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Producibility Cost Reductions Through Alternative Materials And Processes

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ABSTRACT

The competitive nature of shipbuilding requires that successful builders use the most cost effective means to construct their ships. This paper describes ongoing research to test the use of alternative materials and processes to reduce material and labor costs. Some of the traditional methods and materials used in shipbuilding are questioned and alternatives are evaluated. The research, backed by the NSRP through the SP-8, Industrial Engineering Panel of the SNAME Ship Production Committee, looks specifically at fiberglass and plastic pipe, adhesives and rubber hose as areas where cost and producibility gains may be found. Cost comparisons between traditional and alternative methods will be presented as well as applicability to regulatory and classification society requirements.

NOMENCLATURE

ASTM	American Society for Testing and Materials
FRP	Fiber Reinforced Plastic
GRP	Glass Reinforced Plastic
NSRP	National Shipbuilding Research Program
PVC	Poly Vinyl Chloride
SNAME	Society of Naval Architects and Marine Engineers
SP	Ship Production Committee Panel

INTRODUCTION

The competitive nature of shipbuilding requires that successful builders use the most cost effective means to construct their ships. The SP-8, Industrial Engineering Panel of the Society of Naval Architects and Marine Engineers (SNAME) Ship Production Committee, frequently studies the mechanics of the ship production process and looks at ways to make the process more efficient and cost effective.

The SP-8 Panel developed the project as part of the National Shipbuilding Research Program's (NSRP) FY95 program to look specifically at fiberglass and plastic pipe, adhesives and rubber hose as alternatives to traditional materials and processes. This paper describes ongoing research conducted by the Marine Systems Division of the University of Michigan Transportation Institute, the Shipyards Division of Avondale Industries and Damilic Corporation, to investigate and test the use of alternative materials and processes to reduce the overall costs (including life cycle) of ships. For each of the subject focus areas of fiberglass and plastic pipe, adhesives and rubber hose, traditional methods and materials are questioned and alternatives are evaluated. The research task arrangement is as follows.

- Task 1. Identify Areas of Potential Use
- Task 2. Identify Function Specifications
- Task 3. Identify Potential Candidates
- Task 4. Test and Evaluate Candidates
- Task 5. Seek Regulatory Acceptance

The research team has established the most likely areas where adhesives, flexible hose and fiberglass pipe can be used to save significant time and cost. A preliminary list of items in each of the interest areas was developed and has been expanded through shipyard visits and discussions about the work of the project team and the SP-8 Panel. The first three tasks are nearly completed and on site testing is to follow shortly. Regulatory considerations are being checked in parallel.

The focus of the research is primarily on applications to commercial vessels, followed by naval auxiliaries and combatants. This research is in progress will be released as an NSRP report in the summer of 1997.

AREAS OF POTENTIAL USE

Adhesives

The adhesives area seems to be the most promising in the area of labor savings. The research is centering on the choice of adhesives that offer the best combination of holding power and ease of application without some of the negative attributes of volatile compounds (that would require additional ventilation, worker protection, or both) or excess preparation.

Adhesives bonding is an alternate means for mechanical fastening and welding non-structural and non-critical shipboard items. Adhesives also provide a means for easy on site repair or modification to fixtures. Potential shipboard applications for adhesives include clocks, thermostats, attachment of small diameter pipe and gauge tubing, label plates, brackets, and curtain plates (see Table I). These attachments can be exposed to temperatures between -18^{o}C and 49^{o}C (0 ^{o}F and 120^{o}F) and a relative humidity of 90% or more, during both installation and service life. Adhesives can be formulated to be either thermally conducting, electrically insulating or visa versa.

Bonded Items	Bond Area (sq. in.)	Comments
Curtain Plates	100-2000	Vertical placement, large surface area, good tack or green strength desired
Equipment Brackets	10-200	Vertical placement, high strength needed, long working time desired
Equipment Foundations	100-2000	Large volume application, strength and durability required
Insulation Mounting Clips	10-50	Long working time not necessary, good tack, medium strength, good temperature resistance
Label Plates	10-200	Long working time not necessary, low strength, good peel strength
Pipe Hangers	10-50	Intermediate fixturing time desirable, medium to high strength
Plumbing Fixtures	10-200	Low to medium strength, hydrophobic, attachment to plastics and other materials
Thermal/Acoustical Insulation	50-1500	Good tack, medium strength, good temperature resistance
Wire Hangers	10-50	Various levels of strength required, attachment over various substrates, easy attachment late in the building process
Zinc Anodes	50-250	Medium strength, electrically conductive, eliminates the need to weld stainless steel studs, eliminate chasing threads on studs for replacements

Table I - Candidates for Attachment by Adhesives.

Many forms of structural adhesives are available commercially. Table II describes the five most widely used chemically reactive structural adhesives (1):

- Epoxies,
- Urethanes,
- Acrylics,
- Cyanoacrylates, and
- Anaerobics.

Candidate adhesives were selected from a broad review of commercially available adhesives because of their general utility (Table III, page 4) and because they:

- Can be cured at ambient temperatures with minimal additional heat required,
- Pose minimal exposure hazard to workers, and
- Can be easily applied with a trowel, caulking gun, syringe, or gun dispenser.

Chemical Family	Advantages	Comments
Epoxy	High strength, good solvent resistance; good elevated temperature resistance; good gap filling capa-bilities; wide range of formulations	Ambient cure is almost always a two component system which requires either metering and premixing or dispensing equipment. Short pot life.
Polyurethane	Flexible, tough; is used in adhesive sealant formulations	Moisture sensitive; if purchased as a two component system one component is unreacted isocyanate - a toxic chemical
Acrylics	Good flexibility; peel and shear strength, will bond oily surfaces room temperature cure, moderate cost	Some are toxic and flammable (modified acrylics); more expensive than general purpose epoxies
Cyanoacrylates	One component, good adhesion to metal, minimal quantities required	Instant cure limits fixturing time, low viscosity, good capillary action, more commonly known as super glue
Anaerobic	One component, long pot life, nontoxic	Thread locking adhesive, brand names include Locktite®

Table II Adhesives Types.

Adhesives Testing

From the list in Table III, seven epoxies and four acrylic based adhesives (Table IV) were tested for their performance, ease of use, and compatibility with primed steel and a smooth aluminum surface. Cyanoacrylates were not pursued because they are susceptible to hydrolytic attack.

Epoxies	Acrylics
Lord 320	Hernon 761,730
TA-30	Lord 206/19
Epoxies, etc 10-3005	AA 4325
Norcast FR 7316	Plexus MA310
Magnolia plastics	
Lord 310	
Armstrong A-12	

Table IV. Tested Adhesives.

The preliminary screening of the selected adhesives was as follows. Primed steel plates 300mm x 300mm x 3mm (12 in. x 12 in. x 0.125 in.) weighing roughly 2.3 kg (5 lbs.), representative of a ship's joiner bulkhead, were cleaned with acetone and scoured an abrasive pad (to remove loose debris). The acetone removes most of any finish paint but only a minimal amount of primer. A generous amount of adhesive was applied to a small area on the steel plate (oriented horizontally) either through a syringe mixing applicator or with a putty knife (after mixing the two components by hand). The plate was then turned to stand vertically. A formed 0.1mm (0.003 in.) aluminum foil cup was placed right side up on top of the adhesive. Hand pressure was applied to distribute the adhesive evenly between the substrate pair (aluminum / steel). All of the adhesives except three (relatively low viscosity) exhibited sufficient tack to support the aluminum on a vertical surface immediately after application. Following an overnight cure at room temperature, adhesive strength was tested by lifting up the steel by the rim of the foil cups. Of the eleven adhesives tested, five (Table V) bonded well enough to lift the whole steel plate. This was as much a tensile as a peel test.

Adhesive	Average Lap Shear Strength (psi)	Standard Deviation
AA4325	658	282
Lord 206/19	2631	484
TA-30 Philibond	2560	605
Norcast 2316	3270	142
Lord 320/322	2570	276

Table V. Adhesives Passing the Preliminary Test and Tested for Lap Shear.

Adhesive Type	Brand Name	Material Form	Applicable Substrate	Application Method	Cure Conditions	Special Features
epoxy	DAPCO 3004	two component	metal, wood, concrete, plastic	extrusion, trowel	4 hours	3,000 psi tensile strength
epoxy	Magnobond 6155	two component	plastic	trowel	7 days @ 70^{o}F	same as above
epoxy	Norcast 7285-1	one component	metals, plastics,	trowel	3 hrs @ 250^{o}F	fire retardant
epoxy	Norcast 9310	two component	general purpose	casting resin		
epoxy	Lord 310, 320	two component	steel, wood, FRP	syringe	24 hrs @ 77^{o}F	resists moisture, sunlight, thermal cycling, 320 is toughened for impact
epoxy	Epoxies, etc 10-3050	one component	steel	trowel	24 hrs @ 77^{o}F	8,000 psi tensile strength
modified acrylate	Advanced Adhesives Systems 4325	two component	primed steel/fiberglass	dispensing gun	24 hrs @ 77^{o}F	3,500 psi ten strength/ high humidity
acrylate	Dymax 828	liquid, two part	primed steel	brush or bead on	local pressure	3,000 psi ten strength/ 300^{o}F
epoxy	Armstrong A-12	liquid, two part	primed steel	brush or bead on	local pressure	Milspec epoxy, 2900 psi 300^{o}F
methacrylate	Plexus MA-310	liquid, two part	steel/fiberglass		local pressure	250^{o}F/tough
epoxy	Masterbond EP76M	liquid, two part	steel/fiberglass	trowel	24 hour @ 77^{o}F	300^{o}F
epoxy	Philadelphia Resins TA-30	two component	metal, rubber, wood, glass	trowel	24 hours @ 77^{o}F	very high tack
cyanoacrylate	Pacer Tech. M-100	100 cP liquid	primed steel	rough, clean	instant 30 sec	poor with moisture, brittle
cyanoacrylate	Pacer Tech. HP-500	5000 cP paste	general	brush on	1 min	
cyanoacrylate	R-X	thick	general	gel, paste	2 min	
epoxy	West Systems 105/205 hardener	two component	fiberglass, steel	hand mixed brush on	8-24 hrs @ 77^{o}F	no post cure, 200^{o}F no load 130^{o}F w/load
Polyester	ATC Chemical - Poly-bond B41F	two component	fiberglass, steel	thix. paste, putty knife, trowel	24 hrs @ 77^{o}F	tough, low shrinkage, used in FRP hull to deck marine applications
urethane	Sika 241	one component	steel, fiberglass,	gun dispenser	24 hrs @ 77^{o}F	semi permanent
urethane	3M Scotch-Seal 5200	one component	steel, fiberglass,	dispenser, trowel	24 hrs @ 77^{o}F	semi permanent
acrylic/Ag/Ni	3M 9703	tape	alcohol wipe, abrasion	40 psi pressure	72 hrs	conductive, 250^{o}F
methylmeth-acrylate mod	Hernon MI React 730; Act 56 and React 761; Act 63	two component	unprimed steel primed, painted	syringe appl bead on trowel (761)	24 hrs @ 77^{o}F	visc 6000 cps, 1-2 min fix time tensile str 3.000 psi/grit blast steel; -60^{o}F -250^{o}F; nonflammable
acrylic	Lord 206	two component	unprimed steel primed, painted	syringe type caulking gun	24 hour @ 77^{o}F	minimum prep, excellent moisture, temperature and UV resistance.
cyanoacrylate	Quantum 108	one component	steel	oily surfaces ok; wicking action	instant 5-20 sec	not good around water and moisture

Table III. Preliminary Adhesives Selection Table

Following this test the adhesive assembly was placed in an hot and humid test chamber (an oven heated to 100°C (212°F) containing a pan of boiling water). Using protective gloves, the strength bearing capacity of the bonded aluminum and steel assembly was tested again. Four of the five adhesives: TA-30, Norcast FR2316, Lord 206/#19, and Lord 320/322 experienced no noticeable loss of strength. A slight loss of strength, exhibited as peeling was observed for the AA 4325 adhesive.

For these five adhesives, laboratory lap shear specimens were prepared from 100 mm x 25 mm (4 in. x 1 in.) coupons machined from primed steel plate and tested according to ASTM D1002. In order to be accommodated by the grips in the tension testing machine, one end of each coupon was machined to a 1.6mm (.06 in.) thickness. As before, surface preparation was limited to a solvent wipe with acetone and a mild scouring with an abrasive pad. Five lap shear specimens were prepared and tested for each of the five adhesives. The lap shear test results are provided in Table V.

In addition to their ability to bond to smooth and rough metal surfaces, a high initial tack makes these adhesives ideally suited to bonding applications on a vertical surface such as a bulkhead.

Based on the above results, the four highest strength adhesives have been selected for further testing at the shipyard. The two component thixotropic paste epoxies can be applied either manually with a trowel or putty knife, or with pneumatically operated dispensing equipment. The other epoxy adhesives are available in a double barrel syringe type applicator. The acrylic adhesive is also available in higher viscosity so that it can be applied with a caulking gun.

Flexible Hose

The use of flexible hose in commercial and military shipbuilding has been approved by classification societies and regulatory bodies well beyond its current state of new construction general usage. With the advent of new materials, testing has been performed and approvals have been secured for the use of flexible hose in a number of areas. A general lack of awareness of the extent to which the use of flexible hose has been approved, coupled with the natural inclination of shipbuilders to retain the use of traditional shipbuilding practices and materials, has inhibited the widespread use of flexible hose to the extent allowable.

The researech team has not discovered thorough studies that have analyzed the potential labor savings from the use of flexible hose to the extent allowable under current approvals. Table VI depicts the current areas of approval for various flexible hose applications.

In determining the suitability of flexible hose for a given application, hose assemblies are first classified as critical or non-critical depending on the system they are used in and the redundancy in that system. The level of criticality determines the replacement cycles for various hose assemblies and thereby contributes to determining the type of hose approved for use. In determining the level of criticality assigned to a given hose, the following attributes are considered and weighted as pertinent factors.

System. The system category is divided into five major sections, each reflecting a fluid type, except for drains, which are all inclusive.

- Gasses
- Water
- Sea water
- Drains
- Oil systems

Pressure Ratio. The pressure ratio is determined by dividing the rated working pressure of the hose by the system working pressure

Impulse. Impulse is defined as any pressure spike that momentarily raises the pressure in the hose.

Temperature. This is the working temperature range of the hose including the maximum temperature that the hose could be exposed to.

The project team is currently identifying and documenting those areas in which the use of flexible hose is acceptable according to classification societies and regulatory bodies, and comparing the potential use to actual existing standard shipyard practice. The potential labor savings and ancillary economies that could be recognized by fully adopting the use of flexible hose in all approved areas is being analyzed.

It is anticipated that the incorporation of flexible hose to the extent currently allowable in new ship construction would reduce manufacturing, modification, and repair costs as well as reduce vessel weight and reduce long term maintenance, operation and repair costs.

PVC/GRP Pipe

The use of Poly Vinyl Chloride (PVC) or Chlorinated PVC (CPVC), also called plastic pipe, and Glass Reinforced Plastic (GRP) or Fiber Reinforced Plastic (FRP), also called fiberglass, pipe on board commercial as well as military ships has proliferated substantially although sporadically over the past

HOSE TYPE	REINFORCED	WATER							OIL						GAS			APPROVALS
		FRESH	SALT	DEIONIZED	POTABLE	REACTOR EFFLUENT	CONDENSATE	STEAM	OIL BASE	FIRE RESISTANT	WATER BASE	DIESEL	JP-5	LUBE	AIR	NITROGEN	REFRIGERANT	
SYNTHETIC RUBBER	2 WB	X	X			X	X		X		X	X		X				MIL-H-24135
SYNTHETIC RUBBER	TB / 4 SW	X	X				X		X		X	X		X				MIL-H-24135
SYNTHETIC RUBBER	TB / 4SW								X		X							MIL-H-24135
SYNTHETIC RUBBER	2 WB	X	X			X	X		X		X	X		X				MIL-H-24135 SAEJ1942
SYNTHETIC RUBBER	2 WB														X	X		MIL-H-24135 SAEJ1942
SYNTHETIC RUBBER	4 SW								X									MIL-H-24135 SAEJ1942
SYNTHETIC RUBBER	TB / 1WB /TB	X	X				X		X			X		X				MIL-H-24135 SAEJ1942
AQP	TB / 1WB	X	X				X		X			X		X	X	X		MIL-H-24135 SAEJ1942
AQP	2 WB	X	X			X	X		X			X		X				MIL-H-24135 SAEJ1942
SYNTHETIC RUBBER	TS	X	X				X		X			X		X				MIL-H-24136
SYNTHETIC RUBBER	TB	X	X				X		X			X		X				MIL-H-24136
SYNTHETIC RUBBER	TB	X	X				X		X			X		X				MIL-H-24136 J1942
SYNTHETIC RUBBER	TS	X	X				X					X		X				MIL-H-24136
SYNTHETIC RUBBER	TB	X	X						X			X	X	X				MIL-H-13444 TYPE 1
SYNTHETIC RUBBER	TB / 1WB								X			X		X				MIL-H-13444 TYPE III
SYNTHETIC RUBBER	WB	X	X										X	X	X			MIL-H-13531 TYPEI
SYNTHETIC RUBBER	2 WB								X			X	X	X				MIL-H-13531 TYPE II
SYNTHETIC RUBBER	WB																X	S6430-AE-TED-010
PTFE	SSB	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		MIL-H-38360 , AS1339
PTFE	SSB	X	X	X	X	X	X	X				X	X	X	X			SAE J 1942
CONVOLUTED PTFE	SSB	X	X	X	X	X	X	X				X	X	X	X			SAE J 1942
CONVOLUTED PTFE	SSB	X	X	X	X	X	X	X				X	X	X	X			SAE J 1942

WB = WIRE BRAID

TB = TEXTILE BRAID

SSB = STAINLESS STEEL BRAID

TS= TEXTILE SPIRAL

SW = SPIRAL WIRE

* SAE J 1942 = COAST GUARD APPROVAL

Table VI. Flexible Hose Applications and Approvals several years (2-5). Several recognized classification societies and regulatory bodies have approved the use of fiberglass pipe in designated areas, other areas have not been addressed or do not currently have widespread approval.

The team's preliminary consideration for application of PVC and CPVC pipe is in:

- Potable water,
- Exterior deck drain,
- Low pressure air,
- Fresh water,
- Sea water washdown,
- Chill water,
- Hot water, and
- Sanitary drainage systems.

GRP pipe is likely to gain acceptance in the following systems:

- Seawater fire main,
- Seawater intake cooling,
- AFFF,
- Seawater overboard discharge,
- Oily water transfer,
- Crude oil washing ,
- Ballast tank flood and drain systems, and
- Cargo oil systems within tanks.

A chart of current approvals for GRP piping is listed in Table VII.

	ABS	USCG	LLOYDS	DNV
Inert gas (effluent overboard lines only through machinery or cofferdams)	YES	YES	YES	YES
Inert gas - distribution lines on deck	YES	YES	YES	YES
Sanitary / Sewage	YES	YES	YES	YES
Cargo piping - except on deck, in machinery spaces, and in pump rooms	YES	YES	YES	YES
Ballast system	YES	YES	YES	YES
Crude oil washing - in the tanks (not on deck)	YES	YES	YES	YES
Fire system	NO	NO	NO	NO
Cargo vent piping - within tanks only	YES	YES	YES	YES
Chilled and hot water system	YES	YES	YES	YES
Bilge system	NO	NO	NO	NO
Fresh and seawater cooling systems - aux.	YES	YES	YES	YES
Fresh and seawater cooling - vital	NO	NO	NO	NO
Cool steam condensate return system	YES	YES	YES	YES
Sounding tubes	YES	YES	YES	YES
Fire systems - offshore production platforms	N/A	N/A	N/A	N/A

Table VII. Classification Society and Regulatory Body Approval for GRP Pipe.

With the recent introduction of poly-siloxane modified phenolics in fiberglass pipe fabrication, a number of previously beneficial attributes of fiberglass pipe have been enhanced and a number of significant advances have been attained. At the same time, some heretofore negative characteristics have been mollified. Tables VIII and IX lists some of the positive and negative attributes of conventional phenolics an the newer poly-siloxane modified phenolic pipe materials.

A substantial amount of testing has been performed to verify the enhanced physical characteristics as well as improved fire performance of poly-siloxane modified phenolics. Among these tests are the following:

- IMO fire endurance testing - level 3 - eight tests carried out in two sizes and four configurations - in accordance with ASTM F1173 -95;
- SINTEF jet fire;
- ASTM E-84 - standard test method for surface burning characteristics of building materials;
- Pittsburgh toxicity;

- ASTM E-162 - test method for surface flammability of materials using a radiant heat energy source;

CONVENTIONAL PHENOLICS	
Positive Attributes	**Negative Attributes**
Excellent high temperature resistance	Poor adhesion for bonded joints
Low flame spread	Limited pressure performance due to low elongation and brittle nature
Corrosion resistance	Limited impact resistance
Low smoke and toxicity in fire	
Light weight	

Table VIII. Attributes of Phenolic Pipe

POLY-SILOXANE MODIFIED PHENOLICS	
Positive Attributes	**Negative Attributes**
All the same plus	To be seen.
Improved fire resistance	
Improved adhesion (160 %)	
Improved elongation (30 %)	
Improved impact resistance (40 %)	

Table IX. Attributes of Poly-Siloxane Modified Phenolic Pipe.

- ASTM E-662 - test method for specific optical density of smoke generated by solid materials;
- ASTM D-635 - rate of burning and/or extent of burning of self supporting plastics in a horizontal position;
- ASTM E-1354 - test method for heat and visible smoke release rates for materials and products using an oxygen consumption calorimeter;
- Lap shear strength physical;
- Short term burst;
- Hoop stress;
- Impact resistance;
- Flexural;.
- Modulus of elasticity;
- Chemical resistance;
- Weathering resistance;
- Steam resistance; and
- Corrosion resistance.

Comparison To Metallic Piping Systems. Compared to metallic piping systems, fiberglass, composite or plastic piping has a number of advantages. The following list shows some of the detractors of metallic materials compared to plastic.

- Carbon Steel is inherently corrosion prone and requires constant maintenance and frequent replacement. requires high level of installation and/or repair expertise.
- Copper Nickel has high initial material and installation cost but is costly to repair or modify and requires a high level of installation and repair expertise.
- Stainless Steel also has a high initial material and installation cost and is costly to repair or modify.
- Fiberglass Pipe has a moderate initial installation cost, will not corrode, has very low maintenance and a low skill level is adequate for installation. FRP pipe modification and repairs can be accomplished without certified welders, welding machines or burning equipment.

Table X is a comparison of the installed costs of a typical 100mm (4 in) offshore fire protection piping system.

Pipe System Material	Cost per Meter	Cost per Foot
Carbon Steel	$82	$25
Copper Nickel	$295	$90
Stainless Steel	$312	$95
Composite	$115	$35

Table X. Comparative Cost of a Fire Protection Piping System

The composite fire protection piping system, with intumescent coating, is capable of maintaining serviceability of the pipe for a minimum of three hours in a severe fire test. The life cycle advantages of the non-corroding composite pipe are expected to overcome the installed cost disadvantage.

With this type of performance available, the goal of the project is to promote the certification and approval of fiberglass pipe into areas currently not approved including:

- cargo piping,
- fire system piping,
- bilge systems,
- freshwater cooling,
- sea water cooling, and

- similar critical areas.

The project team is promoting the acceptability of fiberglass pipe for use on military vessels as already approved by non-military regulatory and classification societies.

The expanded incorporation of fiberglass pipe on both military and non-military vessels is expected to reduce manufacturing, modification, and repair costs as well as reduce vessel weights and lower long term maintenance and operation costs.

CONCLUSIONS

Initial findings of the team are that the alternative materials in the study are capable of reducing material and labor costs significantly in certain areas. Although this particular project is related to just adhesives, plastic and fiberglass pipe, and flexible hose, a methodology is being set up to consider the use of alternatives to traditional materials and methods in other areas of shipbuilding.

The use of adhesives to replace welding and mechanical attachments can save both material and labor costs. Adhesive strengths are adequate to support a number of shipboard items currently attached mechanically. The epoxies promise to provide base material protection so that make-up painting is not required.

Ongoing cost benefit analyses will determine the best applications of composite and plastic pipe and flexible hose. Fire protection and critical systems considerations are the focus of the research.

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