desirability of testing and evaluating the Twin-Arc Weather-Ometer using the 18-102 water cycle.

SINGLE ARC WEATHERING UNITS VERSUS OUTDOOR WEATHERING

Several uncommon cycle changes were made with single arc machines in this study; the results are shown in Table VI.

Poor correlation as to order and type of failure is seen in the first two XW machine studies; performance was much better in the first special cycle XW. Except for high tack, this would constitute almost ideal type of failure performance. The second special cycle XW machine showed one of the best order of failure performance patterns; but increased discoloration and decreased spotting lowered the type of failure performance to an unacceptable level. Clearly, the XW machine offers promise at some point of adjustment between these two special cycles. The old BWM-C Model Weather-Ometer, an obsolete machine, gave the best order and type correlation with outdoor weathering of any machine tested. It has one serious penalty, however; it is so slow in rate of failure that it takes more than twice as long as other acceptable machines to produce good results.

SUMMARY OF MACHINE TEST RESULTS

Four machines, using specified operating conditions, were found to give satisfactory correlation with outdoor weathering, in both type and order of failure. One of these, the BWM-C Weather-Ometer, is obsolete and impractically slow.

The Twin Arc Weather-Ometer (dry), the FDA-R Fade-Ometer at 125°F. black panel, and the Single Arc XW machine with special cycle, all correlated satisfactorily. The first two machines are in wide usage and can be readily operated in the proper working range. As long as care is taken in maintaining black panel temperatures of 140°F. or lower, and regular checks against outdoor weathering are made, the prediction of weathering life of vinyl plastics will have reasonable accuracy.

The new Xenon units which are being offered for artificial light testing are most interesting. They are reported to have a spectral distribution more closely approximating sunlight than any other machine. Reports of correlation studies with outdoor weathering controls will be very important to the vinyl industry.

ACKNOWLEDGEMENT

This discussion is based largely on the work of Committee III of The Society of the Plastics Industry. The author served as one member of a group of twenty-five; the scope of the work of this committee demonstrates adequately the amount

of patience, time and labor involved. The members of the committee who performed such a diligent task were the following:

J. G. Hendricks, Chairman, M. J. Babey, Martin Bachner, G. R. Buchanan, L. E. Calkins, A. J. Carter, C. R. Caryl, F. B. Clark, J. D. Da Coste, E. M. De Noon, P. J. Fynn, W. J. Goodwin, A. J. Hanley, F. H. Lieb, R. Metzinger, J. R. Norton, E. Pittinger, F. W. Reinhart, A. W. Schatzel, I. J. Schmidt, J. W. Sinner, P. W. Spink, J. W. Tamblyn, V. T. Wallder, E. L. White.

TABLE I

ORDER AND TYPES OF FAILURE AT DIFFERENT LOCATIONS

Location	Order of Failure Average Deviation	Type of Initial Failure Spot.	Stiff.	Discolo.	Tack
Miami, Fla.	0.0 (Standard)	15	5	3	3
Phoenix, Ariz.	0.5	13	4	4	4
Kingsport, Tenn.	0.1	17	3	1	10
St. Louis, Mo.	0.1	14	5	4	6
Bound Brook, N.J.	0.3	11	4	6	4
Sayville, N. Y.	0.9	13	5	5	8
MEAN	0.3	14	4	4	6

TABLE II

AVERAGE DAYS EXPOSURE FOR MEDIAN STOCK TO SHOW FIRST FAILURE

	Miami	Phoenix	Kingsport	St. Louis	Bound Brook	Sayville
Direct	133	68	103	106	104	91
Under Glass	132	180	-	-	231	182
Factor	1.0	2.6			2.2	2.0

TABLE III

SUNLAMP PERFORMANCE

	Order of Failure		Type of Failure				
Test Machine	A.D.	Rating	Sp.	St.	D.	T.	Rating
	Direct						
S-1	4.2	E.Poor	3	10	19	5	E.Poor
S-1,Fog box 60°C	4.0	E.Poor	6	3	12	5	Poor
S-4	3.6	V.Poor	0	19	13	11	E.Poor
RS	4.7	E.Poor	3	9	16	4	E.Poor
Calkins RS			Low		(very	low	E.Poor
Fluorescent			0		high)		E.Poor
Outdoors, direct, avg.	(0.3)	Std.	14	4	4	6	Std.

TABLE IV

FADE-OMETER PERFORMANCE

	Order of Failure		Type of Failure				
Test Machine	A.D.	Rating	Sp.	St.	D.	T.	Rating
	Direct						
FDA-R at 125°F.	2.3	Fair	12	4	7	6	V.Good+
ibid at 160°F.	3.1	V.Poor+	12	3	6	5	V.Good
ibid at 200°F.	3.4	V.Poor	11	4	9	6	Good-
ibid at 200°F.	3.4	V.Poor	9	3	10	4	Poor
Outdoors, direct avg.	(0.3)	Std.	14	4	4	6	Std.

TABLE V

TWIN-ARC WEATHER-OMETER PERFORMANCE

Test Machine	Order of Failure A.D. Direct	Order of Failure Rating	Type of Failure Sp.	St.	D.	T.	Rating
Dry	1.6	Good+	14	3	3	9	V.Good
3-17 Cycle (mineral spray)	2.6	Poor+	11	10	4	1	Poor
3-17 Cycle 8 sunlamps	2.6	Poor+	11	12	8	3	V.Poor
9-51 Cycle	1.8	Good	16	3	2	11	Poor
Continuous water	3.4	V.Poor	11	12	1	0	E.Poor
"Single Twin" 18-102 cycle	3.3	V.Poor	10	8	7	2	Poor
Outdoors, direct, avg.	(0.3)	Std.	14	4	4	6	Std.

TABLE VI

SINGLE ARC WEATHERING UNIT PERFORMANCE

Test Machine	Order of Failure A.D. Direct	Order of Failure Rating	Type of Failure Sp.	St.	D.	T.	Rating
XW, dry	2.8	Poor	9	11	14	7	V.Poor-
XW, cont. water	5.1	E.Poor	2	19	3	0	E.Poor
Spec. XW[1]	2.2	Fair	14	6	5	9	V.Good+
Spec. XW[2]	1.9	Good	11	3	8	7	Fair+
XIA 18-102	2.6	Poor+	10	14	10	1	V.Poor
BWM-C, dry	1.8	Good	13	3	6	5	V.Good+
Outdoors, direct, Avg.	(0.3)	Std.	14	4	4	6	Std.

[1] 2 hours dark at 100% R.H., 6 hrs. light at 135°F. B.P. and 60% R.H.

[2] 18-102 cycle, 12 hrs. light, 12 hrs. dark.

Plastec Ref. # ~~[illegible]~~ 1676

STANDARDS FOR VINYL CHLORIDE PLASTICS

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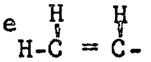
Standards for plastics, as the term is generally used in the industry, includes definitions, methods of tests, recommended practices, specifications, codes and design criteria. ~~It will be~~ the purpose of this paper to indicate for vinyl chloride plastics the standards available in each of these subgroups and something about their nature. + [illegible]

DEFINITION OF TERMS

This section includes nomenclature as well as definitions because when a term is defined nomenclature is thereby established also.

The most widely accepted definitions concerned with plastics are those developed by Committee D-20 on Plastics of the American Society for Testing Materials (ASTM)[1,2]. The definitions in the SPI Polyvinyl Chloride Manual[3], and the SPI Plastics Engineering Handbook[4] are based on ASTM definitions where such are available. The SPE Editorial staff uses the ASTM definitions. They are also generally accepted for use in Federal and Military Standards.

ASTM Committee D-20 is currently combining D883 and D675 into one standard. It is their intent to add definitions scattered throughout the ASTM plastics standards to this master standard so that all the definitions will be in one place. Some pertinent definitions have also been formulated by ASTM Committee D-14 on Adhesives[5] and D-11 on Rubber[6].

There is more confusion in the basic terminology with the use of the term "vinyl" than with any of the other chemical names for types of plastics materials. First, there are those who use the term "vinyl" in the chemical sense, that is for any chemical containing the  $\mathrm{H{-}\overset{H}{C}{=}\overset{H}{C}{-}}$ group and any resins or plastics made from these chemicals. This results in vinyl chloride, styrene, methyl methacrylate and other plastics being called "vinyl plastics". One helpful factor is that the members of this group more often say "vinyl resins" than they do "vinyl plastics". This concept is based on the system of nomenclature adopted by chemists through national and international scientific bodies many years ago.

Second, the term "vinyl" is also used to refer to plastics based on polyvinyl chloride polymers and copolymers of vinyl chloride with other monomers. In more exact terminology, this group of materials is called "vinyl chloride plastics" and this term is recognized in the written definitions of the industry. The terms "vinyl" and "vinyl plastics" are being used in this technical conference in this sense.

Third, the term "vinyl" is used in the adhesives industry, closely related to plastics because of common usage of many resins, to refer to vinyl acetate adhesives.

Fourth, the term "vinyl" is used by some of those concerned with vinyl alcohol polymers and vinyl acetate-vinyl alcohol copolymers in referring to these products.

Thus, it is easy to see why use of "vinyl" as technical slang can be confusing at times to those concerned with many facets of plastics and resins and in derivative industries in which these materials are used, such as packaging, coatings, etc. It is suggested that in writing and in the initial phases of discussions that the exact terminology for the meaning of the word "vinyl" be used so that there will be no misunderstandings.

Another source of confusion is in the use of the terms plastics, rubber and elastomers. There seems to be a general, but not universal, consensus that plastics and rubber are similar except that rubbers are characterized by "high extensibility and forcible quick retraction". Although not universally accepted, it seems that the most general concept for elastomer is that it includes all rubbers, some plastics, and all materials in the questionable area between them. The conclusion might be that vinyl chloride plastics are all plastics and not rubbers and that those vinyl chloride plastics that are highly extensible may also be called elastomers. There is a joint plastics-rubber group in ASTM working to prepare mutually acceptable definitions of these three terms.

There is still some confusion, but not nearly as much as there was 10 years ago, on the meaning of the terms sheet or sheeting and film.[1] Sheeting is a continuous form in which the thickness is very small in proportion to length and width. Sheet is a short piece of sheeting. Film is sheeting 0.010 inch or less in thickness. Thus the common phrase "sheet and film" or "sheeting and film" is redundant.

Standard abbreviations for plastics and plasticizers[7] have been developed by ASTM. Some of those of interest to vinyl chloride plastics are as follows:

Poly(vinyl acetate)	PVAc
Poly(vinyl alcohol)	PVA
Poly(vinyl butyral)	PVB
Poly(vinyl chloride)	PVC
Poly(vinyl chloride-acetate)	PVCAc
Dibutyl phthalate	DBP
Dicapryl phthalate	DCP
Diisooctyl phthalate	DIOP
Dioctyl phthalate	DOP
Tricresyl phosphate	TCP
Trioctyl phosphate	TOF
Solvent welded plastics pipe	SWP

METHODS OF TEST AND RECOMMENDED PRACTICES

The following methods of test are some of those commonly used to determine the properties of vinyl chloride plastics. The ASTM methods are given in reference 8 and the Federal Standard methods in reference 9 (designated as FS 406 in this test). It is intended in this discussion to state in very general terms the nature of the test and to indicate the usual selection of the optional procedural details in testing vinyl chloride resins and plastics. Some recent advances in these test methods are described by De Coste.[10]

Definitions of terms relating to mechanical testing are given to ASTM E 6. Recommended practices for sampling and choice of sample size are given in ASTM E 105 and D 1898 respectively. A recommended code for designating form of material and direction of testing is given in ASTM D 1009. Mechanical testing machines are verified in accordance with ASTM E 4.

CONDITIONING AND MOLDING

A. Conditioning, ASTM D618, D 759, D 1197, E 41, E 104, E 171, E 337, and FS 406

Results for vinyl chloride plastics are usually based on tests made after prior conditioning. Standard temperature and humidity used for conditioning and testing as well as other conditions that are frequently used are given in ASTM D 618. Definitions concerned with conditioning and weathering are given in ASTM E 41. Standard atmospheres for conditioning and testing a number of materials are summarized in E 171. Problems and procedures used in the conditioning and weathering of plastics are reviewed in reference 11. Methods for maintaining constant relative humidities by means of aqueous chemical solutions are given in E 104 and methods for determining relative humidity are given in E 337.

Many of the test methods described briefly below may be used to determine properties at various temperatures and relative humidities provided proper auxiliary equipment is used. Specifications for equipment for this purpose are given in D 1197. Methods for measuring tensile and compressive properties at subnormal and supernormal temperatures are described in ASTM D 759.

B. Molding, ASTM D 647, D 955, D 957, D 958 and D 1130

Standard molds for molding specimens are specified in D 647. Molding conditions are not given. Recommended practices for determing temperatures of these molds are given in D 958 and for surfaces of commercial molds in D 957. Methods of measuring shrinkage are described in D 955. Recommended practices for injection molding specimens are given in D 1130.

MECHANICAL PROPERTIES

A. Bearing Strength, ASTM D 953 and FS 406 Method 1051

The method contains two procedures, A and B. Procedure A is for tension loading and is more commonly used than Procedure B which is for compression loading. In this test a rectangular specimen with a hole near one end is used. A load is applied to a hardened steel pin through this hole. The bearing strength is defined as the stress when the total strain is 4 percent of the bearing hole diameter. Results obtained when the specimen fails in tension or compression are invalid. A universal type of mechanical testing machine with special fixtures is needed to make this test.

B. Compressive Properties, ASTM D 695 and FS 406 Method 1021

Specimens with slenderness ratios in the range of 11 to 15 are subjected to compression at a controlled rate of head motion in a universal type of mechanical testing machine. Special fixtures are needed to obtain uniform loading over the cross-section of the specimen. Results obtained with specimens that fail by buckling, bending, or crushing of the ends are invalid. Compressive strength, yield stress, and modulus are obtained.

C. Flexural Properties, ASTM D 790 and D 797 and FS 406 Method 1031

In D 790, rectangular specimens are supported near the ends and a load applied on the top in the center of the span. The span depth ratio is 16 or greater to reduce or eliminate shear failures. The rate of loading is controlled to give a unit rate of fiber strain in inches per inch of outer fiber length per minute of 0.01. Special fixtures of relatively simple design and a universal mechanical testing machine are required to make this test. Flexural strength and modulus are obtained. A method of determining Young's Modulus in flexure of elastomers at room and low temperatures is described in D 797.

D. Impact Resistance, ASTM D 256, D 758 and D 1822 and FS 406 Method 1071

The methods in D 256 are used to determine the relative susceptibility to fracture by shock as indicated by the energy expended by a special pendulum type machine in breaking in one blow a standard specimen. Method A is the cantilever or Izod test in which the notched specimen is held as a cantilever beam and is broken by a blow from the pendulum. The notch is intended to produce a standard degree of stress concentration. Method B is the simple beam or Charpy test in which the specimen is supported as a simple beam and is broken by a blow delivered midway between the two supports. Charpy tests are made on plain or notched specimens. Method C is similar to Method A except that a procedure is included to determine the tossing energy; it is not recommended for materials that have Izod impact strengths greater than 0.5 ft-lb per inch of notch. Although most test specimens are not 1-inch wide, results are calculated and reported to ftplb/inch (of notch or width). Values less than 0.2-ft-lb/inch are meaningless. Results obtained by one method cannot be compared directly with those obtained by another. Impact test results cannot be translated into service behavior unless the service conditions are such that similar loading conditions are encountered. Although a simple test to make, great care must be taken in preparing the test specimens, particularly for notched specimens, and in making the test to obtain reliable results. Equipment and conditions for making impact tests in accordance with ASTM D 256 at low moisture contents, and at high and low temperatures are given in ASTM D 758. The energy required to rupture standard tensile specimens by a tensile-impact blow in a modified Izod impact testing machine is given in D 1822. The specimen is mounted on a pendulum.

E. Falling Ball Impact, FS 406 Methods 1073, 1074 and 1075

Specimens 12 inches square are subjected to impact in Method 1074 by a falling 0.5-pound steel ball at successive 1-foot intervals until fracture occurs. For testing a group of specimens to single impacts it is recommended that the "Up and Down" method described in references 12 and 13 be used. Method 1073 is similar to 1074 except that a 2-pound ball is dropped from a height of 54 inches on the test specimen. In method 1075, the specimen is 2.5 by 4.5 inches and a 0.5 steel ball is dropped in 3-inch intervals. Simple equipment is needed.

F. Shatterproofness, FS406 Method 1072

Method 1072 is intended to measure the effects of shock on sheets mounted in frames in or on structures which are subject to shock (such as battleships).

G. Shear Strength (Punching), ASTM D 732

The shear strength of plastic sheet, 0.005 to 0.500 inch thick, is determined by means of a special punching tool on a universal testing machine. The maximum load required to punch through the sheet so that the punching tool has completely cleared the stationary portion is measured. The shear strength is expressed in psi based on the area of the sheared edge (thickness of the specimen multiplied by the circumference of the punching tool).

H. Tensile Properties, ASTM D 638 and FS 406 Method 1011

Specimens may be cut from sheets, rods and tubes, or molded. Strain measurements are made in a 2-inch gage length on a reduced section in the middle of the long specimen. A universal testing machine with special grips is required. Properties commonly reported are tensile strength (stress or rupture) in psi, tensile yield strength in psi, elongation at rupture in percent, and modulus of elasticity in psi. Corollary elementary information on tension testing of plastics is given in reference 14.

I. Tensile Properties of Thin Sheets, ASTM D 882, D 1530, and D 1708, and FS 406 Method 1013

Three methods for determining the tensile properties of thin plastic sheets are described in D 882. The results obtained by the three methods cannot be compared directly. Method A requires a universal mechanical testing machine which has a weighing head that moves less than 0.005 inch during the test. The grips holding the specimen separate at a constant rate. Method B requires a pendulum machine in which the weighing head moves a relatively greater distance during the test. The more rigid the material, the greater the movement of the weighing head. The powered grip moves at a constant rate. The rate of grip separation is variable, being dependent on the relative movements of the grips and the elongation characterisitcs of the specimen. Method C requires an inclined plane weighing head. The angle of inclination of the tilting table on which the loaded carriage moves to apply the load is changed to give a constant rate of load application. The rate of grip separation is variable, being dependent on the elongation characteristics of the specimen. Tensile strength is reported in psi, elongation in inches, percentage maximum elongation (strain) in percent of the original gage length, elastic modulus in psi, and breaking factor in lb per-inch width.

A procedure for determining the tensile moldulus of elasticity of plastic films is described in D 1530. A testing machine of the constant rate of jaw separation type is required. This separation of jaws is used as a measure of the extension. Results can be compared only when spcimens of identical dimensions are used. The tensile modulus is often used as an index or stiffness.

A method for determining the tensile strength and elongation properties of plastics with microtensile specimens is described in D 1708. It is designed for use when only small amounts of material are available for test. Modulus of elasticity can not be determined. It is not intended to replace the more accurate methods, namely D 638 and D 882.

J. Tensile Time-Fracture and Creep, FS 406 Method 1063

This method is used for determining the ability of rigid plastics to withstand creep and fracture as a result of sustained tensile loads. The equipment is relatively simple.

K. Bursting Strength of Round Rigid Tubing, ASTM D 1180

A very high visocisty hydraulic medium is placed in a speciment of the tubing and the ends closed with movable plugs placed inside the tubing. A load is applied to the movable plugs on a universal type mechanical testing machine so that the hydraulic medium is in compression. The bursting strength is reported as the fluid pressure required to rupture the tubing.

L. Tubing Tests, D 876

Methods for testing nonrigid tubing for use as electrical insulation are given. These include dimensions, flammability, tensile strength and elongation, heat again, oil resistance, brittleness temperature, resistance to penetration, electrical insulation resistance, dielectric strength at 50 and 96.5 percent relative humidities, and strain relief.

M. Hydrostatic Pressure, ASTM D 1598 and D 1599

The hydrostatic pressure required to rupture pipe or tubing is measured in a long-term test in D 1598 and in a short-time test in D 1599. Special equipment is required in both tests. Special care must be given to detail in order to obtain satisfactory results particularly with respect to reproducibility and consistency.

N. Pipe Working Stress, SPI

A method for determining the long-term strength and working stresses of thermoplastic pipe was developed by the SPI Thermoplastic Pipe Division and adopted in January 1961. It is now undergoing a thorough study by means of an interlaboratory testing program in the joint ASTM-SPI plastic pipe group.

O. Repeated Flexural Stress (Fatigue), ASTM D 671

The effect of repetitions of stress is determined by a special fixed-cantilever type of testing machine which is designed to produce the same deflection of the cantilever beam (the specimen) in each cycle. The test is made at

1720 ± 25 cycles of stress per minute. Three types of specimens are used, plain, V-notched, and drilled-hole notched (used for thin sheets). Test reports require cycles per minute, fatigue ratio, total number of cycles, fatigue strength in psi at the number of cycles of stress and the mean stress, the mean stress of the cycle in psi, and whether the stress is in tension or compression.

P. Flexural Fatigue, FS406 Method 1061 and 1062

Method 1061 is a constant-strain flexural fatigue strength test made with a cantilever beam machine. Method 1062 is a constant-stress flexural strength test made with a rotating-beam machine.

Q. Stiffness, ASTM D 747, D 1043

The stiffness in flexure is determined in D 747 with a special machine from a plot of deflection of a cantilever beam versus load. Stiffness is calculated in psi by means of a modulus of elasticity expression. However, the results are not true modulus values. The stiffness is determined as the apparent shearing modulus of elasticity by means of a torsion test in D 1043. The test can be made over a wide range of temperature. Special apparatus is required.

R. Creep or Stress-Relaxation, ASTM D 674

This recommended practice describes general procedures for making long-time creep or stress-relaxation tests under tension or compression loads at various temperatures. Detailed test procedures and equipment must be developed by the experimenter.

S. Snag and Tear Resistance, ASTM D 1004 and FS406 Method 1121

A method of determining the snag resistance of coated fabrics and plastic films is described in reference 13. In this test, the maximum angle of inclination of a specimen that will not allow tearing of the material as a moving needle is passed over it and the energy to tear are measured. The resistance to tear is determined by this angle, the energy, and the character of the tear.

The method of determining tear resistance of plastic sheeting described in D 1004 uses a special specimen in standard tensile testing machines.

T. Hardness

Hardness is measured by many methods involving several different properties. Thus a hardness value is a function of the test machine, of the test procedure, and of some combination of properties of the material under test. Hardness tests may be classified into two types: indentation and scratch.

U. Rockwell Hardness, ASTM D 785 and FS406 Method 1081

The Rockwell hardness is an indentation test in which a steel ball is forced into the body of the plastic. Steel balls of different diameters and at various loads are used to cover several ranges. A special machine is used to make this test. Method A measures the indentation remaining 15 seconds after a given major load has been released from the penetrator after being applied for a given length of time. Method A results are reported as a capital letter followed by a number, for example, M80 (the scales used for plastics are R, L, M, and E which are related to various loads and diameter of the penetrator). Method B measures the indentation resulting from a 60-kg load being applied by a 1/2-inch penetrator for a given period, the measurement being made with the major load applied. Method B is referred to as the alpha hardness and the test results are reported as numbers preceded by a , for example, a 120.

V. Durometer Hardness, D 1706 and FS406 Methods 1082, 1083 and 1084

The durometer hardness is an indentation test which utilizes special hand-testing devices. Type A durometer is used for nonrigid and semirigid materials. A method of calibrating the durometers is included.

W. Scratch Hardness, D 1526

The Bierbaum scratch hardness is determined by a device that produces a scratch under controlled conditions. The hardness value is the load on the scratching diamond point divided by the square of the width of the scratch at the surface. A high degree of skill is required to obtain reliable measurements. Although the method gives very useful results, the special apparatus required to produce the scratch is no longer made commercially. A microscope and a filar micrometer are required to measure the width of the scratch.

X. Abrasion Resistance, ASTM D 1242

Procedure A utilizes loose abrasive with a special machine on which the revolving specimen is pressed against a revolving disk. Procedure B utilizes bonded abrasive on cloth or paper on a special machine on which the specimens are moved in one direction and the abrasive sheet moves in the opposite direction.

Y. Surface Abrasion, ASTM D 1044 and FS 406 Method 1092

A Taber abraser is used with CS-10F Calibrase wheels at a load of 250, 500, or 1000 grams to produce abrasion on transparent sheet. The amount of abrasion is determined by haze measurements.

Z. Abrasion Wear, FS406 Method 1091

This method uses a Taber Abraser and CS-10 Calibrase wheels with a 1,000 gram load on each wheel. The weight loss in milligrams per 1000 abrading revolutions is reported. Special equipment is required.

OPTICAL PROPERTIES

A. Index of Refraction, ASTM D 542 and FS406 Method 3011

The index of refraction of transparent plastics is measured with repactometer or precision microscope. The immersion liquid recommended for use with vinyl resins is a-monobromnaphthalene. If the results are given to more than 3 places, the wave-length of the light should be included. The sodium D-line is the one most commonly used.

B. Luminous Transmittance and Haze, ASTM D 1003 and FS 406 Method 3022

An integrating sphere instrument is used to measure the light transmission and the haze of transparent and translucent materials.

C. Optical Uniformity and Distortion, ASTM D 637 and FS 406 Method 3041

The distortion of images observed through transparent sheet is measured.

D. Light Diffusion, ASTM E 166 and E 167 and FS 406 Method 3031

These are goniophotometric recommended practices for measuring the spatial distribution of light transmitted through materials and reflected from surfaces by special optical instruments of the research type.

E. Gloss, ASTM D 523 and D 1471 and FS 406 Method 3051

Gloss measurements are made to obtain some idea of the surface finish and appearance. This is a function of the angle of reflected light, color, and surface geometry. Since the angle changes as the observer moves, there is difficulty in relating measurements made at specific angles to what the obsever sees. An article by Hunter (15) on this problem is recommended for those interested. These methods require the use of special expensive optical equipment.

THERMAL PROPERTIES

A. Linear Thermal Expansion, ASTM D 696 and FS 406 Methods 2031 and 2032

A quartz tube apparatus is used to measure the coefficient of linear thermal expansion over a wide temperature range. The values most commonly reported are for -30°F to +30°C and are expressed as change in length per unit length per degree. Method 2032 is a less accurate procedure made with a strip of plastics sheeting.

B. Cubical Thermal Expansion, ASTM D 864

The volume thermal expansion is determined by placing small pieces in a glass dilatometer, evacuating the air, filling with mercury, and then measuring the change in volume of the spcimen and mercury on cooling or heating. Results are reported as change in volume per unit volume per degree.

C. Deformation Under Load, ASTM D 621 and FS 406 Method 1101

Method A in this standard is used to determine the deformation under compression of rigid plastics. The principle is essentially that of a parallel plate plastometer. The specimen is placed between parallel plates, a constant force applied, and the change in thickness measured as a function of time at the selected temperature. A special test machine is used. Results are reported as the change in height in mils in 24 hours or as the percent change in the original height.

D. Tensile Heat Distortion, ASTM D 1637

The temperature at which sheeting deforms appreciably under a small tensile stress is measured in a special apparatus which is relatively simple. The method is applicable to sheets 0.001 to 0.060 inches in thickness.

E. Deflection Temperature, ASTM D 648 and FS 406 Method 2011

This is an arbitrary procedure that measures the temperature at which a simple beam is deflected 10 mils under load while the temperature is increased at a rate of 2°C per minute. Polyvinyl chloride plastics are usually tested at a fiber stress of 264 psi. Special equipment is needed to make this test.

F. Flow Properties, ASTM D 569 and D 1703 and FS 406 Method 2041

The temperature at which a thermoplastic flows under prescribed extrusion conditions is described in Procedure A of D 569. In Procedure B, the degree of flow at a specified pressure, temperature, and time in a standard extrusion mold is determined. These tests require special equipment and experience to assess the usefulness of the results. Recommended practices for reporting data obtained with a capillary rheometer on molten thermoplastics and a description of possible sources of experimental error are given in D 1703

G. Flammability, ASTM D 568, D 635, D 757, D 1433, D 1692 and E 162, and FS 406 Methods, 2021, 2022 and 2023

These methods measure the rate of burning at controlled conditions with relatively simple equipment, except for D 1433 which uses special apparatus. D 1433 was prepared jointly by the SPI and ASTM. D 568 is for material 0.050 inch or less in thickness and reports results in square inches per minute for specimens 1 inch wide. D 635 is for material over 0.050 inch in thickness and reports the results in inches per minute for spcimens 0.5 inch wide. D 757 is for "self-extinguishing" materials and reports the results in inches per minute for specimens 0.5 inch wide by 0.125 inch thick. D 1433 is for foams and flexible sheeting; in both of these methods provision is made for sheeting (or film) that can support itself horizontally as a cantilever beam. E 1632 describes a method to measure surface flammability using a radiant heat source. These methods are not intended to indicate the behaviour of materials in actual service but instead to give comparative rates of burning for differentiating between materials and for specification purposes.

H. Welding Performance, ASTM D 1789

The quality of a welded vinyl chloride plastics joint is determined from the tensile strength of welded specimens. Suggestions on techniques to obtain and identify good joints are included.

I. Brittleness, ASTM D 746 and D 1790, and FS 406 Method 2051

The temperatures at which plastics become brittle are determined in D 746 by striking cold specimens a quick blow by means of a controlled power-operated hammer. The results are calculated statistically as that temperature at which rupture will occur 50 per cent of the time for the particular set of specimens. The temperature at which plastics film becomes brittle is determined in D 1790 by a relatively simple device in which a looped specimen is struck by a falling hammer.

J. Blocking, ASTM D 884 and D 1893 and FS 406 Method 1131

Qualitative degrees of blocking of plastic sheets are determined by placing loaded stacks of sheets in ovens at specified temperatures for 24 hours. Only very simple equipment an an oven are required. A quantitative measure of blocking is given in D 1893. In this method, the force required to separate the blocked sheets is measured with a tensile testing machine.

PERMANENCE PROPERTIES

A. Simulated Service Conditions, ASTM D 756 and FS 406 Method 6011

Seven sets of cyclic conditions of heat and relative humidities are given to determine the comparative resistance of materials to laboratory versions of typical service conditions. Procedure I (Section 8) evaluates warping, weight change, and exudation in plastic parts. Procedure II (Section 9) is designed to reveal poorly cured plastics by developing cracks in them. Procedures III and IV are more severe measures of the same tendencies developed in procedure I; the contions of procedure IV will produce noticeable chemical decomposition in many plastics. Procedure V (Section 12) is especially valuable in testing the tendency of plastic parts with metallic inserts and laminates to crack on exposure to temperature change. Procedures VI and VII are modifications of procedure I, applying to thermoplastics of impact-resistant and low heat-distortion temperature types, respectively. These tests are made with relatively simple laboratory equipment.

B. Dimensional Changes, ASTM D 1042 and D 1204

Procedures are given for measuring the dimensional changes resulting from exposure to various temperatures and relative humidities, and to cyclic service conditions such as those in D 756. Relatively simple apparatus is used. Results are reported as percent changes for each dimension. Method D 1204 is particularly applicable to nonrigid sheet materials.

C. Chemical Resistance, ASTM D 543, D 1239 and D 1712 and FS 406 Method 7011

The effects of a wide variety of chemicals on materials are determined by immersing them in the selcted chemicals. D 543 is for materials 1/8 inch thick and an immersion period of 7 days at 23°C. D 1239 is for films at a standard immersion period of 24 hours at 23°C., alternative conditions are 4 hours at either 23° or 40°C or 24 hours at 40°C. Simpel laboratory equipment is used. Changes in weight and dimensions are reported in percent. Observations of visual examination and solubility are also reported. D 1712 describes a test to determine resistance to sulfide staining.

D. Colorfastness, ASTM D 620 and FS 406 Method 6031

Colorfastness is determined by exposure for 50 hours to the radiant energy from an S-1 sunlamp bulb under standard conditions. Special viewing conditions should be used to judge color changes. This method will probably be cancelled in the near future because the lamp equipment is no longer being manufactured, and be replaced by one based on other radiant energy sources such as the fluorescent sunlamp or carbon arcs. Special equipment is needed for this test.

E. High Energy Radiation, ASTM D 1672 and D 1671

Recommended practices for exposing polymeric materials to high energy radiation are given in D 1672 and a test to measure the absorbed gamma radiation dose by means of the Fricke Dosimeter is described in D 1671.

F. Volatile Loss, ASTM D 1203 and FS 406 Method 6081

The volatile loss is determined under defined conditions of time and temperature utilizing activated carbon as the immersion and absorbing medium. Relatively simple equipment is used. Changes in weight, thickness, and appearance are reported.

G. Drying for Weight Loss, FS 406 Method 7041

The loss in weight on drying for 24 hours at 105°C (221°F) is determined. This loss may consist of water, solvents, and/or volatile plasticizers. In a restricted sense it is a measure of the stability of the composition in storage or indoors where no strenuous degrading environments or forms of energy are present.

H. Warpage, ASTM D 1181 and D 1604, and FS 406 Methods 6051 and 6051

The dimensional distortion of a sheet is measured by means of a special, relatively simple device in D 1181. The warpage is the average heights at the corners minus the average thickness at the corners. Changes in warpage as a result of exposure to simulated service conditions may also be determined. In D 1604, the flatness is a direct linear measurement of the edges and center section of the sheet. Lack of flatness is characterized by fullness of the center section.

I. Artificial Weathering, ASTM D 795, E 42, D 822, D 1499, and D 1501, and FS 406 Methods 6011, 6022, 6023, and 6024

In D 795, specimens are exposed to cycles of radiant energy from an S-1 sunlamp and fog under defined conditions. Changes in appearance, weight, dimensions, or properties are reported. Special equipment is used. This method will be cancelled in the near future because the equipment is no longer being manufactured. D 1501 is similar to D 795 and is intended to replace D795. It uses a Westinghouse fluorescent sunlamp as the source of radiant energy. E-42, D 822, and D 1499 give recommended practices for the operation of special equipment in which specimens are exposed to cycles of radiant energy from carbon arc machines and water.

J. Outdoor Weathering, ASTM D 1435

Recommended practices for exposure of specimens outdoors are described. Exposure racks are relatively easy to build. Instruments to measure and record climatological conditions are special equipment. Changes in appearance, weight, dimensions, or properties are reported.

K. Mildew Resistance, FS 406 Method 6091

Method 6091 is a mixed culture, agar-medium procedure. The fungi used are aspergillus niger, aspergillus flavus, pencillium funculosum, and trichoderma sp. The amount of growth under the controlled conditions is reported as none, traces, partial, moderate, or abundant.

L. Corrosivity, FS 406 Method 7071

The specific conductance of a water extract of plastics and fillers is used as an index of the likelihood that, in humid atmosphere, metal surfaces in contact with these materials may corrode due to galvanic action or direct chemical attack.

M. Effect of Heat, ASTM D 794 and E 145

Permanent changes in properties are determined by testing for the specific property or properties selected before and after exposure for 4 hours to selected temperature on an increasing scale of 25°C. increments. The maximum temperature to which the specimens are exposed with a change in property not exceeding the agreed limit is reported. Laboratory ovens and testing equipment to make property tests are required. Specifications for gravity-convection and forced-ventilation ovens are given in E 145.

N. Stability, ASTM D 793 and FS 406 Method 7051

Plastics containing chlorine are heated under defined conditions at 180°C for 30 minutes. The short-time stability is defined as the milligrams of hydrogen chloride evolved per gram. A controlled temperature bath and chemical laboratory equipment are required.

MISCELLANEOUS PROPERTIES

A. Specific Gravity and Density, ASTM D 792 and D 1505 and FS 406 Methods 5011 and 5012

Specific gravity is the ratio of the weight of an object in air to the weight of an equal volume of water. Method A is used for molded or finished pieces. Method B is used for molding powder or pellets or flakes. An analytical balance and relatively simple laboratory equipment are required.

B. Apparent Viscosity or Consistency, D 1823, D 1824 and D 1084

The apparent viscosity of plastisols and organosols is determined at high shear rates by the Castor-Severs Viscometer (D 1823) and at low shear rates by the Brookfield Viscometer (D 1824). Method A in D 1084 is a cup technique, Method B uses a Brookfield instrument, and Method C a Stormer viscosimeter. All of these are special devices.

C. Thickness ASTM D 374

Three methods are described for measuring thickness. Method A uses an adjusted ratchet micrometer with a definite manipulative procedure by which the pressure exerted on the specimen is controlled. Method B uses a micrometer without a ratchet. The pressure is controlled by checking the resistance to movement of the specimen between the instrument surfaces. Method C uses a dead weight dial micrometer. Methods A and C may be used interchangeably. Method B is not accepted as a reference standard.

D. Color, ASTM D 1535, D 1482, D 307, D 791 and D 1729

The Munsell system, D 1535, is recommended for specifying color. The tristimulus system of designating colors is described in D 307 and a detailed method to use this system is given in D 791. Instrumental methods for determining color differences are given in D 1482 and visual methods in D 1729.

E. Coefficient of Friction, ASTM D 1894

Procedure A uses a stationary sled and a moving plane to measure the coefficient of friction of plastic films. Procedure B uses a moving sled and a stationary plane. Both starting and sliding friction when the film is sliding over itself or over other materials can be measured.

F. Viscosity, ASTM D 1243

The specific viscosity of vinyl chloride polymers and copolymers in nitrobenzene is calculated from kinematic viscosity measurements. Special equipment is needed.

G. Chlorine Content, ASTM D 1303

The chlorine content of vinyl chloride polymers and copolymers is determined by oxidizing the material with sodium peroxide and making the usual analytical test for chlorine in the residue. Analytical laboratory equipment is required.

H. Gas Permeability, ASTM D 1434

The permeability of plastic films to gases is determined in a special apparatus in which the pressure and volume change of gas transmitted through the specimen from a chamber of gas at a specified temperature and at a static and essentially constant pressure into an initially evacuated, calibrated micrometer are measured.

I. Water Vapor Permeability, ASTM E 96 and FS 406 Method 7032

The water vapor permeability of sheet is determined with specimens mounted in special cups which are placed in cabinets with controlled atmospheres and the changes in weight observed. Several combinations of relative humidities both inside and outside the cup are covered. Tests are made at three temperatures.

J. Water Absorption, ASTM D 570 and FS Method 7031

Procedures are given for measuring the water absorption of standard size specimens in 2-hour, 24-hour, repeated, and long-term immersion at 23°C., 2-hour boiling, 0.5-hour boiling, and 48-hour immersion at 50°C. Vinyl chloride plastics are predried at 50°C for 24 hours. The most commonly reported values are for the 24-hour immersion period at 23°C.

K. Machinability, FS 406 Method 5041

This is essentially a recommended practice which gives a few general rules to be used in evaluating machinability of plastics. No specific machining instructions or requirements are given.

L. Electrical Tests, ASTM D 149, D 150, D 229, D 257, D 495, D 1531, D 1673, D 669, and D 1371, and FS 406 Methods 4011, 4021, 4031, 4041, 4042, and 4052.

The ASTM electrical test methods were developed by Committee D-9 on Electrical Insulating Materials. Methods for measuring capacitance, dielectric constant, loss characteristics, arc-resistance, dielectric breakdown, dielectric strength, dissipation factor, electrical resistance, and cleaning specimens for test are described. These tests require highly specialized laboratory equipment and trained personnel to obtain reliable results.

TESTS FOR SPECIFIC PRODUCTS

A. Molding Compound Properties, ASTM D 1705, D 1895

The method in D 1705 is for the particle size analysis of powdered vinyl chloride plastics and is based on a wet sieve technique. It is applicable to powders with particle sizes larger than 44 microns (No. 325 sieve). Methods for determining apparent density, bulk factor, and pourability of molding powders are given in D 1895.

B. Plasticizers, ASTM D 1045

Sampling procedures and test methods are given for measuring acidity, ester content, specific gravity, color, and refractive index of liquid plasticizers. Special equipment is required. Acidity is reported as acid number, the milligrams of potassium hydroxide required to neutralize one gram. Ester content is expressed in milligrams of potassium hydroxide required to saponify one gram with correction for acid content. Specific gravity is measured with a pysnometer. Color is expressed in colors of 5, 10, 15, etc., based on standard platinum-cobalt solutions. The higher the number, the deeper the color. Refractive index is reported for the D line of sodium at 23°C.

C. Adhesives, ASTM D 896, D 897, D 905, D 1781, D 1002, D 1144, D 1151, D 1174, D 1183, D 1286, D 1382, D 1383, and FS 175

D 896 for chemical resistance is similar to D 543 except that specimens bonded with adhesives are used. Tensile properties of specimens bonded with adhesives are determined in accordance with D 897, compressive shear properties with D 905, impact strength with D 950, peel strength with D 1781, tensile shear properties by D 1002, rate of strength development with D 1144, effect of moisture and temperature with D 1151, effect of bacteria with D 1174, resistance to simulated service conditions with D 1183, effects of fungi with D 1286, attack by roqches with D 1382, and attack by rats with D 1383. A new T-peel strength test is being developed.

SPECIFICATIONS

Most of the specifications for vinyl chloride plastics materials and products are promulgated by ASTM, the Federal Standards group, the Military agencies and the U. S. Department of Commerce (as Commercial Standards).

Federal Specifications are prepared by government agencies to describe products needed for government-wide operations. Military specifications are prepared by military agencies to describe products needed for military operations. Commercial Standards are developed by industry committees in cooperation with the National Bureau of Standards to establish a national standard of quality, to provide a basis of fair competition among manufacturers, and to give the general public confidence in the quality of the products and a means of identifying products conforming to the standard. Most of the plastics industry committees have been and are sponsored by the Society of the Plastics Industry. The final drafts are prepared and issued by the Office of Technical Services of the U. S. Department of Commerce. ASTM standards and specifications are prepared by technical committees with a balanced representation from producers, consumers and general interest members and are intended for general industrial use. Efforts are made to coordinate the technical aspects of Commercial Standards, ASTM, Federal and Military specifications for plastics materials to the fullest extent possible. However, because of the differences in objectives, it is not always possible to achieve full coordination.

Specifications for plastics can be divided into three categories, namely, materials, standard forms, (such as sheets, rods, tubes, film and pipe) and end items. The Federal and Military standards cover all three categories. However, there is a voluntary division of effort between the ASTM and the SPI. ASTM Committee D-20 on Plastics has been concerned with materials and some standard forms specifications. The SPI industry committees have restricted their work to end items and some standard forms specification. The Commercial Standards refernce the ASTM materials specifications and use ASTM definitions and test methods wherever possible.

No attempt will be made to consider all the vinyl chloride plastics specifications. This discussion will be concerned with only a few aspects of each of three categories. Fairly complete lists of these specifications are included; the Federal Specifications are in Appendix A, the Military Specifications in Appendix B, the ASTM specifications in Appendix C, and the Commercial Standards in Appendix D.

A. Materials

There are materials specifications for vinyl chloride acetate, (ASTM d 28), nonrigid vinyl chloride plastic (ASTM D 1432 and D 1277), rigid PVC compounds (ASTM D 1784, FS L-M-530A, MIL-P=3410, and MIL-P-20307), elastomeric vinyl chloride (MIL-R-3584), and rigid PVC resin molding and extrusion compounds (ASTM D1755). Some new grades are under consideration for addition to the ASTM specifications. There is a specification for plastisols (MIL-P-20689) and one for DOP plasticizers (ASTM D1249).

B. Standard Forms

Specifications for rigid vinyl chloride plastic sheets (ASTM 708, MIL-P-6264A, FS L-V-351), for rigid PVC sheets (CS 201-55 and L-P-510), for nonrigid vinyl chloride sheet (ASTM D 1593, MIL-P-6264A , and L-P-550), for vinyl chloride plastic film (CS 192-53, L-P-375a, MIL-F-10400A, MIL-P-17998A, and MIL-P-18080A), for PVC rods (FSL-P-503), for pipe and tubing (CS 207-60, ASTM D 1785, ASTM D 922, MIL-I-22076, L-P-540, and MIL-P-19119A), for pipe fittings (MIL-P-22011), and for foams (ASTM D 1565, MIL-C-40010, and MIL-S-11036) are available.

Groups in SPI and ASTM are actively developing specifications and/or revising specifications for sheet, film, pipe, pipe fittings and foams. Groups in SPI and ASTM are developing test methods and property data on vinyl chloride plastisols and organosols with a goal of writing specifications for these products when sufficient standard test methods and data are available.

C. End Items

Most of the specifications for vinyl chloride plastics end items have been prepared by Federal and Military agencies. They cover a wide variety of products such as upholstery materials (coated fabrics), flooring, gloves and tapes. Commercial standards have been issued for garden hose (CS 209-57) and weatherstrip (CS 230-60). Commercial Standards are being developed for PVC extrusions and window frames.

CODES AND DESIGN CRITERIA

There is activity underway in the code area to get plastics pipe and fitting, PVC window frames and other products entered in building codes. This task is difficult but some progress is being made, notably by the SPI.

There is a great need for reliable engineering design criteria for all plastics and the vinyl chloride materials are no exception. In the housewares area this is not as important as it is in the building, transportation, aerospace, military and other industrial areas. The activity on the development of working stresses for plastics pipe and fittings in the SPI and ASTM reveals the difficulties of establishing design criteria for plastics as well as a scientific approach to the problem[16].

FOREIGN STANDARDS

No effort has been made to consider foreign standards. Other countries have standards for vinyl chloride plastics, notably Great Britain and West Germany. There appears to be no foreign standards for products not already covered by USA standards.

GENERAL STATUS

There appears to be fairly good coverage as regards standards for definitions, test methods and materials specifications and there is a fair amount of effort underway in ASTM to keep these areas up-to-date and to improve them, although more effort would be helpful to the industry. Much more effort is needed to achieve a satisfactory status for end item specifications, codes and design criteria. The plastics industry cannot afford to wait for years of experience to gain full acceptance for the use of plastics in critical uses. They must achieve this goal in a shorter time on the basis of laboratory and engineering investigations, the results of which are, in part, sound standards, the most effective long-term sales argument and public relations medium.

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APPENDIX A

FEDERAL SPECIFICATIONS FOR VINYL CHLORIDE PLASTICS

Cloth, coated, upholstery (vinyl resin base)	CCC-C-418
Flooring, vinyl plastic	L-F-00450(2)
Molding Plastic, polyvinyl chloride, rigid	L-M-530a(3)
Plastic rod, solid, polyvinyl chloride, rigid	L-P-503
Plastic sheet, modified unplasticized polyvinyl chloride, rigid	L-P-510(1)
Plastic tubes and tubing, heavy walled, polyvinyl chloride: rigid	L-P-540
Plastic, vinyl chloride, cartographic sheeting	L-P-550
Tile, floor, vinyl asbestos	L-T-00345
Vinyl chloride polymer and copolymer rigid sheet	L-V-351(2)
Artificial, leather, cloth, coated, vinyl resin (upholstery)	CCC-A-700b

APPENDIX B

MIL SPECIFICATIONS FOR VINYL CHLORIDE PLASTICS

Cloth coated, nylon, vinyl coated	MIL-C-40039
Coating system polyvinyl chloride plasticizer dispersion (plastisol)	MIL-C-21006 (1)
Curtain, shower, vinyl film	MIL-C-18366A
Cushioning material, polyvinyl chloride, plasticized cellular	MIL-C-40010
Film flexible, vinyl	MIL-F-10400A
Gloves, protective, acid resistant, vinyl coated cotton Type R 1	MIL-G-4244A (1)
Insulation tubing, electrical, non-rigid, vinyl, very low temperature grade	MIL-I-22076 (1)
Molding plastic, polyvinyl chloride, rigid, fabricated parts	MIL-M-14584 (1)
Pipe fittings, plastic, rigid, unplasticized, high impact polyvinyl chloride	MIL-P-22011
Pipe, plastic, rigid, unplasticized, high impact, polyvinyl chloride	MIL-P-19119A (1)
Plastic sheet, vinyl, copolymer, thin	MIL-P-6264A (2)
Plastic sheet, vinyl film, white, table covering	MIL-P-17998A
Plastic sheets, vinyl flexible, transparent, optical quality	MIL-P-18080A
Plastic-material, molding, rigid thermoplastic polyvinyl chloride & copolymers thereof, for use in electronic communications and allied electrical equipment	MIL-P-3410 (1)
Plastic, plastisol, fabricated parts	MIL-P-3999
Plastic, plastisol, molding, extruding, casting and dipping compound	MIL-P-20689 (1)
Polyvinyl chloride	MIL-P-20307
Resin, synthetic, plasticized (elastomeric vinyl chloride)	MIL-R-3584 (1)
Sponges, synthetic, vinyl type	MIL-S-11036
Tape, pressure-sensitive adhesive, vinyl-plastic opaque, photographic	MIL-T-4239A

APPENDIX C

ASTM SPECIFICATIONS FOR VINYL CHLORIDE PLASTICS

D 728-50	Vinyl chloride-acetate resin molding compounds
D 734-60	Insulated wire and cable; vinyl chloride plastic insulating compound
D 1047-49T	Thermoplastic vinyl chloride plastic sheath compounds for electrical insulated cords and cables
D 1432-58	Nonrigid vinyl chloride polymer and copolymer molding and extrusion compounds
D 708-53T	Vinyl chloride polymer and copolymer rigid sheets
D 922-59	Nonrigid vinyl plastic tubing
D 1565-60T	Flexible foams made from polymers or copolymers of finyl chloride
D 1593-58T	Nonrigid vinyl chloride plastic sheeting
D 876-58T	Nonrigid vinyl chloride polymer tubing
D 1785-60T	IPS rigid poly(vinyl chloride)(PVC) plastic pipe
D 1784-60T	Rigid poly (vinyl chloride) compounds
D 1249-54	Primary octyle phthalate ester plasticizers
D 1277-59	Nonrigid thermoplastic compounds for automotive and aeronautical application
D 1755-60T	Poly(vinyl chloride) resins

APPENDIX D

COMMERCIAL STANDARDS FOR VINYL CHLORIDE PLASTICS

Number	TITLE
CS 192-53	General purpose vinyl plastics film
CS 201-55	Rigid polyvinyl chloride sheets
CS 209-57	Vinyl chloride plastics garden hose
CS 230-60	Vinyl plastic weatherstrip
CS 207-60	Rigid unplasticized polyvinyl chloride pipe

SOCIETY OF PLASTICS ENGINEERS, INC.

National Executive and Business Offices
65 Prospect Street
Stamford, Connecticut

APPLICATION FOR MEMBERSHIP

Gentlemen:

I hereby make application for membership in the Society of Plastics Engineers, Inc. on the basis of my training and experience given herewith. I wish to affiliate with the ______________________ Section. (Geographical Location)

I certify that the statements made in the record of my training and experience are correct. I agree, if elected, to be governed by the Constitution, By-Laws and Rules as long as my connection with the Society shall continue. I agree to promote the object of the Society as far as shall be within my power.

Date of application. ______________________

Signature in ink. ______________________

REFERENCES

The By-Laws require the names of three men who are familiar with your work. One of them should be a member of the Society. Assistance in providing member-references when needed will be provided on request to National Office or Section.

1. ______________________ Address ______________________
2. ______________________ Address ______________________
3. ______________________ Address ______________________

ADDRESSES—Please print or type

Applicants Full Name ______________________

Please fill in both addresses and check one to which mail should be sent. (Advise immediately of any change)

☐ Business: Company Name: ______________________

Street No.: ______ Street: ______________ City: ______________ Zone No. ______ State: ______________

☐ Home. Street No.: ______ Street: ______________ City: ______________ Zone No. ______ State: ______________

APPLICANTS: Do not write below this line on this side.

COMPLETE BOTH SIDES OF THIS APPLICATION

This Space For Credentials Committees Use Only

(This Record must be completed by the local section)

Report of Application to Nat'l. Office (Blue Copy) Date ______________

Submitted to Section Credentials Committee Date ______________

Years of credit given for:

Education ______________

Experience ______________

Total ______________

This man is classed as a:

______ Senior Member

______ Associate Member

______ Junior Member

______ Student Member

______________________ Date ______________

Signature of Chairman Section Credentials Committee

Approved by Section Board of Directors, Date ______________

____

Signature of Section Secretary

____

____

____

Signatures of National Credentials Committee

For National Office Use Only

Initiation Fee Rec'd. ______________

Application Ackn. ______________

Elected as ______________

Section ______________

Number ______________

Date processed ______________

Remarks

OVER

Record of Training and Qualifying Experience

(Please type or print information)

Full Name ______________________________ ____________ ____________ ____________
Birthplace Citizen of Birthdate

RECORD OF EDUCATION

Technical education and the holding of a degree are NOT necessary to qualify for membership, however credit will be given on the following basis in lieu of, and in addition to qualifying experience: Doctorate in technical subject - 5 years; Masters in technical subject - 4 years; Other in technical subject - 3 years; Other in non-technical subject - 2 years.

SCHOOL	PLACE	ATTENDANCE		MAJOR SUBJECTS
		FROM	TO	

Degree of ______________________ from ______________________ date ______________

PRESENT OCCUPATION

Title or Position ______________________ Name of Company ______________________

Company address ______________________

Nature of work done by company ______________________

Explain in detail, the nature of your work and responsibilities ______________________

RECORD OF QUALIFYING EXPERIENCE

In the space below, supply complete record of past connections in detail. Describe duties fully and state briefly any important engineering work you have done. If space is not sufficient continue record on separate sheet of same size. Your proper classification depends greatly upon the clarity of your record of experience and the degree of technical knowledge or skill required.

DATES	NAME AND ADDRESS OF COMPANY	TITLE or POSITION	*RESPONSIBILITIES

PROFESSIONAL ACTIVITY GROUPS — CHECK ONE OR MORE OF PRIMARY INTEREST

☐ Casting and Plastic Tooling	☐ Finishing	☐ Metals for Plastic Molds	☐ Plastics In Electrical Insulation	☐ Standards for Reporting Properties
☐ Extrusion	☐ Forming	☐ Plastics in Buildings	☐ Polymer Structure and Properties	☐ Thermosetting Molding
☐ Fabricating	☐ Injection Molding	☐ Plastics in the Automotive Industry	☐ Reinforced Plastics	☐ Vinyl Plastics

COMPLETE BOTH SIDES OF THIS APPLICATION AND MAIL WITH INITIATION FEE TO S.P.E. OFFICE