NTIS #

SSC-442

LABOR-SAVING PASSIVE FIRE PROTECTION SYSTEMS FOR ALUMINUM AND COMPOSITE CONSTRUCTION

SHIP STRUCTURE COMMITTEE
2005

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Address Correspondence to:

Executive Director
Ship Structure Committee
U.S. Coast Guard (G-MSE/SSC)
2100 Second Street, SW
Washington, D.C. 20593-0001
Web site: http://www.shipstructure.org

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MAY 2005

LABOR-SAVING PASSIVE FIRE PROTECTION SYSTEMS FOR ALUMINUM AND COMPOSITE CONSTRUCTION

Lightweight structural materials, such as aluminum and composites, are required to produce ships capable of meeting high speed requirements. However, traditional passive fire protection (PFP) systems are labor intensive to install and add weight where it is least desirable on these ships.

Spray-applied passive fire protections systems are used extensively in civil engineering and offshore applications. These coatings can be applied very cost-effectively and have the ability to easily vary thickness according to anticipated heat exposure. However, one concern is the durability of these products. The goal of this project was to develop a low-cost test that would simulate dynamic forces acting on ship structural panels and test candidate products to determine their durability.

Due to the fact that testing to military shock and vibration endurance standards is cost prohibitive and is not designed to evaluate coatings, a low-cost evaluation protocol has been developed to determine the suitability of existing and emerging coating systems for shipboard applications. Test apparatuses were built for fatigue and impact testing of coatings. A wide variety of coatings were evaluated and video documentation produced.

T. H. Gilmour

T. H. GILMOUR
Rear Admiral, U.S. Coast Guard
Chairman, Ship Structure Committee

Technical Report Documentation Page

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16. Abstract

Lightweight structural materials, such as aluminum and composites, are required to produce ships capable of meeting high speed requirements. However, traditional passive fire protection (PFP) systems are labor intensive to install and add weight where it is least desirable on these ships.

Spray-applied passive fire protections systems are used extensively in civil engineering and offshore applications. These coatings can be applied very cost-effectively and have the ability to easily vary thickness according to anticipated heat exposure. However, one concern is the durability of these products. The goal of this project was to develop a low-cost test that would simulate dynamic forces acting on ship structural panels and test candidate products to determine their durability.

A low-cost evaluation protocol has been developed to determine the suitability of existing and emerging coating systems for shipboard applications. Test apparatuses were built for fatigue and impact testing of coatings. The industry is encouraged to adopt the test geometry and methodology developed during this project to evaluate the suitability of spray-applied passive fire protection systems for high-performance marine vehicles.

NOTICE

The Ship Structure Committee / United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the objective of this report.

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CONVERSION FACTORS
(Approximate conversions to metric measures)

To convert from	to	Function	Value
LENGTH			
inches	meters	divide	39.3701
inches	millimeters	multiply by	25.4000
feet	meters	divide by	3.2808
VOLUME			
cubic feet	cubic meters	divide by	35.3149
cubic inches	cubic meters	divide by	61,024
SECTION MODULUS			
$inches^2$ $feet^2$	$centimeters^2$ $meters^2$	multiply by	1.9665
$inches^2$ $feet^2$	$centimeters^3$	multiply by	196.6448
$inches^4$	$centimeters^3$	multiply by	16.3871
MOMENT OF INERTIA			
$inches^2$ $feet^2$	$centimeters^2$ meters	divide by	1.6684
$inches^2$ $feet^2$	$centimeters^4$	multiply by	5993.73
$inches^4$	$centimeters^4$	multiply by	41.623
FORCE OR MASS			
long tons	tonne	multiply by	1.0160
long tons	kilograms	multiply by	1016.047
pounds	tonnes	divide by	2204.62
pounds	kilograms	divide by	2.2046
pounds	Newtons	multiply by	4.4482
PRESSURE OR STRESS			
$pounds/inch^2$	$Newtons/meter^2$ (Pascals)	multiply by	6894.757
kilo $pounds/inch^2$	mega $Newtons/meter^2$ (mega Pascals)	multiply by	6.8947
BENDING OR TORQUE			
foot tons	meter tons	divide by	3.2291
foot pounds	kilogram meters	divide by	7.23285
foot pounds	Newton meters	multiply by	1.35582
ENERGY			
foot pounds	Joules	multiply by	1.355826
STRESS INTENSITY			
kilo $pound/inch^2$ $inch^{1/2}$(ksi√in)	mega Newton $MNm^{3/2}$	multiply by	1.0998
J-INTEGRAL			
kilo pound/inch	$Joules/mm^2$	multiply by	0.1753
kilo pound/inch	kilo $Joules/m^2$	multiply by	175.3

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Executive Summary

The maritime industry is increasingly looking at high speed vessels to meet both military and commercial objectives. On the military side, the ability to rapidly transport equipment and personnel and to avoid the enemy has the US Navy enamored with large ships moving at 50 knots or more. Increased congestion on interstates I-10 and I-95 that parallel the western and eastern seaboard respectively has produced a surge in interest for operating high-speed passenger and freight ferries in coastal service. Lightweight structural materials, such as aluminum and composites, are required to produce ships capable of meeting these performance requirements. However, traditional passive fire protection (PFP) systems mandated by the International Maritime Organization (commercial) and NAVSEA (US Navy) are labor intensive to install and add weight where it is least desirable on these ships.

Spray-applied passive fire protections systems are used extensively in civil engineering and offshore applications. These coatings can be applied very cost-effectively and have the ability to easily vary thickness according to anticipated heat exposure. However, one concern that has been voiced both by the NAVSEA Technical Warrant Holder for Fire Protection and mega yacht builders is the durability of these products. The goal of this project was to develop a low-cost test that would simulate dynamic forces acting on ship structural panels and test candidate products to determine their durability.

Composite and aluminum panels were cut to measure 6 x 72 inches. These long, narrow beams would make it possible to produce severe deflections without using an inordinate amount of force. Eleven different combinations of coatings and panel materials were tested to 100,000 cycles. Ten of the tests were done at 1 Hz, with the last test performed at 2 Hz. for 200,000 cycles. After fatigue testing, a simple drop weight test designed to impact the panels with 50 foot-pounds (10 hits) was performed.

During the fatigue tests, minor amounts of PFP fell off of some of the test panels, but only one panel failed outright. On the other hand, 50% of the impact test panels failed completely. In general, the coatings had a harder time adhering to the aluminum panels.

A low-cost evaluation protocol has been developed to determine the suitability of existing and emerging coating systems for shipboard applications, as testing to military shock and vibration endurance standards is cost prohibitive and not designed to evaluate coatings. Test apparatuses were built for fatigue and impact testing of coatings. A wide variety of coatings were evaluated and video documentation produced. The industry is encouraged to adopt the test geometry and methodology developed during this project to evaluate the suitability of spray-applied passive fire protection systems for high-performance marine vehicles.

1. Introduction

1.1 Assemble Extended Project Technical Committee

The contractor has proactively sought out an extended and diverse Project Technical Committee (PTC) for this project to maximize project resources. The highly specialized nature of this project required oversight and input from individuals that work with or regulate passive fire protection systems for ships. This approach is unique for Ship Structure Committee projects. The extended PTC made it impractical to hold assembled project meetings. Instead, communications were done via E-mail and phone calls to individual PTC members on matters under their expertise. Assistance provided by the PTC proved to be invaluable to this project.

1.2 Project Evolution

This project was originally suggested to the Ship Structure Committee in February of 2001. In the 1990s, the principal investigator had worked on several US Navy-sponsored projects that involved full-scale fire testing of marine composite structures subjected to fire. The state-of-the-art then and now for passive fire protection of aluminum and composites involves "batted" insulation secured with pins. Spray-applied coatings that could achieve equivalent levels of fire protection were viewed as a way to save cost on both material and labor. Fire testing of candidate systems and development of design charts were initially proposed as project objectives.

In July of 2002 the Office of Naval Research sponsored a Workshop on "Analytical Modeling of Composite Ship Structures during and after a Fire." The challenge of predicting thermal degradation of composites subject to fire exposure was illustrated by various investigators at that workshop. Additionally, the US Navy evaluated intumescent coatings on steel substrates with the following conclusion: "The test results with steel substrate show that all candidate coatings failed to meet minimum U.S. Navy fire resistance criteria when used as stand-alone coatings. Furthermore, many coatings demonstrated poor adhesion, and fell off from the substrate during the fire test. These data have led the Navy to conclude that intumescent coatings tested in this study are not sufficient to protect shipboard spaces during a fire and are not equivalent when used alone as direct replacement for batt or blanket type fibrous fire insulation (mineral wool, StructoGard) installed aboard U.S. Navy ships.[1]

Since the US Navy tests, new intumescent and other types of coatings have been developed. However the Navy investigation and feedback from some mega yacht builders indicated the need to evaluate the durability of these coatings. Most PFP manufacturers first do fire testing on their products, but a methodology for cost-effectively evaluating durability on marine structures is often overlooked. The thrust of this project was therefore realigned to focus on coating durability.

[1] U. Sorathia, et al. "Evaluation of Intumescent Coatings for Shipboard Fire Protection," Journal of Fire Sciences, Vol. 21, No. 6, 423-450 (2003)

2. Candidate Spray-Applied Passive Fire Protection Systems

During the 3rd Quarter of the project an additional candidate product was added to the list of spray-applied passive fire protection systems. Table 1 is a summary of the added product. Eric Greene Associates was initially contacted by Nu-Chem upon award of the SSC contract. Their system looks promising, as it can be effective with a relatively thin application.

American Sprayed Fibers, Inc.

Parameter	Coating Characteristic
Product Name	Dendamix Marine
Composition	Blended fiber products
Primary Application	A60 & thermal insulation for steel
Use on Ships	Approved for use on decks & bulkheads
Advantages	Low cost, made with recycled products
Disadvantages	Application consistency, durability
Application Instructions	An aluminum and composite panel are with an associate in New Orleans to be coated by an approved applicator pending approval of American Sprayed Fibers

Table 1. Added Candidate Spray-Applied Passive Fire Protection System

Company	Product	Description
Nu-Chem, Inc.	Thermo-Lag 3000	Thermo-Lag 3000 is a two component, subliming, epoxy based, fire resistive coating which is spray applied directly to primed steel surfaces. It provides a hard, durable, aesthetically pleasing finish that allows the shape of the steel to be maintained while providing the specified level of fire resistance.

Some of the candidate spray-applied passive fire protection systems have been received at our corporate offices, some have been forwarded to Structural Composites in Melbourne, FL for spray application and some will be applied at the manufacturer's facility. The following tables summarize the status of candidate spray-applied passive fire protection systems indicated planned application instructions.

2.1 American Sprayed Fibers, Inc

American Sprayed Fibers, Inc.
Dendamix Marine
blended fiber products
A60 & thermal insulation for steel
Decks & bulkheads
Steel, aluminum, composite
Van Howard
VP of Marine Operations
228-769-5565
228-219-1496
vanasfi@aol.com
2503 Criswell
Pascagoula, MS 39567

2.2 Esterline Kirkhill-TA

Esterline Kirkhill-TA
FASTBLOCK® 800
Water-based, Sprayable Fire and Thermal Barrier
Coatings thermal barriers for extreme heat flux environments such as sensitive materials in weapons systems, containers, aircraft, and ships
graphite/epoxy, aluminum, and other sensitive materials

714-529-4901
300 E. Cypress,
P.O. Box 1270
Brea, CA 92822

Esterline Kirkhill-TA

Parameter	Coating Characteristic
Product Name	FASTBLOCK® 810
Composition	Water-based, sprayable fire and thermal barrier coating
Primary Application	Thermal barriers for extreme heat flux environments such as sensitive materials in weapons systems, containers, aircraft, and ships
Use on Ships	Under consideration for future naval platforms
Advantages	Proven fire resistance to UL1709 fire insult, durability
Disadvantages	Cost, as this system has been developed for aerospace industry
Application Instructions	Apply 0.25” per pass, therefore 2 passes required to achieve 0.5”. Sample quantities of 810A & B are in hand at Structural Composites

2.3 Isolatek International

Isolatek International
Cafco Blaze Shield II
Spray - Applied Fire Resistive Material (SFRM)
compositely reinforced portland cement

SFRM is designed to endure construction abuse as well as exposure to extreme weather conditions (UL investigated for exterior use).

A-60 bulkhead rating available steel.

Bijou Ganguly, Manager
Phil Mancuso, Technical Analyst
Diego Penta, Industrial Marketing Engineer
800-631-9600 ext 214/219

bGanguly@isolatek.com
Pmancuso@isolatek.com
DPenta@isolatek.com

Isolatek International

Parameter	Coating Characteristic
Product Name	Cafco Blaze Shield II
Composition	Spray - Applied Fire Resistive Material (SFRM) compositely reinforced portland cement
Primary Application	SFRM is designed to endure construction abuse as well as exposure to extreme weather conditions (UL investigated for exterior use).
Use on Ships	A-60 bulkhead rating available
Advantages	Long-term fire resistance, corporate experience
Disadvantages	High density and ability to withstand vibration
Application Instructions	Principal Investigator will deliver test panels to Isolatek headquarters for coating with Cafco Blaze Shield II or other product mutually determined to be better for marine applications.

2.4 Mascoat Products

Mascoat Products
Delta T Marine
composite (one-part) coating comprised of air filled ceramic and silica beads held in suspension by an acrylic binder
thermal insulation and antisweat capabilities

Weather exposed surfaces; Stiffeners; Overheads; Interiors: Pipes; Walls

All metal surfaces: Wood & Fiberglass

713-465-0304
10890 Alcott, Unit 102
Houston, TX 77043

Mascoat Products

Parameter	Coating Characteristic
Product Name	Delta T Marine
Composition	Composite (one-part) coating comprised of air filled ceramic and silica beads held in suspension by an acrylic binder
Primary Application	Thermal insulation and antisweat capablities, 500 °F Max operating temp; 350 °F working temp
Use on Ships	Used extensively on weather exposed surfaces; stiffeners; overheads; interiors: pipes; and walls to improve insulation properties
Advantages	Easy application in shipboard environment
Disadvantages	Low working temperature would require product to be used as a system with a higher heat resistant product
Application Instructions	Product applies 20 mils wet (18 mils dry) per pass with 80 mils max recommended; company is working on product more appropriate for fire protection.

2.5 NoFire Technologies, Inc

NoFire Technologies, Inc
A-18 NV
Fire Protective Intumescent Coating

NoFire® is a one part non-flammable water based intumescent coating similar in appearance to ordinary latex base paint. Upon exposure to flame or heat, it immediately foams and swells (intumesces) providing an effective insulation and heat shield to protect the subsurface.

NoFire® Technologies, Inc. is a manufacturer of high performance fire retardant products and systems that offer superior protection against heat and fire. Applications include the construction, telecommunications, nuclear power plants, utility, automotive, marine, military, and housing industries.

NoFire can be applied to many types of surfaces providing an attractive flat finish.

NoFire can be readily topcoated by many types of latex base paints, urethanes or acrylics for attractive weather resistant finishes.

Dr. Sam Gottfried
President
800-603-4730
nofirenj@aol.com
21 Industrial Avenue
Upper Saddle River, NJ 07458

NoFire Technologies, Inc

Parameter	Coating Characteristic
Product Name	A-18 NV Fire Protective Intumescent Coating
Composition	NoFire® is a one part non-flammable water based intumescent coating similar in appearance to ordinary latex base paint. Upon exposure to flame or heat, it immediately foams and swells (intumesces) providing an effective insulation and heat shield to protect the subsurface.
Primary Application	Substitute for ordinary paints to improve fire performance
Use on Ships	Approved as fire-retardant paint
Advantages	Easy application, low cost and weight
Disadvantages	Insufficient fire resistance properties – must be used as part of a system
Application Instructions	Recommended by manufacturer to use in conjunction with mineral wool for 2000° fire. No-Fire working with NGSS for LPD-17 solutions.

2.6 Span-World Distribution

Span-World Distribution
Temp-Coat™ 101
Liquid Ceramic Thermal Barrier Insulation Coupling Engineered Hollow Ceramics in a Micro-Porous Latex Emulsion

800-950-9958
swspl@aol.com

Span-World Distribution

Parameter	Coating Characteristic
Product Name	Temp-Coat™ 101 and Fyre Sheild™
Composition	Liquid ceramic thermal barrier insulation coupling engineered hollow ceramics in a micro-porous latex emulsion
Primary Application	Insulation for building structures
Use on Ships	Not documented
Advantages	Low cost and ease of application over large area
Disadvantages	Temp-Coat temperature range up to 500°F @ 260 mils with mesh, 20 mils each pass requires another product to work as a system
Application Instructions	One gallon of Fyre-Shield delivered to EGA by CHI Technologies. Can apply up to ¼” by damming sides and cure with IR lamps.

2.7 Superior Products, North America

Superior Products, North America
SP2001F Fire Retardant
Insulation Coating

formulated from resins and ceramics to withstand severe climate changes and severe heat peaks with no adhesion loss metal, concrete, stucco, plasterboard, wood, fiberglass, plastics and composites

Joe Pritchett
Shawnee, KS
913-962-4848
Supertherm@aol.com

40442 Koppernick Rd.
Canton, MI 48187-4279

Superior Products, North America

Parameter	Coating Characteristic
Product Name	SP2001F Fire Retardant
Composition	Formulated from resins and ceramics to withstand severe climate changes and severe heat peaks with no adhesion loss
Primary Application	High-temperature fire retardant
Use on Ships	Not documented
Advantages	Heat-resistant to 5000° F and remains intact above 2000° F, forming a pliable film that reacts to flame by glazing over to form a protective shield
Disadvantages	Product designed as insulator and not tested for fire resistance
Application Instructions	Will coordinate with George Steele of Newport News Shipbuilding to have panels sent to Superior Products for coating

2.8 Carboline

Tim Riley
Regional Fireproofing Manager
585-394-0251

Carboline

Parameter	Coating Characteristic
Product Name	Intumastic 285
Composition	A water-based, flexible mastic coating
Primary Application	Fire protection of cables
Use on Ships	Not documented
Advantages	Long-term fire resistance, durable finish
Disadvantages	Weight
Application Instructions	Carboline fire expert (ex-Navy) indicated that a 2-hour UL 1709 rating with 0.415” on steel. Max wet film of 60 mils/pass sprayed dries to 40 mils

2.9 Other Manufacturers Contacted During Project

Albi Manufacturing, Division of StanChem, Inc.

Parameter	Coating Characteristic
Product Name	Clad TF & Clad 800
Composition	Water and solvent-based intumescents good for E119 & UL 1709, respectively
Primary Application	Long-lasting fireproofing with high abrasion & impact resistance
Use on Ships	Not documented
Advantages	Good durability and fire resistance
Disadvantages	Smoke production with solvent-based products
Application Instructions	Will ship panels to Albi for coating after determining best product to use

W.R. Grace

Parameter	Coating Characteristic
Product Name	FlameSafe® FS 300
Composition	Water based, elastomeric coating
Primary Application	Architectural joint systems
Use on Ships	Not documented
Advantages	Durability, long-term fire resistance
Disadvantages	Typically used in conjunction with mineral wool
Application Instructions	Small quantities of FS 3000 and FS900TSL on hand at EGA for trial application; trowelable by hand

Nelson Firestop

Parameter	Coating Characteristic
Product Name	Firestop Joint Compound (FSC3™)
Composition	Water based acrylic latex, elastomeric, fire protective coating
Primary Application	Construction joints, wall to wall, floor to wall, floor to floor, head of wall and perimeter joint curtain wall applications where thermal expansion and contraction of joints, wind sway or seismic conditions may occur.
Use on Ships	Used in cable bulkhead penetrations
Advantages	Durability in marine environment
Disadvantages	Vendor indicated product not suitable for large area application
Application Instructions	This system has been removed from our program based on vendor's recommendation.

PPG Aerospace - PRC Desoto

Parameter	Coating Characteristic
Product Name	P/S 700
Composition	Two-part, synthetic rubber compound
Primary Application	Aircraft bulkheads & structural gaps
Use on Ships	Not documented
Advantages	Good fire resistance and durability when subjected to dynamic stresses
Disadvantages	Application requires extrusion gun or spatula; high cost as this is an aerospace product
Application Instructions	Received test quantities at Structural Composites from Bergdahl Associates; can be applied with spatula; designed to retain pressure after 2000°F flame exposure

Nu-Chem, Inc.

Parameter	Coating Characteristic
Product Name	Thermo-Lag 3000
Composition	Two component, subliming, epoxy based coating
Primary Application	Structural columns, beams, vessel skirts, bulkheads, underdecks and electrical raceways
Use on Ships	ABS, Lloyds & DnV certificates for hydrocarbon fires
Advantages	Thin application of product required
Disadvantages	Possible unacceptable smoke from epoxy
Application Instructions	Panels will be shipped to manufacturer for coating

3. Significant Communications and Visits

Of the numerous project communications that occurred during this project, several are significant for providing early project direction. The Principal Investigator strived to take advantage of the great wealth of information that exists within the industry. Extra care was taken not to include any professional bias that may be associated with candidate products.

3.1 Hopeman Brothers

On September 10th, 2003 David Heller of MARAD and Eric Greene visited Hopeman Brothers in Wayneboro, VA. Rupert Chandler, PE is a fire protection engineer and has worked for some time at Hopeman, both on naval and commercial projects. Hopeman had recently completed a comprehensive evaluation of spray-applied passive fire protection, starting with vibration and shock tests. Their shock test facility was reviewed as this resource could have been utilized by this project, in part because of the favorable price quote given by Mr. Chandler. The below figures show the Medium Weight Shock Table that Hopeman Brothers uses to qualify outfit products for the U.S. Navy.

Figure 1 David Heller and Rupert Chandler Inspect Medium Weight Shock Test Equipment at Hopeman Brothers

Figure 2 Seat Being Tested to MIL-STD 901D with 45° Test Fixture

Mr. Chandler was also very instructive in his assessment of available products for passive fire protection. One product that looked attractive at fist glance was MONOGLASS, but it turned out this company wants to limit the use of its product to insulation and not fire protection for fear of legal ramifications.

We also discussed how effective he's found mineral wool to be as compared with the more expensive Structo Gard treatment that the U.S. navy now specifies. He cited the current LPD 17 project where 8 lb/ft^3 mineral wool using commercial pins and spacing could meet Navy requirements as an example where a lot of cost savings could be realized.

We discussed the merits of cementous products but Mr. Chandler noted that these products tend to be dense, making them hard to pass vibration and shock tests. Indeed, the heavier the product, the more inertia it will have in operational and shock environments.

Mr. Chandler noted that it is important when considering spray systems that training and verification of achieved coating composition are critical. For instance, if a product is applied with 30% paper content and was tested with only 3-5% paper content, the amount of fire protection being applied will not meet the requirements that the test panel survived.

Mr. Chandler pointed to some promising results from urethanes that may be able to pass non-combustibility requirements.

Mr. Chandler & Mr. Greene have served together on ASTM Panel 25 on Shipbuilding. Mr. Chandler noted that ASTM is developing a commercial version of MIL STD 901 D for Medium Weight Shock testing. Mr. Chandler presented "Current Fire Testing for SOLAS: An Insight into the Test Procedures and Approval Process" at the ASTM December 7, 2004 meeting.

3.2 Isolatek International

Mr. Bijou Ganguly at Isolatek International was the initial point of contact there. Mr. Ganguly indicated that the project will benefit greatly from his experience in the structural fire protection industry.

3.3 NoFire Technologies, Inc

Mr. Greene has previously tested water-based intumescent products from NoFire under MARITECH programs. On August 7th, 2003 Mr. Greene discussed NoFire products with Dr. Sam Gottfried, company president. NoFire had an Office of Naval Research contract to develop a Structo Gard alternative for the DD(X) platform. That project used a combination of mineral wool products in conjunction with NoFire intumescent coatings to provide protection from UL 1709 fire insults.

Dr. Gottfried expressed his skepticism about achieving the required fire resistance with spray-applied products alone. For a product like the water-based NoFire, too many layers would be required, which would drive up labor cost. He also said the non-combustibility requirement would be tough to meet with spray coatings only.

3.4 Aerogel Products - Aspen

Aerogels are nanoporous, light weight materials that exhibit extraordinarily low thermal and acoustic conductivity. Aerogels have the highest thermal insulation value, the highest specific surface area, the lowest density, the lowest speed of sound, the lowest refractive index, and the lowest dielectric constant of all solid materials. These properties give aerogels multiple applications in a wide range of consumer, commercial, and military markets. Aspen manufactures a variety of forms of aerogel including flexible blanket, powder, beads, and clear monolithic sheets.

To date, Aerogels have not been widely commercialized due to very high production costs and initial capital investment. In March 1999, Aspen invented a low cost, high speed manufacturing process for aerogels for which the company received the 1999 SBIR (Small Business Innovation Research) Technology of the Year Award in Manufacturing/Materials. Aspen just received a $1M DoD Challenge Program award to develop their product for the Navy's DD(X). Although this is not envisioned to be a spray-applied system, future consideration should be given to determine if Aerogels can be applied in a spray form.

4. Vibration Test Arrangement

Figures 3 through 11 represent the vibration test configuration for evaluating the durability of candidate coatings applied to aluminum and composite panels. Figure 3 is a schematic drawing of the test configuration showing a variable speed, DC motor flexing 5 feet of a six-foot long coated test panel. The orientation is such to simulate a deck overhead.

Figure 4 shows the test panel requirements for both the aluminum and composite test panels. Figure 5 illustrates the first mode shape that is expected to be forced by driving the test panel at the center with the ends fixed. The test panel is loaded as depicted in Figure 6.

Figures 7 and 8 are detailed panel load analyses for a 0.25 inch thick aluminum and 0.385 inch thick composite panel, respectively. The panels were sized for equal bending stiffness.

Figure 9 is a detail of the cam assembly that is attached to the drive motor. The first table in Figure 10 shows the relationship between Motor RPM and the number of fatigue cycles. The other two tables illustrate that the required motor horsepower is very sensitive to the speed at which we run the test. A 1 horsepower motor, like the one shown in Figure 11, should be sufficient.

Figures 12 through 16 show details of the fatigue test apparatus built for this project.

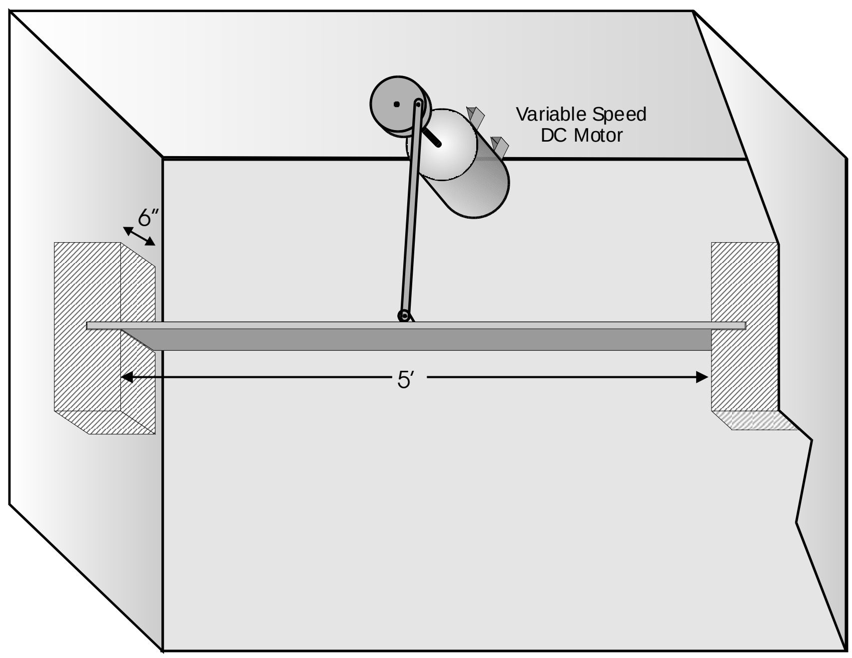


Figure 3 Vibration Test Arrangement

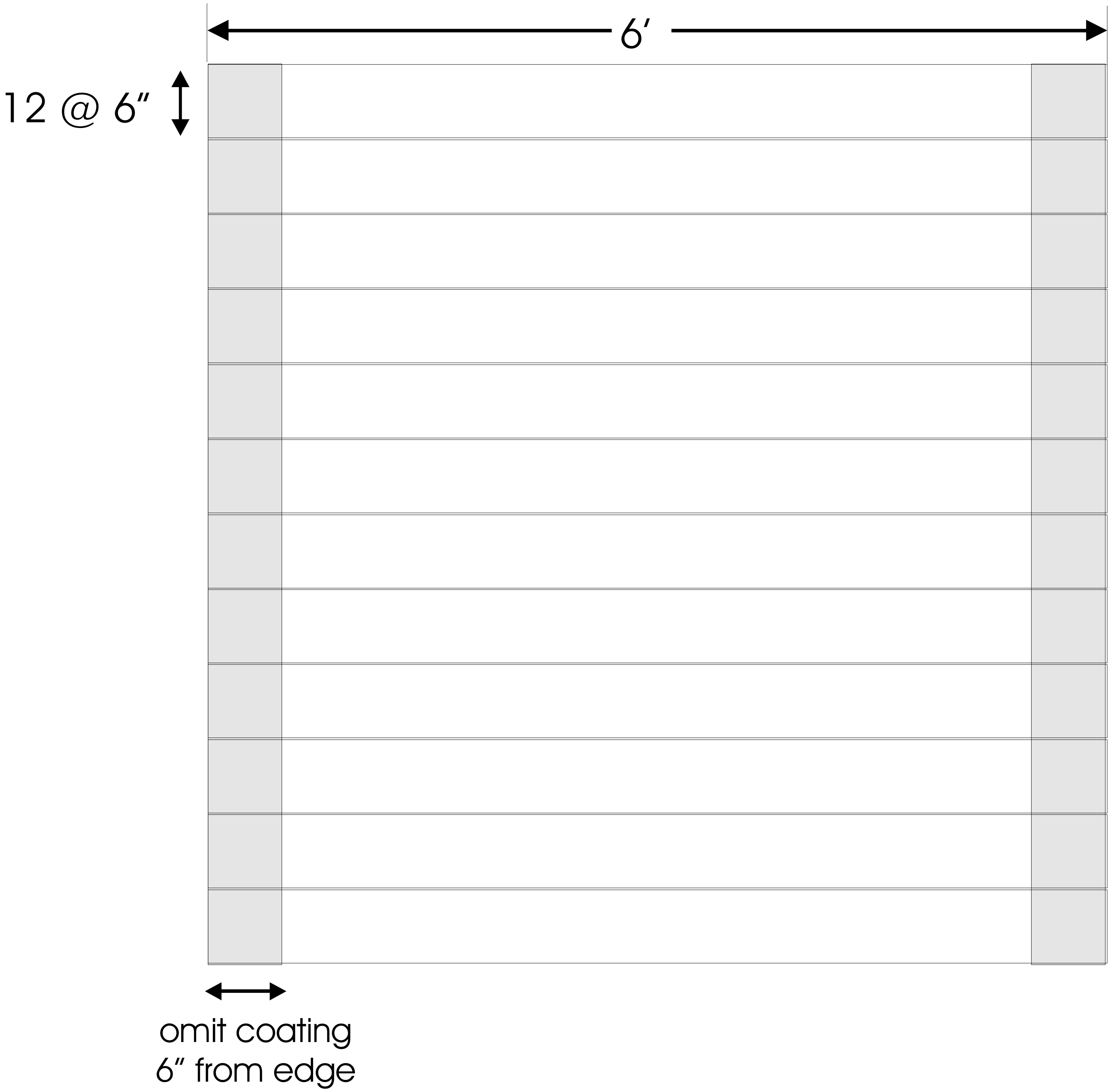


Figure 4 Test Panel Requirement

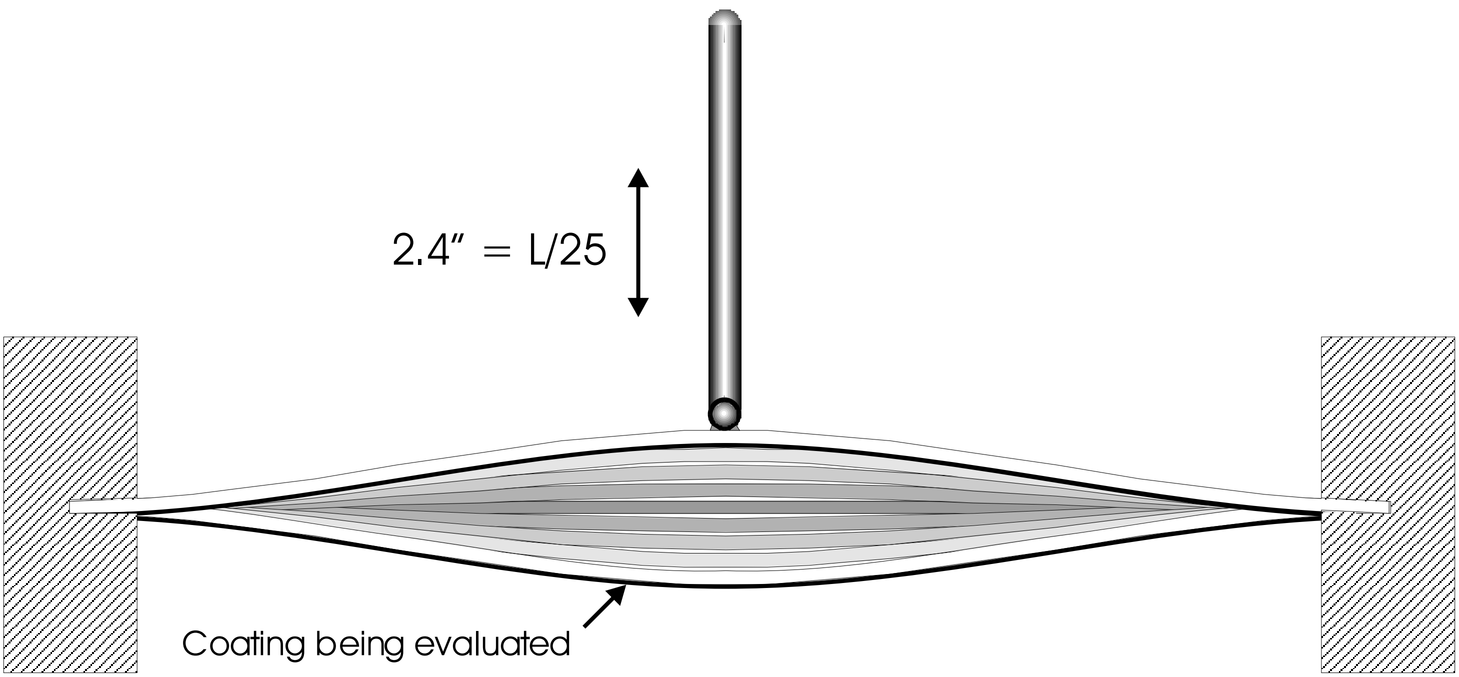


Figure 5 Expected Deflection Modes
(Displacement Exaggerated)

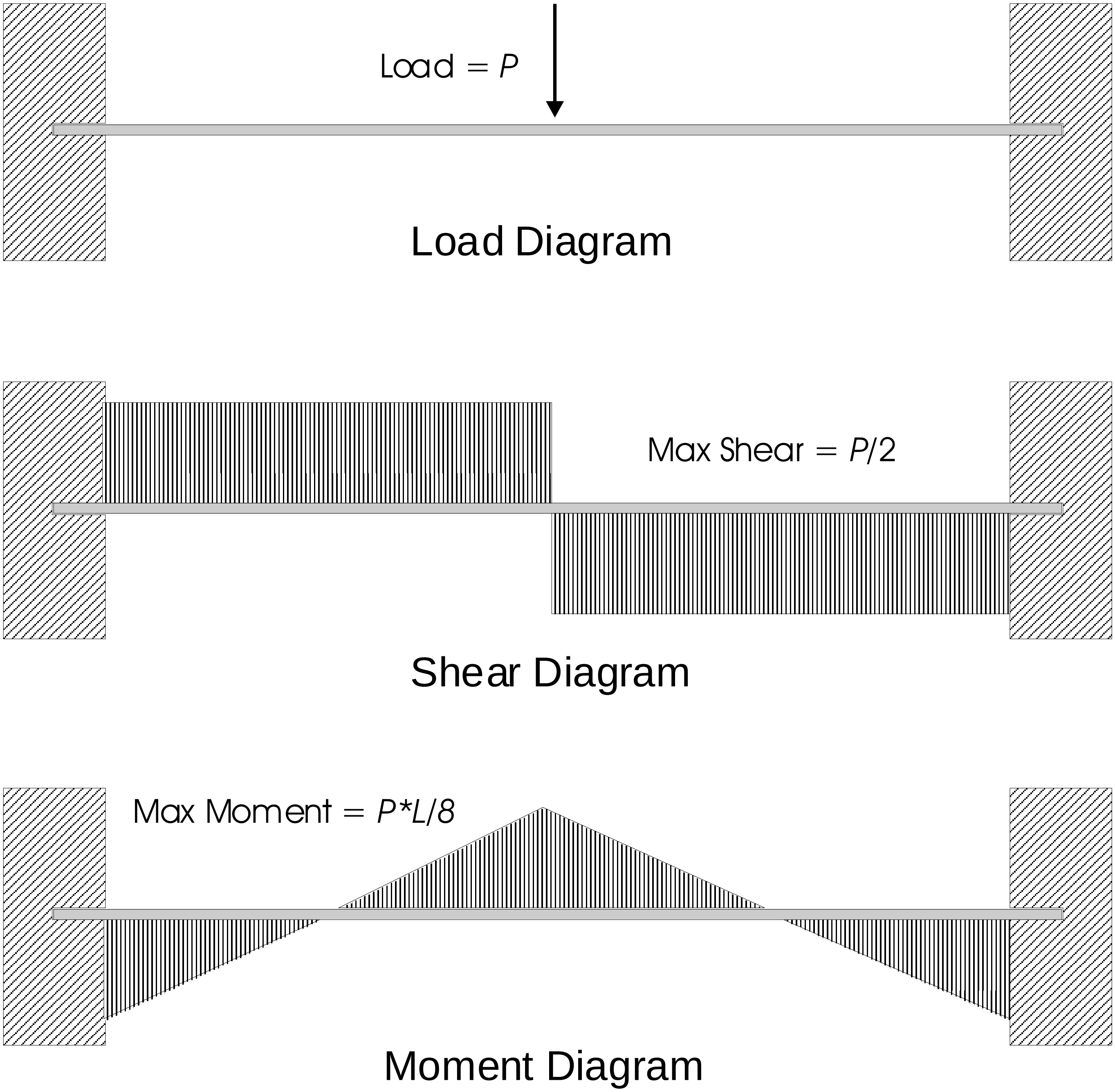


Figure 6 Loads & Stresses on Test Panels

Deflection, *y*	Force, *P*	Maximum Skin Stress	Coating Shear Force	Maximum Moment, *M*	
inches	lbs	lbs/in^2	lbs/in^2	inch-lbs	
0.1	7.2	867	4	54	
0.2	14.4	1,733	7	108	
0.3	21.7	2,600	11	163	
0.4	28.9	3,467	14	217	
0.5	36.1	4,333	18	271	
0.6	43.3	5,200	22	325	
0.7	50.6	6,067	25	379	
0.8	57.8	6,933	29	433	
0.9	65.0	7,800	33	488	
1	72.2	8,667	36	542	
1.2	86.7	10,400	43	650	test max
1.3	93.9	11,267	47	704	
1.4	101.1	12,133	51	758	
1.5	108.3	13,000	54	813	
1.6	115.6	13,867	58	867	
1.7	122.8	14,733	61	921	
1.8	130.0	15,600	65	975	
1.9	137.2	16,467	69	1029	
2	144.4	17,333	72	1083	
2.1	151.7	18,200	76	1138	
2.2	158.9	19,067	79	1192	
2.3	166.1	19,933	83	1246	
2.4	173.3	20,800	87	1300	

Aluminum Panel		
Thickness	**0.25**	**inches**
Area	1.5	inches^2
Section Modulus	0.0625	inches^3
Moment of Inertia, *I*	0.0078125	inches^4
Maximum Allowable Stress	73,000	lbs/in^2
Young's Modulus (x 10^6), *E*	10.4	lbs/in^2
Length, *L*	60	inches

$y = P * L^3 / 192 * E * I$

Skin Stress = $M * c / I$

c = panel thickness / 2

Test Stress/Allowable 14.2%

Figure 7 Loads & Stresses on Aluminum Panels

Deflection, *y*	Force, *P*	Maximum Skin Stress	Coating Shear Force	Maximum Moment, *M*	
inches	lbs	lbs/in^2	lbs/in^2	inch-lbs	
0.1	7.1	359	4	53	
0.2	14.2	719	7	107	
0.3	21.3	1,078	11	160	
0.4	28.4	1,437	14	213	
0.5	35.5	1,797	18	266	
0.6	42.6	2,156	21	320	
0.7	49.7	2,515	25	373	
0.8	56.8	2,875	28	426	
0.9	63.9	3,234	32	479	
1	71.0	3,593	36	533	
1.2	85.2	4,312	43	639	test max
1.3	92.3	4,671	46	692	
1.4	99.4	5,031	50	746	
1.5	106.5	5,390	53	799	
1.6	113.6	5,749	57	852	
1.7	120.7	6,109	60	905	
1.8	127.8	6,468	64	959	
1.9	134.9	6,827	67	1012	
2	142.0	7,187	71	1065	
2.1	149.1	7,546	75	1119	
2.2	156.2	7,905	78	1172	
2.3	163.3	8,265	82	1225	
2.4	170.4	8,624	85	1278	

Composite Panel		
Thickness	**0.385**	**inches**
Area	2.31	inches^2
Section Modulus	0.148225	inches^3
Moment of Inertia, *I*	0.0285333	inches^4
Maximum Allowable Stress	50,000	lbs/in^2
Young's Modulus (x 10^6), *E*	2.8	lbs/in^2
Length, *L*	60	inches

$y = P * L^3 / 192 * E * I$

Skin Stress = $M * c / I$

c = panel thickness / 2

Test Stress/Allowable 8.6%

Laminate Schedule

(10) Layers of 1810 @ 0 deg

Figure 8 Loads & Stresses on Composite Panels

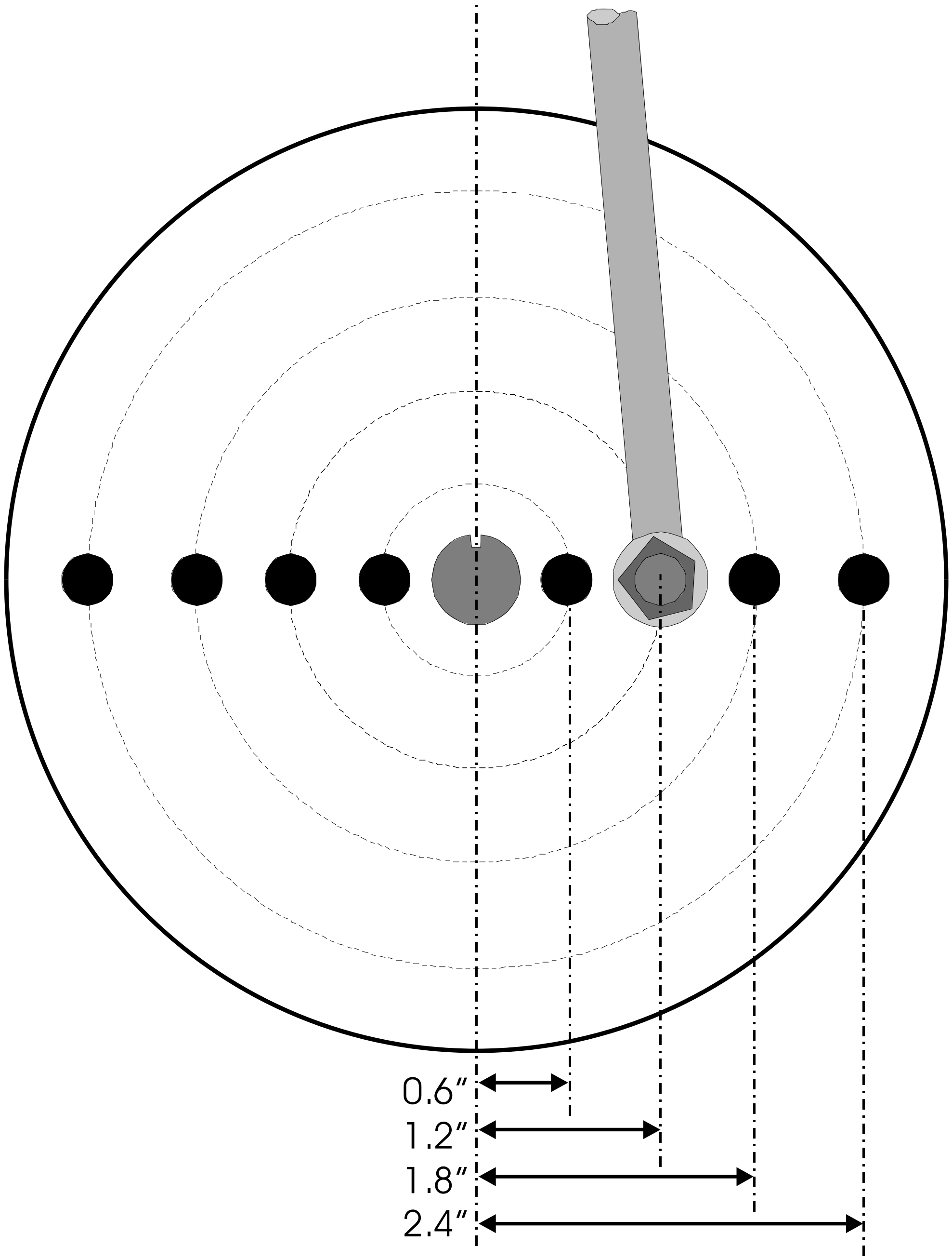


Figure 9 Drive Cam Assembly

Test Parameters

Hz	Motor RPM	Cycles per Day	Hours to Reach 10^6 Cycles	Days to Reach 10^6 Cycles	
0.1	6	8,640	2778	115.7	
0.2	12	17,280	1389	57.9	
0.3	18	25,920	926	38.6	
0.4	24	34,560	694	28.9	
0.5	30	43,200	556	23.1	
0.6	36	51,840	463	19.3	
0.7	42	60,480	397	16.5	
0.8	48	69,120	347	14.5	
0.9	54	77,760	309	12.9	
1	60	86,400	278	11.6	test max
5	300	432,000	56	2.3	
10	600	864,000	28	1.2	
30	1,800	2,592,000	9		
60	3,600	5,184,000	5		
90	5,400	7,776,000	3		
120	7,200	10,368,000	2		

Required Motor HP @ 1 Hz (60 RPM)

Arm Force	Arm Location (inches)			
lbs	1	1.2	1.8	2.4
1	0.00	0.00	0.00	0.00
10	0.01	0.01	0.02	0.02
20	0.01	0.02	0.03	0.05
30	0.02	0.03	0.05	0.07
40	0.02	0.05	0.07	0.09
50	0.03	0.06	0.09	0.11
60	0.03	0.07	0.10	0.14
80	0.05	0.09	0.14	0.18
100	0.06	0.11	0.17	0.23
120	0.07	0.14	0.21	0.27
140	0.08	0.16	0.24	0.32

Required Motor HP @ 10 Hz (600 RPM)

Arm Force	Arm Location (inches)				
lbs	1	1.2	1.8	2.4	
1	0.01	0.01	0.02	0.02	
10	0.06	0.11	0.17	0.23	
20	0.11	0.23	0.34	0.46	
30	0.17	0.34	0.51	0.69	
40	0.23	0.46	0.69	0.91	
50	0.29	0.57	0.86	1.14	
60	0.34	0.69	1.03	1.37	
80	0.46	0.91	1.37	1.83	test max
100	0.57	1.14	1.71	2.29	
120	0.69	1.37	2.06	2.74	
140	0.80	1.60	2.40	3.20	

HP = ft-lbs * RPM/5250

Figure 10 Test Parameters

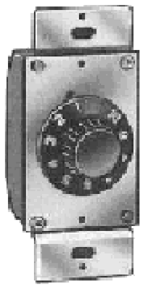
Table 2 Major Mechanical and Electrical Test Jig Elements

Component	Product	Source
Geared Motor	33A-5F DC Right Angle Gearmotor Model #6636	Bodine Electric Company 2500 West Bradley Place Chicago. IL 60618
Controller	KB-KBWS-225	Electro Sales Co., Inc. 100 Fellsway West Somerville, MA 02145
Tachometer	EX-461501 Digital Tachometer Counter	Extech Instruments Corporation 285 Bear Hill Road Waltham, MA 02451

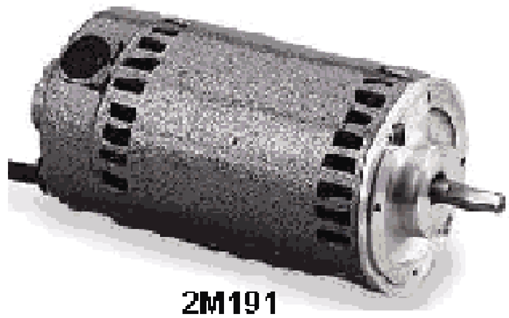
Dayton Universal Type AC/DC 115volts 60hz. Non-Reversible Motor

Catalog #	HP	Rotation	RPM	Bearings	Shaft	Amps
2M191	1	CCW	10,000	Ball	7/16 x 1 1/4	12.1

Speed Control for AC/DC Motors



Part# 4X797
10 amp



available from www.ElectricMotorWarehouse.com

Figure 11 Recommended Motor & Controller

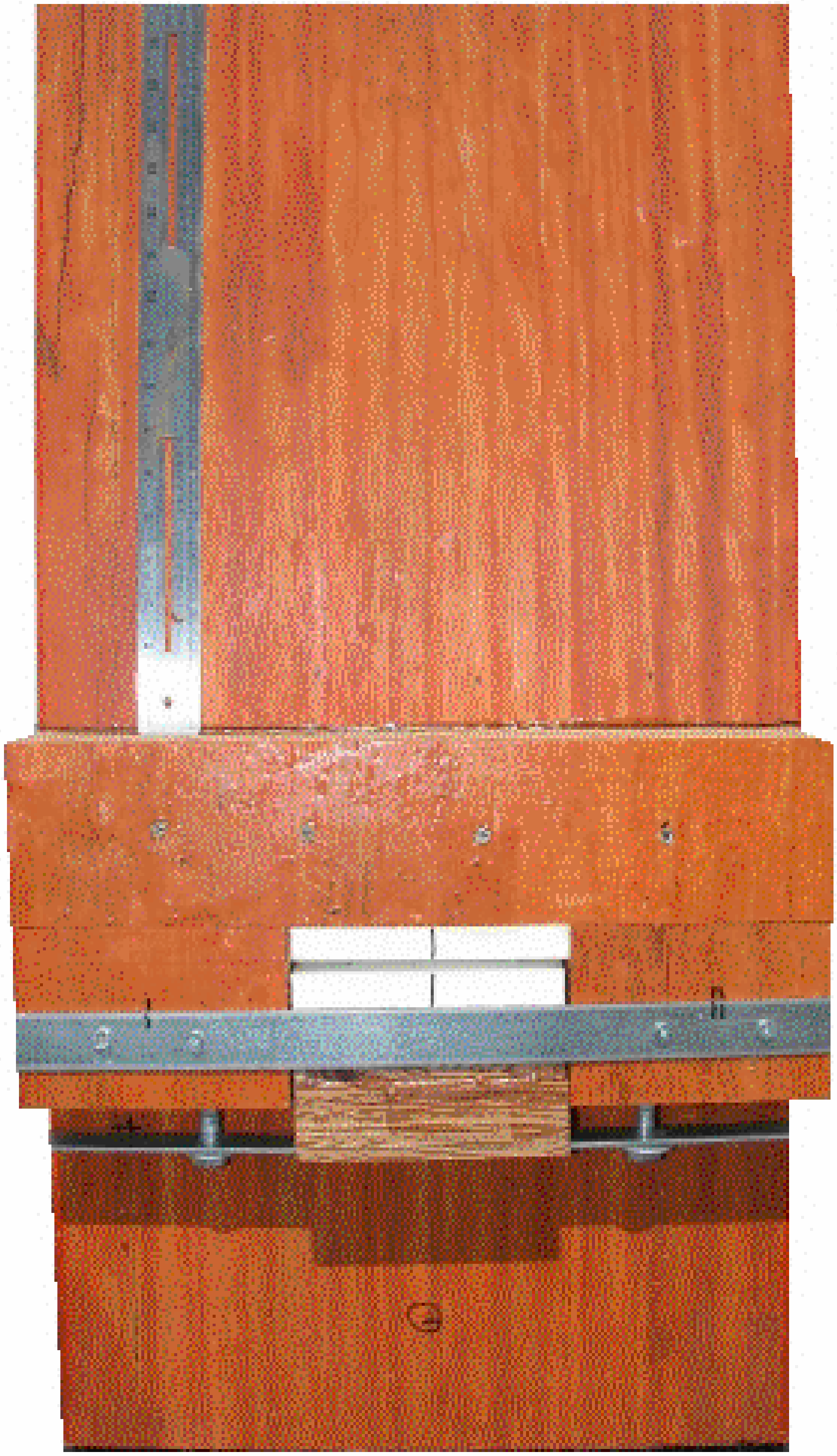


Figure 12 Grip Assembly will form Each End of Test Jig
(note: 18 inch ruler included for scale)

Figure 13 Detail of Grip Assembly

Figure 14 End View of Grip Assembly

Figure 15 Composite Test Panel Provided by Northrop Grumman Ship Systems (left) and Aluminum Panel Provided by Trinity Yachts (right)

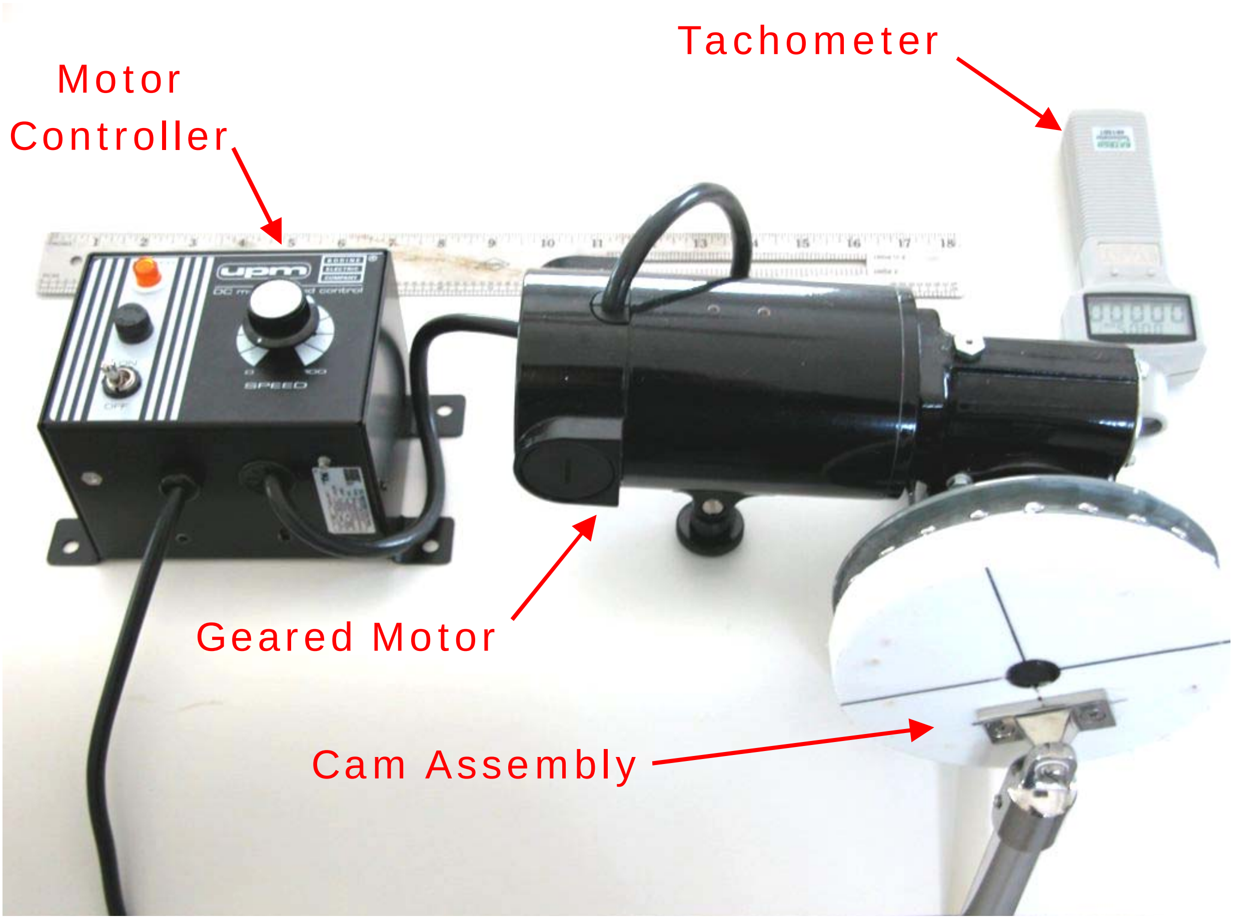
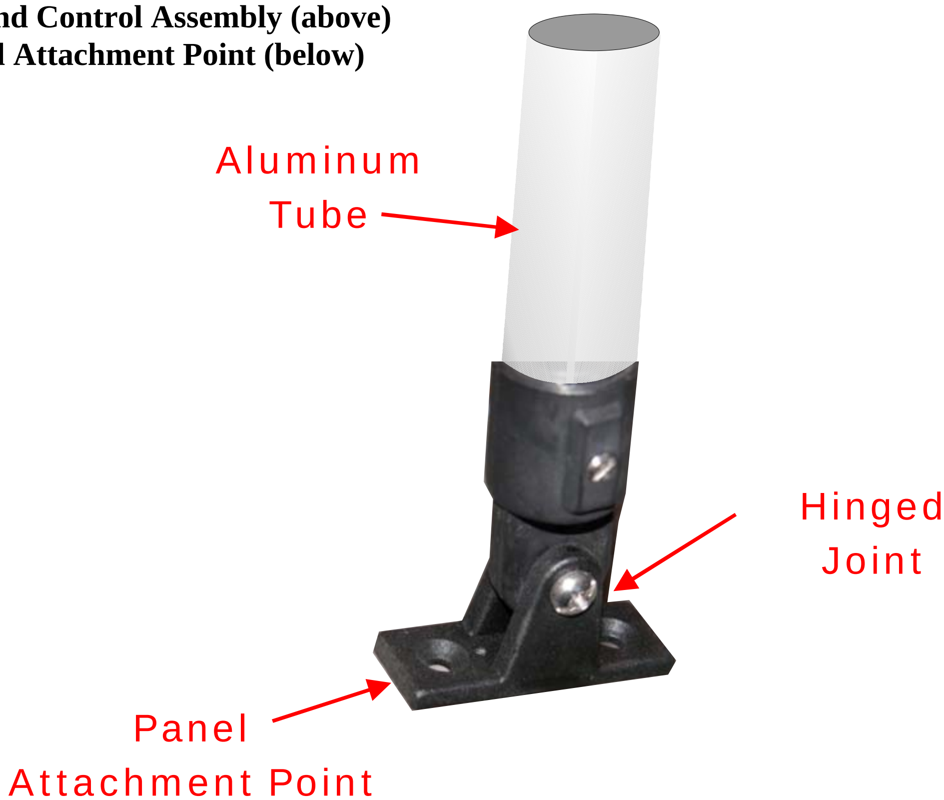


Figure 16 Motor and Control Assembly (above) and Hinged Panel Attachment Point (below)



4.1 Review of Test Jig Performance

The specialized vibration test jig constructed for this project has been able to test both aluminum and composite panels at 100,000 cycles in a repeatable fashion. Some care must be exercised securing the panels in the jig to ensure that the same degree of fixity occurs in successive tests. The tests are currently run with “simply supported” ends, that is the ends are not clamped tightly. Because the test apparatus is a constant displacement device, operating with fully clamped ends would require significantly more force from the driving motor. Presently, the panel ends are secured with a ¼ - inch gap to create a pinned end condition. Where the lag bolts that hold the panel in place mount to the frame, some loosening has occurred on one end so the holes were filled and re-drilled to regain a tighter connection. In general, the heavy wood construction used to build the test apparatus has worked well to transmit loads to panel while damping out high frequency “rattling” making it possible to operate the test without hearing protection.

A small plastic pad eye is mounted on the back side of test panels to transmit the load from the actuating arm. Tapping screws into the back of the panels has worked well but requires care not to drill through the coating if pad eyes are installed after the coating is applied. The screws initially used were “self-tapping” type, but later tests used machine screws with the panel “tapped” with a tool. The screw attached to the cam that the actuator arm rotates on was replaced once due to wear.

4.2 General Response of Tested Panels

Cycling the test panels to ±L/50 displacements creates significant stresses at the coating interface. However, only one of the coatings tested to date has failed catastrophically at the interface to the substrate. The most common failure mode is minor surface cracking near the center of the panel.

5 Candidate Sprayable PFP Systems Tested

5.1 Fyre Shield

CHI Technologies
Joe Mooney

Panel Material: Aluminum
Panel Test Date: July 7, 2004
Test Start Time: 1235
Total Test Cycles: 10^5

Description of Test Specimen Condition before Test:

Panel was coated at Eric Greene Associates as per instructions from Joe Mooney. Mr. Mooney indicated that coating can be applied at full thickness and cured with an IR heat lamp. This was done using a dam arrangement (see Figure 17) to keep the coating from running off of the edge. The coating did take some time to cure and resulted in a stipple finish seen in Figure 17. In practice, the coating would need to be applied using successive coats of less film thickness each, which may result in smoother surface appearance.

Fyre Sheild

Figure 17 Preparation, Coating and Finished Coating Surface for Fyre Shield Product from CHI Technologies (note coating being "trowel applied" using built up dam)

Description of Test Specimen Condition after Test:
The bottom right photo in Figure 17 shows the test panel after testing. There was no loss of coating material during the test. However, hairline surface cracks did appear near the center of the panel.

Panel Material: Composite
Panel Test Date: July 7, 2004
Test Start Time: 1235
Total Test Cycles: 10^5
Description of Test Specimen Condition before Test:
Panel was coated at Eric Greene Associates similar to the aluminum panel.

Description of Test Specimen Condition after Test:
The coating on the composite performed in a fashion similar to the aluminum panel. Minor surface cracking was observed but no material was dislodged from the surface during the test.

5.2 AkroTherm
AkroFireguard
Tim Johnson
Dr. Harold Brashears of Northrop Grumman Ship Systems (NGSS) made us aware of Akro Fireguard's AkroTherm product as part of his research to find a suitable passive fire protection system for the new DD(X) destroyer. Tim Johnson of Akro Fireguard inquired as to the cost for testing their product in the vibration test jig to evaluate coating durability. We offered to evaluate the coating without charge as this test is still in the R&D stage.

Akro Fireguard coated two composite panels supplied by NGSS at their facility in Lenexa, Kansas. One panel was tested and the other is being held in reserve.

Panel Material: Composite
Panel Test Date: August 2, 2004
Test Start Time: 1440
Total Test Cycles: 10^5

Description of Test Specimen Condition before Test:
The test panels arrived at Eric Greene Associates well packaged in very good condition. Akro Fireguard applied the coating in such a way as to leave square edges on the significant coating thickness (see Figure 18.)

Description of Test Specimen Condition after Test:
No material was dislodged during the test nor was there a change in the condition of the surface coating. The AkroTherm material was soft enough not to crack during testing. However, the durability of such a surface without a protective skin would be problematic in a shipboard environment.

AkroTherm

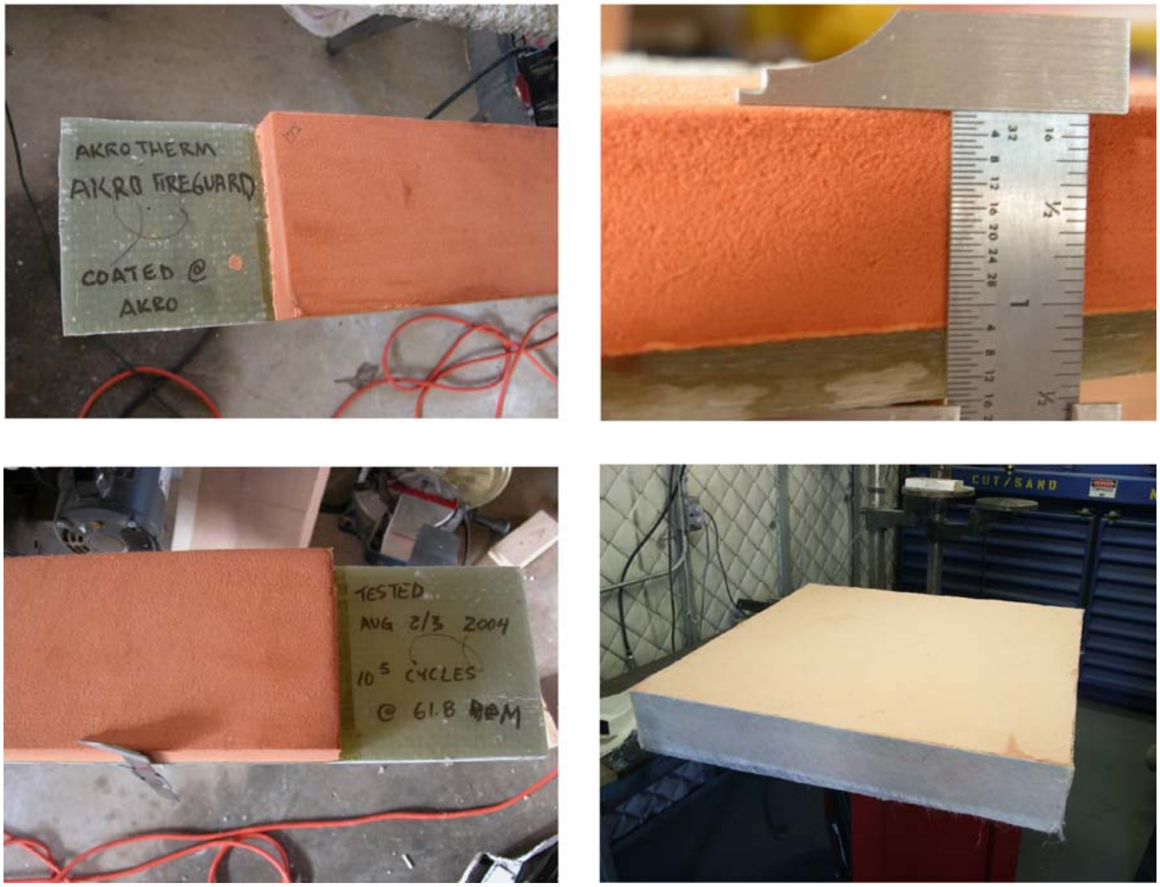


Figure 18 Photos of the Panel Coated with Akro Therm by Akro Fireguard. The Photograph in the Lower Right Shows a Test Panel that NGSS and Akro Fireguard Fire Tested using UL 1709 Fire Insult

5.3 Fastblock 810
Esterline Kirkhill - TA
Kelly Ford/Himat Gupta

The Fastblock 810 product is also under consideration by NGSS for use on future DD(X) destroyers. Sample quantities of the material were sent to Structural Composites in early April. Coating was applied by hand (see Figure 19).

Panel Material: Composite
Panel Test Date: August 27, 2004
Test Start Time: 1520
Total Test Cycles: 10^5

Description of Test Specimen Condition before Test:
The coating was applied to test panels at Structural Composites using a “trowel” method. The maximum thickness of the coating is 3/8 to 1/2 inches thick at the center of the panel. Near the edges of the panel, some of the material “sheared off” in pieces up to ½ inch wide. Some longitudinal cracks were also present on the surface. During the mounting of the test padeye a small hole was inadvertently drilled through the coating. This area was marked and observed not to propagate during testing.

Description of Test Specimen Condition after Test:
There was no noticeable loss of fire protection material during the test period. A transverse hairline crack developed near the center of the panel. There appears to be some shear failure of the coating at the substrate interface near the edges of the panel as well.

5.4 Dapco 2032
Cytec Engineered Materials
D Aircraft
Toby Dembrowsky

Panel Material: Composite
Panel Test Date: September 14, 2004
Test Start Time: 1645
Total Test Cycles: 10^5

Description of Test Specimen Condition before Test:
Dapco 2032 has a rubbery consistency after cured. With only a small test quantity of coating available, coating was applied at the minimum thickness required for durability evaluation.

Description of Test Specimen Condition after Test:
The test panel looked virtually unchanged before and after testing.

Fastblock 810

Figure 19 Photographs Showing Fastblock 810 in Liquid Form and after Cured in a Paint Bucket (top row) The Photos in the Middle Row Shows Area Where Mounting Screw Penetrates Coating Surface and Transverse Cracking Evident after Testing. The Bottom Row Shows Overall Surface Unevenness.

Figure 20 Dapco 2032 from Cytec Engineered Materials Supplied by D Aircraft Products. Shown at top in Liquid Form and on a Test Panel. Bottom Pictures Show Air-Entrapped on the Surface and Thin Application of Coating

5.5 Cafeco Blaze Shield II
Isolatek International
Diego Penta

An aluminum and a composite test panel were delivered to Isolatek corporate headquarters in Stanhope, New Jersey June 29th, 2004 after a non-disclosure agreement was signed by the Principal Investigator. The panels were coated by Isolatek to a thickness required for 30 minutes of protection from UL 1709 fire insult. Panels were received at the Eric Greene Associates facility on September 17th, 2004.

Panel Material: Aluminum
Panel Test Date: September 20, 2004
Test Start Time: 1400
Total Test Cycles: 10^5

Description of Test Specimen Condition before Test:
The panels were packaged with Styrofoam sheets by Isolatek prior to shipping. Some of the Styrofoam broke apart and mixed with the fire protection surface. As shown in Figure 21, a small vacuum was used to remove loose Styrofoam and passive fire protection prior to testing. Some additional fire protection material dislodged during the handling and mounting of the test panels in the test apparatus. All material was cleaned from the test apparatus prior to start of the test. The finished surface of Cafeco Blaze Shield II is very rough. The material appears to have the potential for significant water uptake in a marine environment.

Description of Test Specimen Condition after Test:
The panel itself looked the same both before and after the test. This is due in part to the fact that the finished surface is very irregular. Dislodged material was collected and weighed to by approximately 0.1 ounces. Although this loss of material probably wouldn't adversely affect passive fire performance, loose material would be objectionable in a shipboard environment, especially on a yacht.

Panel Material: Composite
Panel Test Date: September 22, 2004
Test Start Time: 1310
Total Test Cycles: 10^5

Description of Test Specimen Condition before Test:
The composite panel arrived in a condition similar to the aluminum panel. As shown in Figure 21, a small vacuum was used to remove loose Styrofoam and passive fire protection prior to testing. Some additional fire protection material dislodged during the handling and mounting of the test panels in the test apparatus. All material was cleaned from the test apparatus prior to start of the test. The finished surface of Cafeco Blaze Shield II is very rough.

Description of Test Specimen Condition after Test:
As with the aluminum panel, the composite panel looked similar before and after the test. With both panels, the bond at the interface to the substrate did not deteriorate during the test. After testing, it was determined that hitting the panels lightly with a hammer dislodged more of the fire protection material than occurred during the test.

Cafco Blaze Shield II

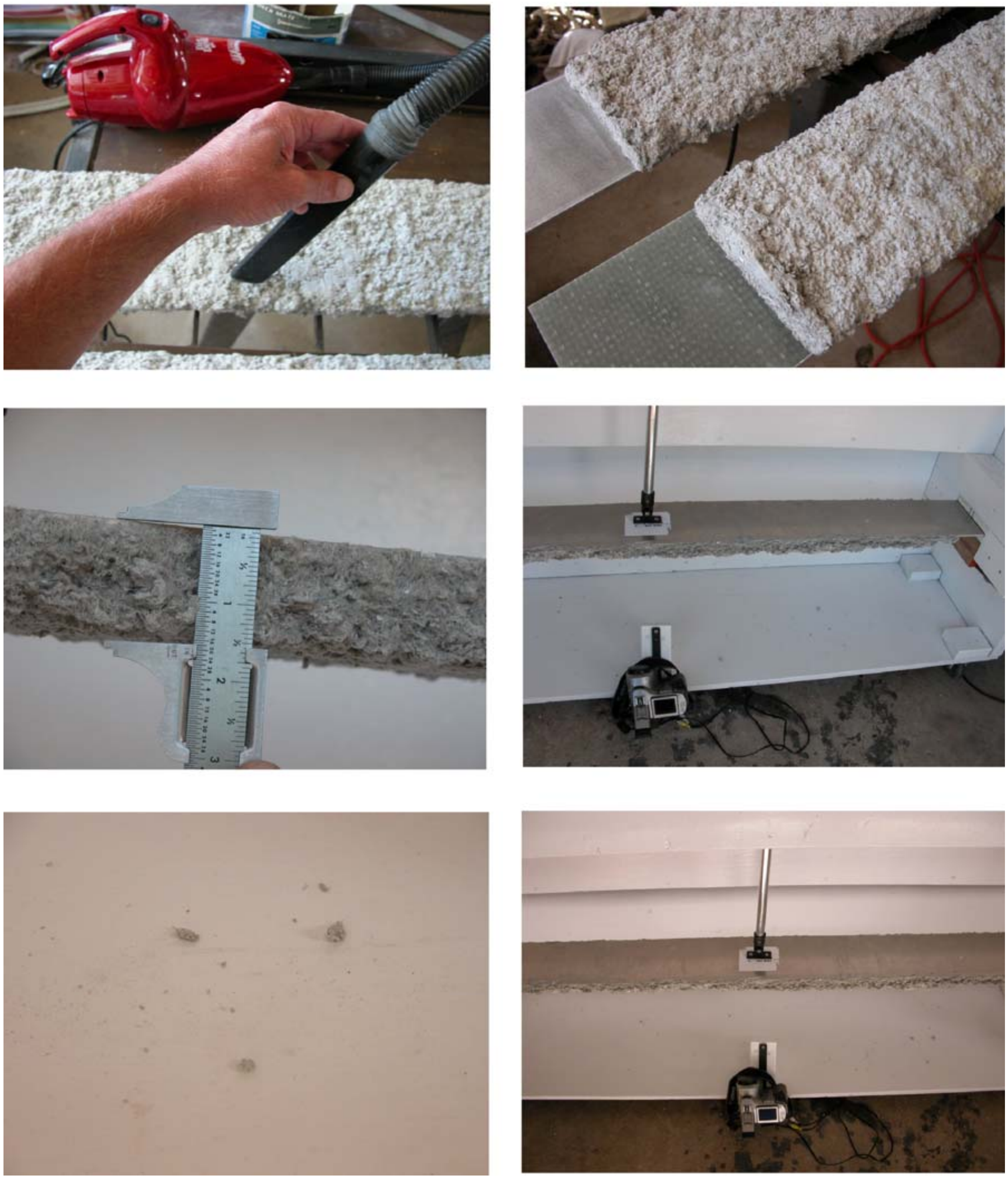


Figure 21 Photographs of Cafeco Blaze Shield II Composite and Aluminum Panels. Top Photos Show Technique for "Cleaning" Panels of Loose Material prior to Testing. Photos at Bottom show "Density" of Loose Material in Collection Area of Test Apparatus and End of Testing.

5.6 SP2001F
Superior Products
J.E. Pritchett

Throughout the project, Drs. Harold Brashears and George Steele of Northrop Grumman Ship Systems (Pascagoula and Newport News, respectively) have provided guidance regarding sprayable passive fire protection being considered for naval surface combatants. Their insight has been invaluable to this project. Dr. Steele has tested the SP2001F product under a UL 1709 heat insult with favorable results. Panels were shipped to Superior Products on August 25th, 2004 and coated to about 400 mils, which has shown to restrict back face temperatures to 350°F on aluminum after 30 minutes. Coated panels were received on October 22nd, 2004.

Panel Material: Aluminum
Panel Test Date: December 8, 2004
Test Start Time: 1510
Total Test Cycles: 10^5

Description of Test Specimen Condition before Test:
The test specimens arrived from Superior Products wrapped in the plastic shipping bubble-wrap that has been used for panel transport. It seemed like some curing moisture was captured in the bubble-wrap and therefore panels were left to post cure at ambient temperature for 30 days before testing.

The specimen grip area was not masked off prior to coating so it was necessary to remove a 6-inch long area of coating at each end. The middle left photo in Figure 22 shows the piece of coating removed using a putty knife. The coating appeared to be soft, yet durable.

Description of Test Specimen Condition after Test:
About halfway through the planned 100,000 cycles, total coating adhesion failure was observed. The entire amount of coating broke into three separate pieces and was found on the base of the test apparatus. Photos of the failed coating are shown in Figure 22.

Panel Material: Composite
Panel Test Date: December 10, 2004
Test Start Time: 0800
Total Test Cycles: 10^5

Description of Test Specimen Condition before Test:
The test specimens arrived from Superior Products wrapped in the plastic shipping bubble-wrap that has been used for panel transport. It seemed like some curing moisture was captured in the bubble-wrap and therefore panels were left to post cure at ambient temperature over 30 days before testing.

The specimen grip area was not masked off prior to coating so it was necessary to remove a 6-inch long area of coating at each end. The middle left photo in Figure 22 shows the piece of coating removed using a putty knife. The coating appeared to be soft, yet durable.

Description of Test Specimen Condition after Test:
The test panel endured 100,000 cycles with no apparent degradation of the coating.

5.7 Intumastic 285
Carboline
Tim Riley

Tim Riley and Steven Evans of Carboline visited Eric Greene Associates on December 6, 2004 to discuss appropriate fire protection coatings for this project. Nullifire S605 and Intumastic 285 were discussed. After Mr. Riley and Mr. Evans reviewed the project test arrangement, it was agreed that Intumastic 285 would be a more durable product to test. Panels were shipped to their St Louis, MO facility on January 4 and were coated with just under ½" (dry) Passive Fire Protection.

Panel Material: Aluminum
Panel Test Date: February 25, 2005
Test Start Time: 0935
Total Test Cycles: 10^5

Description of Test Specimen Condition before Test:
The panels had a finished coating thickness of just under ½ inch. The finish appeared to be very durable with a stipple texture. The coating extended over the edge of the test panels.

Description of Test Specimen Condition after Test:
The panel looked unchanged after the fatigue test.

Panel Material: Composite
Panel Test Date: March 9-10, 2005
Test Start Time: 0935
Total Test Cycles: 2×10^5 Note: Panel tested at 2 Hz

Description of Test Specimen Condition before Test:
The panels had a finished coating thickness of just under ½ inch. The finish appeared to be very durable with a stipple texture. The coating extended over the edge of the test panels.

Description of Test Specimen Condition after Test:
Coating appeared not to degrade after 200,000 cycles at approximately 2 Hz.

Superior Products SP2001F

Figure 22 Photographs of Superior SP2001F Aluminum Panels. Photos at left show panels being prepared for testing and the start of the test. The photos at right show the failed coating on the aluminum panels and the surface of the aluminum panel.

Carboline Intumastic 285

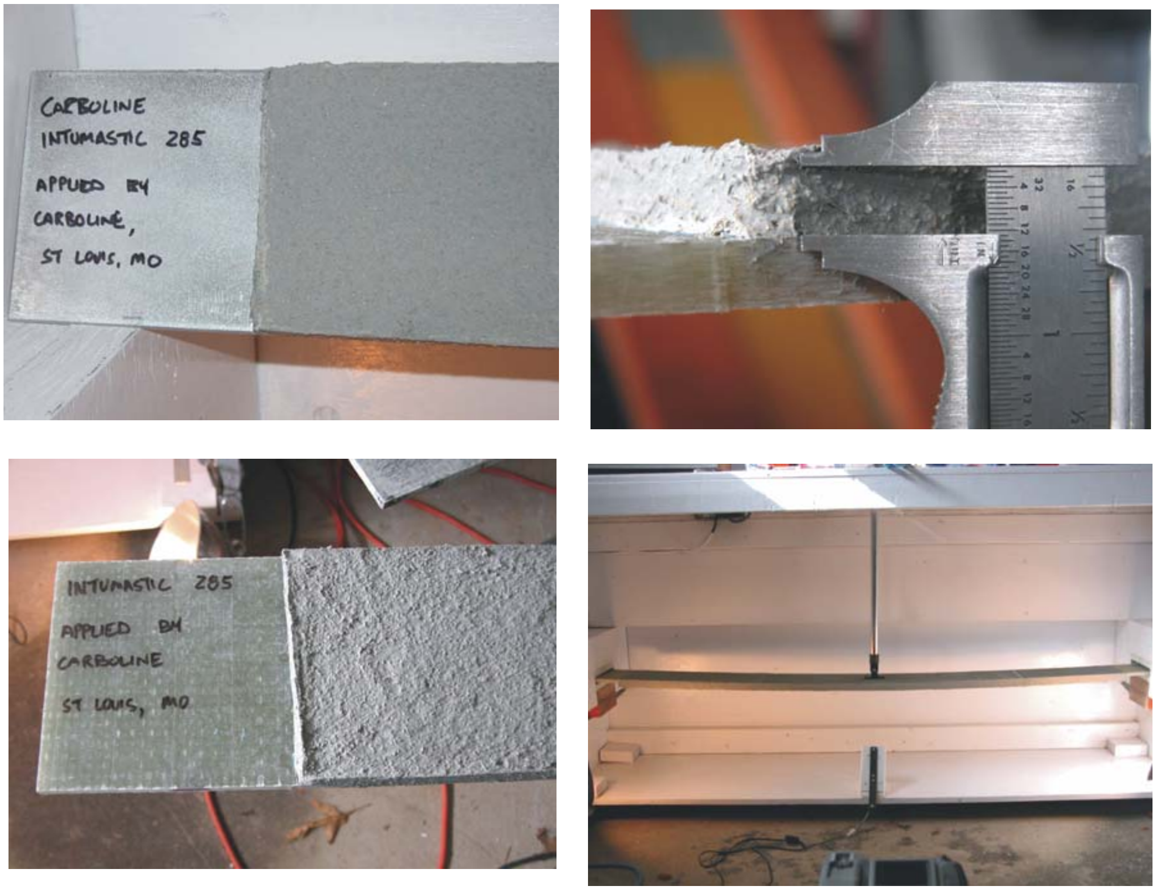


Figure 23 Photographs of Carboline's Intumastic 285 Coated Panels. Photos at left show panels being prepared for testing. The photos at right show typical coating thickness and the composite panel during fatigue testing.

5.8 Summary of Fatigue Testing

The fatigue testing arrangement was designed to be an aggressive test that simulates the dynamic environment that marine structures experience in service. ± L/50 deflections for 100,000 cycles did not seem to damage the panels themselves but did subject the coatings to very high shear stresses at the interface to the panels. With that said, only one of the eleven panels tested experienced complete failure during the test. Some other products lost a very minor amount of material during the test.

The only failure occurred with an aluminum panel. The coating broke off cleanly and suggests that it is much harder to get passive fire protection to adhere to aluminum as compared with composite substrates. Aluminum panels may also vibrate more than composite structures in a marine environment. Table 3 summarizes fatigue test results.

Table 3 Summary of Fatigue Test Results

Supplier	Product	Panel Construction	Date Tested	Complete Failure	Panel Description After Test
Esterline Kirkhill-TA	FASTBLOCK® 810	Composite	8/27/2004	No	There was no noticeable loss of fire protection material during the test period. A transverse hairline crack developed near the center of the panel. There appears to be some shear failure of the coating at the substrate interface near the edges of the panel as well.
Isolatek International	Cafco Blaze Shield II	Aluminum	9/20/2004	No	The panel itself looked the same both before and after the test. This is due in part to the fact that the finished surface is very irregular. Dislodged material was collected and weighed to by approximately 0.1 ounces. Although this loss of material probably wouldn't adversely affect passive fire performance, loose material would be objectionable in a shipboard environment.
		Composite	9/22/2004	No	As with the aluminum panel, the composite panel looked similar before and after the test. With both panels, the bond at the interface to the substrate did not deteriorate during the test. After testing, it was determined that hitting the panels with a hammer dislodged more of the fire protection material than occurred during the test.
Span-World Distribution	Fyre Sheild™	Aluminum	7/7/2004	No	There was no loss of coating material during the test. However, hairline surface cracks did appear near the center of the panel.
		Composite	7/14/2004	No	The coating on the composite performed in a fashion similar to the aluminum panels. Minor surface cracking was observed but no material was dislodged from the surface during the test.
Superior Products, North America	SP2001F Fire Retardant	Aluminum	12/8/2004	Yes	About halfway through the planned 100,000 cycles, total coating adhesion failure was observed. The entire amount of coating broke into three separate pieces and was found on the base of the test apparatus.
		Composite	12/10/2004	No	The test panel endured 100,000 cycles with no apparent degradation of the coating.
		Aluminum	7/15/2005	No	The test panel endured 100,000 cycles with no apparent degradation of the coating.
Carboline	Intumastic 285	Aluminum	2/25/2005	No	The panel looked unchanged after the fatigue test.
		Composite	3/9/2005	No	Coating appeared not to degrade after 200,000 cycles at approximately 2 Hz.
Cytec Engineered Materials	DAPCO 2032	Composite	9/14/2004	No	The test panel looked virtually unchanged before and after testing.
Akro Fireguard Products	Akrotherm	Composite	8/2/2004	No	No material was dislodged during the test nor was there a change in the condition of the surface coating. The AkroTherm material was soft enough not to crack during testing. However, the durability of such a surface without a protective skin would be problematic in a shipboard environment.

6. Impact Testing

Most of the Spray-Applied Passive Fire Protection coatings evaluated in our fatigue test apparatus did fairly well. However, it was noticed during handling of the specimens that some coatings may be susceptible to impact damage. As a follow-on durability test, it was decided to evaluate the coated panels subjected to shock under impact loading. Consideration was given to using Rupert Chandler's shock table, but in consultation with David Heller, Project Technical Chairman, it was decided to develop a simple drop weight test on site that would permit video taping of panels tested individually. As sufficient project funds were available to build the test jig and conduct the drop tests, a design, similar to what is shown in Figure 24 was developed.

For practical purposes, a single 10 foot length of PVC tube was used to house the impactor. A maximum drop weight height of 9 feet is possible. For early evaluation of marine sandwich panels, Rich O'Meara reports that a shipyard used a 50 pound weight dropped from a height of 10 feet. Seemann Composites and Lehigh University use a two-story drop height and weights up to 500 pounds to fail large test panels aligned 30° to the horizontal. The weight of our impactor is 6.25 pounds. With successive hits at 8 feet, the composite panel showed minor damage. Test protocol was thus established as 10 blows at 8 feet. (50 foot-lbs) This impact energy is an order of magnitude less than that shown to totally destroy marine composite laminates.

Results of the Impact Testing are shown in Table 4.

Table 4 Summary of Impact Tests

Supplier	Product		Date Tested	Complete Failure	Failure Description
Esterline Kirkhill-TA	FASTBLOCK® 810	Composite	3/7/2005	No	Minor amount of material broke off
Isolatek International	Cafco Blaze Shield II	Aluminum	3/10/2005	Yes	Majority of material fell off after first hit
		Composite	3/10/2005	Yes	50% of material fell off after first hit
Span-World Distribution	Fyre Sheild™	Aluminum	3/7/2005	Yes	Broke into 2 clean pieces after first hit
		Composite	3/7/2005	No	Minor amount of material broke off
Superior Products, North America	SP2001F Fire Retardant	Aluminum	not tested	failed fatigue	
		Composite	3/10/2005	Yes	Started failure after first hit
		Aluminum	7/20/2005	No	Minor surface cracks noted
		Composite	7/20/2005	No	Minor surface cracks noted
Carboline	Intumastic 285	Aluminum	3/10/2005	No	Minor amount of material broke off
		Composite		No	Very minor amount of material broke off
Cytec Engineered Materials	DAPCO 2032	Composite	3/10/2005	No	
Akro Fireguard Products	Akrotherm	Composite	3/7/2005	Yes	Through-thickness crack after 4th hit; piece dropped off after 7th hit; 80% material off after 10th hit.

Fastblock 810 from Esterline Kirkhill TA, Intumastic 285 from Carboline and DAPCO 2032 from Cytec were the only products to endure the impact testing without complete failure. An aluminum sample of the DAPCO product was not prepared for testing because of the shortage of test material. The "rubber like" appearance of the DAPCO product would suggest a coating that would not easily be affected by vibration or impact of the structure. The Fastblock and especially Intumastic products had more coating mass. However coating tenacity was proven in this test program.

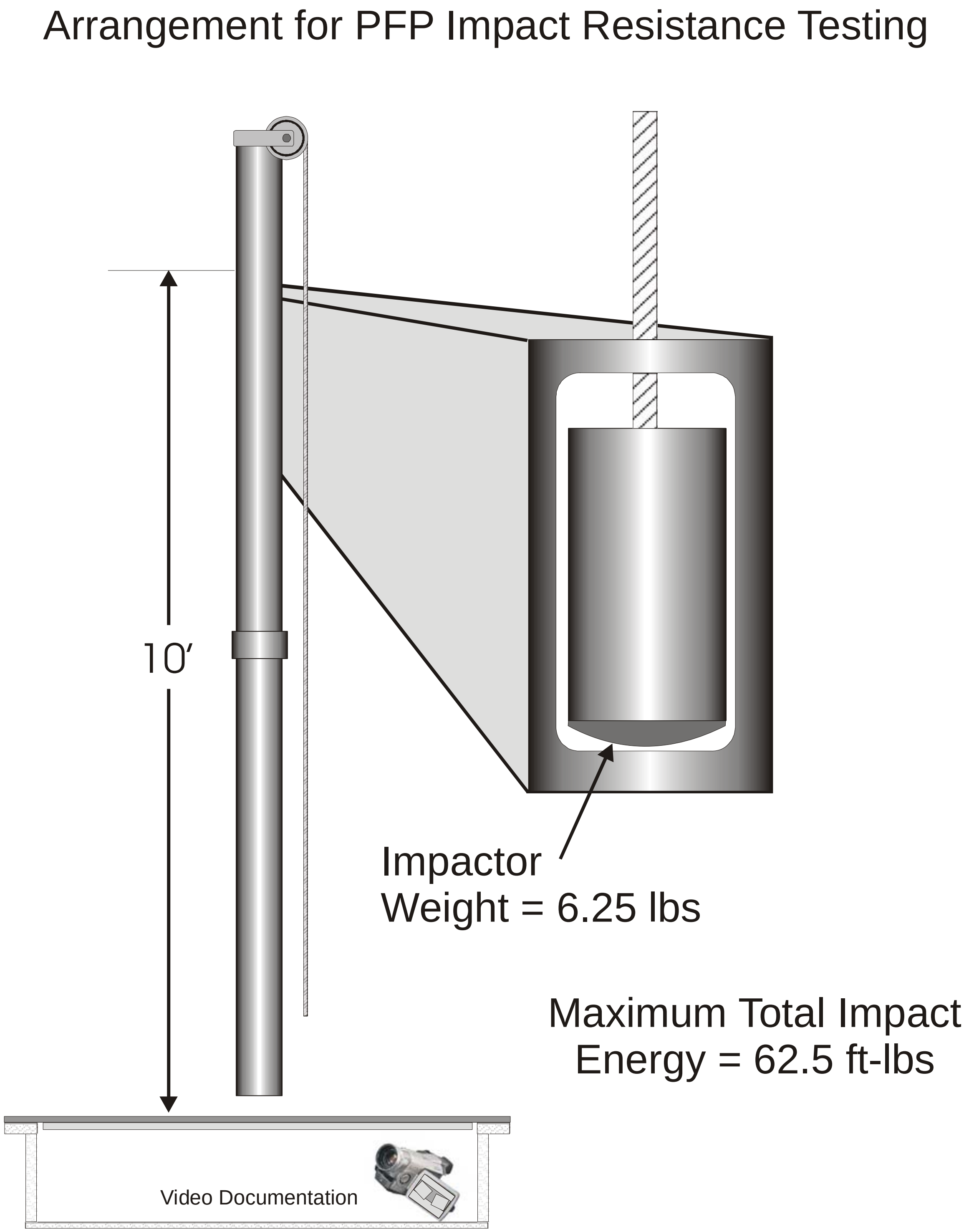


Figure 24 Design for Drop weight Impact tester based on simplified Dynatup 8250

Figure 25 Pictures of Shock Test Arrangement (clockwise from top left) 10' Long PVC Tube Mounted to Elevated Deck; Impactor Relationship to Test Panel; Impactor Shown Fully Extended from Tube; Weight Raised 8 feet for Ten Impact Hits; Impact Effect on Composite Test Panel; and View of Impactor Assembly (6.25 pounds)

7 Discussion of Test Reporting Methodology

As evidenced in this document, reporting on coating performance has been qualitative to date. Only one coating has catastrophically failed the fatigue test at the substrate interface. However, some surface cracking and loss of material has occurred. With eleven panels tested, it is a good juncture to examine what we're learning from the test. Although interpretation of test results will necessarily be a qualitative assessment, it is possible to isolate parameters being evaluated and assign a performance value for that parameter. Performance parameters proposed for consideration are:

- Adhesion of coating to substrate
- Loss of material
- Surface cracking
- Durability of coating during handling

The above factors are stated in order of greater to lesser importance and as such should be weighted accordingly. The pictures in this document show a wide variety of coating composition.

Video documentation is provided for both the fatigue and impact testing. Dislodged material has also been retained, although these amounts are very minor unless there was catastrophic failure.

8 Retest of SP2001F from Superior Products

The complete coating failure experienced by the aluminum panel coated with SP2001F prompted the manufacturer to request a retest with a modified coating formulation. The processing of the binder system was slightly modified to improve adhesion characteristics. As this is considered a product under development, Eric Greene Associates agreed to retest coated panels to see if the performance differed significantly. Panels were sent to Superior for coating May 23, 2005. Coated panels were received July 7^{th}. Superior indicated that they have performed testing at thicknesses from 250 up to 400 mils for the E119 in the labs for the Navy and passed. Therefore, panels were coated to 250 mils this time, versus 400 mils used last time.

Because this was the only panel to fail the initial test, only the aluminum panel was fatigue tested to 10^5 cycles. The coating showed no signs of degradation after the test. Both panels were impact testing using 10 hits from an 8-foot drop height. As shown in Figure 26, only minor surface cracks appeared. No separation of the coating from the panels was observed. Based on the improved performance of SP2001F made with slightly modified processing parameters and applied at 250 mils, this product appears to be a viable marine coating when the revised application parameters are used.

Superior Products SP2001F Retest

Figure 26 Pictures of SP2001F Retest (clockwise from top left) Panels Received July 7, 2005; Detail of Coating Edge Finish; Coating Thickness About Half of Original Panels; Coating Appearance After Impact Test; Aluminum and Composite Panels After Testing; and Detail of Tested Panel Showing Minor Surface Crack

9 Conclusions and Recommendations

The durability of spray-applied passive fire protection continues to be an issue with marine construction. This is especially true as commercial and naval trends are towards high performance craft that require lightweight construction. A low-cost evaluation protocol is required to determine the suitability of existing and emerging coating systems as testing to military shock and vibration endurance standards is cost prohibitive and not designed to evaluate coatings.

More of the evaluated coatings failed to 50 foot-pound impact test then the 10^5-cycle fatigue test. Both phenomena are important to test for so the sequence of fatigue followed by impact testing is recommended. The test panel geometry (60 x 6 x ¼ inch for aluminum) worked well during the tests as large deflections could easily be produced. The only disadvantage with the narrow panels is coating edge effects, although failures did not seem to originate at the edge.

Appendix A contains comparative data on all the candidate coatings considered for this project. Appendix B has web site information for tested and other products. Most products have some fire test data associated with the coatings. Full-scale fire testing is recommended for the most promising coatings, namely Fastblock 810 from Esterline Kirkhill TA, Intumastic 285 from Carboline, SP2001F from Superior Products and DAPCO 2032 from Cytec Materials.

Appendix A Summary of Candidate Spray-Applied Passive Fire Protection

Company	Product	Description	Pimary Use	Where Coating Applied	Date Tested Aluminum	Date Tested Composite	Applications
American Sprayed Fibers, Inc.	Dendamix Marine	blended fiber products	A60 & thermal insulation for steel	Company declined to participate in project			Decks & bulkheads
Esterline Kirkhill-TA	FASTBLOCK® 810	Water-based, Sprayable Fire and Thermal Barrier Coatings	thermal barriers for extreme heat flux environments such as sensitive materials in weapons systems, containers, aircraft, and ships	By hand at SC		8/27/2004	Spray apply with airless sprayer
Isolatek International	Cafco Blaze Shield II	Spray - Applied Fire Resistive Material (SFRM) compositely reinforced portland cement	SFRM is designed to endure construction abuse as well as exposure to extreme weather conditions (UL investigated for exterior use).	at Isolatek	9/20/2004	9/22/2004	A-60 bulkhead rating available
Mascoat Products	Delta T Marine	composite (one-part) coating comprised of air filled ceramic and silica beads held in suspension by an acrylic binder	thermal insulation and antisweat capablities, 500 °F Max operating temp; 350 °F working temp	Product deternmined to be primarily "anti sweat" product and not tested. PFP product under development.			Weather exposed surfaces; Stiffeners; Overheads; Interiors: Pipes; Walls
NoFire Technologies, Inc	A-18 NV Fire Protective Intumescent Coating	NoFire® is a one part non-flammable water based intumescent coating similar in appearance to ordinary latex base paint. Upon exposure to flame or heat, it immediately foams and swells (intumesces) providing an effective insulation and heat shield to protect the subsurface.	NoFire Technologies, Inc. is a manufacturer of high performance fire retardant products and systems that offer superior protection against heat and fire.	After discussions with Dr. Godfried, product eliminated from test matrix			Applications include the construction, telecommunications, nuclear power plants, utility, automotive, marine, military, and housing industries.
Span-World Distribution	Temp-Coat™ 101 Fyre Sheild™	Liquid Ceramic Thermal Barrier Insulation Coupling Engineered Hollow Ceramics in a Micro-Porous Latex Emulsion	Insulation and protection. Applies in paste form or air-assist atomizer type device such as Quik-Gun®	at EGA or SC	7/7/2004	7/14/2004	Can be applied to fiberglass grids in area of heavy traffic or where subject to abuse or harsh conditions.
Superior Products, North America	SP2001F Fire Retardant	formulated from resins and ceramics to withstand severe climate changes and severe heat peaks with no adhesion loss	High-temperature fire retardant	Arranged through George Steel of NNS to have panels coated at Superior	12/8/2004	12/10/2004	SPF 2001 F can withstand severe climate changes and severe heat peaks with no adhesion loss. It's heat-resistant to 5000 degrees Fahrenheit and remains intact above 2000 degrees Fahrenheit, forming a pliable film that reacts to flame by glazing over to form a protective shield against heat, fire, smoke, gases. It's naturally resistant to corrosion, mildew, fungus.
Albi Mfg., division of StanChem, Inc.	Clad TF & Clad 800	Water and solvent-based intumescents good for E119 & UL 1709, respectively.	Interior & exterior	product not tested			Long-lasting fireproofing with high abrasion & impact resistance
W.R. Grace	FlameSafe® FS 3000	FlameSafe® FS 3000 is a water based, elastomeric coating that is designed for spray applications onto construction joints and curtain wall joint assemblies. FS 3000 cures to form a flexible membrane seal. The coating has been tested to dynamic conditions in accordance with ASTM E1399 relating to seismic, wind sway and thermal expansion/contraction environments.	Up to 4 hour fire rating (E 119)	product not tested			Architectural joint systems
Carboline	Intumastic 285	Single package, water-based, flexible mastic fire protective coating for cables and cable trays	Cables and cable trays	Applied by Carboline in St Louis, MO	2/25/2005	3/9/2005	Interior and exterior
Nelson	Firestop Joint Compound	Nelson Firestop Joint Coating (FSC3™) is a water based acrylic latex, elastomeric, fire protective coating for use on construction joints. It is designed for labor saving spray applications onto construction joints and perimeter joint systems.	FSC3™ is specifically for applications in construction joints, wall to wall, floor to wall, floor to floor, head of wall and perimeter joint curtain wall applications where thermal expansion and contraction of joints, wind sway or seismic conditions may occur.	vendor indicated product not suitable for large area application			FSC3™ coating is spray or brush applied over a min. 4" depth of mineral wool insulation packed within the joint width. Actual installation may vary according to the type of joint to be protected. Joint surfaces should be clean and free of dust, dirt, oil
PPG Aerospace - PRC Desoto	P/S 700	P/S 700 is a two-part, synthetic rubber compound. The uncured material is a low sag paste suitable for application by extrusion gun or spatula. It cures at room temperature to form a resilient sealant to common aircraft substrates.	P/S 700 is a high temperature primerless firewall sealant. It has a service temperature range from sealant. It has a service temperature range from -65°F (-54°C) to 400°F (204°C), and will withstand flash temperatures of 2000°F (1093°C).	distributer convinced product too costly for marine application			The material is designed for sealing firewall structures against the passage of air or vapor.
Nu-Chem, Inc.	Thermo-Lag 3000	Thermo-Lag 3000 is a two component, subliming, epoxy based, fire resistive coating which is spray applied directly to primed steel surfaces. It provides a hard, durable, aesthetically pleasing finish that allows the shape of the steel to be maintained while providing the specified level of fire resistance.	Thermo-Lag 3000 is applied to structural columns, beams, vessel skirts, bulkheads, underdecks and electrical raceways to provide hydrocarbon and cellulosic fire rating for 1 through 4 hour protection. Thermo-Lag 3000 can be utilized for exterior and interior environments.	unable to coordinate panel coating with manufacturer			
Cytec Engineered Materials	DAPCO 2032	DAPCO 2032 is a cyrogenic sealant/thermal insulation coating commonly used in areas that require a coating for very high temperature and chemical resistance. DAPCO 2032 can also be used to seal the backside of porous tools used for vacuum retention.	Used to seal aircraft bulkheads to ensure gas tightness and fire resistance	at SC		9/14/2004	The material is designed for sealing firewall structures against the passage of air or vapor.
Akro Fireguard Products	Akrotherm	Syntactic foam systems designed to provide a combination of structure, insulation and fire resistance. Akrotherm materials form the basis of sandwich panels and complex 3-dimensional sandwich structures. Components range from fire resistant enclosures to interior paneling and components		at Akro		8/2/2004	

Company	Substrates	Viscosity	Density	Non-Volitales	Wet Thickness	Dry Thickness	Weight			Ultimate Elongation	Bond Strength	Hardness
		cps	$lbs.ft^3$	% Solid	inches	inches	lbs/ft^2	ASTM E119	UL 1709	%	ASTM E736	ASTM D2240
American Sprayed Fibers, Inc.	Steel, aluminum, composite		10	100%	0.5	0.5	0.42	A-60 ratings have been obtained with 40 mm (1.57 inches) over steel	150 minutes with 2 inches of 22 lb/ft^3 = 3.7 lbs/ft^2		> 357 lbs/ft^2	
Esterline Kirkhill-TA	graphite/epoxy, aluminum, and other sensitive materials		20	100%	0.5	0.5	0.83					50, Shore A
Isolatek International	steel		15	100%		0	0.00					
Mascoat Products	All metal surfaces: Wood & Fibergalss	3550 @ 12 rpm	44.28	61%	0.033	0.02013	0.07			85%		
NoFire Technologies, Inc	NoFire can be applied to many types of surfaces providing an attractive flat finish. NoFire can be readily topcoated by many types of latex base paints, urethanes or acrylics for attractive weather resistant finishes.		55	100%	0.015	0.015	0.07					
Span-World Distribution CHI Technologies	Temp range up to 500°F @ 260 mils with mesh, 20 mils each pass	3565	43.8	100%	0.18	0.18	0.66					
Superior Products International	metal, concrete, stucco, plasterboard, wood, fiberglass, plastics and composites			100%		0	0.00	passed 3 hour rating; 1 hr @ .25" dry; 2 hrs @ .40" dry	passed 2 hour rating			
Albi Mfg., division of StanChem, Inc.	Structural steel, concrete and other construction materials		68	100%	0.2	0.2	1.13	UL Listed for 1 - 3 hours			> 375 psi	65 - 70 Shore D
W.R. Grace	Can be applied over 4 pcf mineral wool. Excellent adhesion and thickness buildup.	50,000 (avg) 24 +/-0,1°C @ 10 rpm	77.79	50%	125	62	0.80 (wet) 0.43 (est., dry)					
Carboline	Primer generally not required for most substrates.		79.34	53%	0.7	0.371	0.717 @ 100 mils					30 - 40 Shore D
Nelson	FSC3™ is used in construction joints, wall to wall, floor to wall, floor to floor, head of wall and perimeter joint curtain wall applications where thermal expansion and contraction of joints, wind sway or seismic conditions may occur. Tested to ASTM E-84.		78.54	54%	0.125	0.0675	0.44					
PPG Aerospace - PRC Desoto	Common aircraft substrates.	1200 @ 2 RPM	33	60%	0.5	0.3	0.83					75 Durameter A
Nu-Chem, Inc.												
Cytec Engineered Materials	Common aircraft substrates.		61.3	33%								
Akro Fireguard Products												

Company	Peel Strength ASTM C794/D903	Shear Strength ASTM D1002	Fire Resistance FAA AC 20-135	Flame Spread UL 732/ASTM E84	Smoke Developed UL 732/ASTM E84	Cost $/gallon	Contact	Title	Phone	Cell Phone
American Sprayed Fibers, Inc.				Flame Spread = 0	Smoke Developed = 0		Van Howard	VP of Marine Operations	228-769-5565	228-219-1496
Esterline Kirkhill-TA	Aluminum: 25 N/cm (15 ppi) original and 31 N/cm (18 ppi) after 72 hours at 204°C (400°F): Graphite/Epoxy: 55 N/cm (32 ppi) original and 65 N/cm (37 ppi) after 72 hours at 204°C (400°F)	Aluminum: 586 kPa (85 psi) original and 607 kPa (88 psi) after 168 hours at 204°C (400°F)	No flame penetration or backside ignition of a slab when impinged upon by an 1100°C, 116kW/m^2 (2000°F, 10 BTU/ft^2-s) kerosene flame for 15 minutes.			$350 - $500	Hemant Gupta	R & D Director	661-775-1190	661-775-1155
Isolatek International							Bijou Ganguly Phil Mancuso	Manager Technical Analyst	800-631-9600 ext 214/219	
Mascoat Products	250 - 300 psi by ASTM D-4541			Flame Spread = 5 Smoke Developed = 5 passes IMO LIFT Test					713-465-0304	
NoFire Technologies, Inc							Sam Gottfried	President	800-603-4730	
Span-World Distribution CHI Technologies				Flame Spread = 5	Smoke Developed = 5 Toxicity = 0	$42	Daniel Dantin Joseph Mooney		800-950-9958 410-326-8149	
Superior Products International				Class A rating	Class A rating		Joe Pritchet Greg Smith		913-962-4848	
Albi Mfg., division of StanChem, Inc.		> 371 Lap Shear	ULI 1709 Rated for Up to 3 Hours Fire Protection	Flame Spread = 15	Smoke Developed = 40		Casey West		860-828-0571	
W.R. Grace				Flame Spread = 0	Smoke Developed = 0		John Goga		800-354-5414, ext 5674	
Carboline				Flame Spread = 19	Smoke Developed = 44		Tim Riley	Regional Fireproofing Manager	585-394-0251	585-415-8587
Nelson			Approved as UL Fill, Void or Cavity Material (XHHW) and tested at Omega PointLabs as Joint Sealant (cat 07920)	Flame Spread = 0	Smoke Developed = 0		Dan Thomasson	Marine Product Manager	918-627-5530	
PPG Aerospace - PRC Desoto	12 - 15 lbs/lineal inch peel strength		No flame penetration after 15 minutes at 2000°F.			$350	Carol Bergdahl	Bergdahl Associates (distributer)	775-323-7542	
Nu-Chem, Inc.			Lloyds Register of Shipping (LRS) H-0/H-60/H-120 Bulkhead H-0/H-60/H-120 Deck; Thermo-Lag 3000-3002 Jet Fire Certificate; American Bureau of Shipping (ABS) Manufacturing Assessment Design Assessment; Det Norske Veritas (DNV) H-0/H-60/H-120 Bulkhead H-0/H-60/H-120 Deck Structural Fire Protection I Sections - 400°C - 538°C - All RHS - 400°C - 538°C - All; Thermo-Lag 3000 / Thermo-Lag 3002 Statement Underwriters Laboratories, Inc. (UL) UL 1709 - Environmental Summary				Bill Langer	Engineering Sales Manager	800-788-6994	
Cytec Engineered Materials						$400 - $500	Tony Dembrowsky	D Aircraft Products	714-632-8444	
Akro Fireguard Products							Tim Johnson	Development Chemist	913-888-7172	

Company	E-mail	Address	City	State	Zip			
American Sprayed Fibers, Inc.	vanasfi@aol.com	2503 Criswell	Pascagoula	MS	39567			
Esterline Kirkhill-TA	Hgupta@kirkhill-ta.com	28065 Franklin Parkway	Valencia	CA	91355-4117			
Isolatek International	bGanguly@isolatek.com Pmancuso@isolatek.com							
Mascoat Products		10890 Alcott, Unit 102	Houston	TX	77043	   		
NoFire Technologies, Inc	nofirenj@aol.com	21 Industrial Avenue	Upper Saddle River	NJ	07458			
Span-World Distribution CHI Technologies	swspl@aol.com jmooney@chitechnologiesinc.com	P.O. Box 725 P.O. Box 428	LaPlace Solomons	LA MD	70069 20688			
Superior Products International	supertherm@aol.com		Shawnee	KS				
Albi Mfg., division of StanChem, Inc.		401 Berlin St.	East Berlin	CT	06023			
W.R. Grace	John.M.Goga@grace.com	62 Whittemore Ave.	Cambridge	MA	2140		FlameSafe® FS 900+ Series Sealant, Non Intumescent, Elastomeric 	FlameSafe® FS 900+ Sealants are cost-effective, water-based, endothermic sealants designed for use in applications that do not require an intumescent sealant. Available in two consistencies; caulkable/trowelable (CG), and self-leveling (SL), the FS 900+ hardens and cures to form a flexible shield against the spread of fire and smoke.
Carboline	Tim_Riley@carboline.com	350 Henley Industrial Court	St. Louis	MO	63144-1599			
Nelson		EGS Electrical Group, P.O. Box 726	Tulsa	OK	74101			
PPG Aerospace - PRC Desoto		2990 Sutro Street	Reno	NV	89512-1616			
Nu-Chem, Inc.		2200 Cassens Drive	Fenton	MO	63026			
Cytec Engineered Materials		1191 N. Hawk Circle	Anaheim	CA	92807			
Akro Fireguard Products		9001 Rosehill Road	Lenexa	KS	66215			

Appendix B - Web Site Addresses for Candidate Products

AD Fire Protection Systems: http://www.adfire.com/index.html

AkroFireguard: http://akrofire.com/ProdComposite-Prop.asp

American Sprayed Fibers, Inc.: http://www.asfiusa.com/index.php

Aspen Aerogel: http://akrofire.com/ProdComposite-Prop.asp

Carboline:
http://www.carboline.com/website/carbopdf.nsf/webview?OpenView&Start=1&Count=500&Expand=11#11

Delta T: http://www.deltacoat.com/

Fastblock 810: http://kirkhill.com/product_catalog/fire_barriers.stm

Isolatek International: http://www.isolatek.com/IsolatekFrontPage.asp

Nelson Firestop: http://www.nelsonfirestop.com/

NoFire Technologies: http://www.nofiretechnologies.com/index.htm

Nu-Chem, Inc. http://nu-chemusa.com/

Pitt Char, PPG Industries: http://www.ppg.com/ppgaf/pittchar/cr.htm

SpreFix: http://www.sprefix.com/

SP2001F, Superior Products: http://www.superiorproductsusa.com/sp2001f.html

Starfire Systems: http://www.starfiresystems.com/product_applications/coatings.cfm

Temp-Coat Brand Products, LLC: http://www.temp-coat.com/marine.htm

Zero International: http://www.zerointernational.com/benefits/firestopping.asp

Project Technical Committee Members

The following persons were members of the committee that represented the Ship Structure Committee to the Contractor as resident subject matter experts. As such they performed technical review of the initial proposals to select the contractor, advised the contractor in cognizant matters pertaining to the contract of which the agencies were aware, performed technical review of the work in progress and edited the final report.

Chairman: David Heller, US Maritime Administration, Naval Architect

Members:
Jeff Goldring, US Navy NAVSEA 05M3, Composites Engineer
LT CDR Scott Kelly, U.S. Coast Guard MSC, Hull Division, Major Vessel Branch
Lou Nash, U.S. Coast Guard, Fire Protection Engineer
Gary Smith, Alaska Dept of Transportation, Chief Naval Architect
Dr. Harold Brashears, NGSS – Ingalls, Scientist
Rupert Chandler, US Joiner LLC, Fire Protection Engineer
Peter Duclos, Gladding-Hearn, President
Gavin Higgins, Derecktor Shipbuilding, Project Manager
Tim Kings, Yacht Project Manager
Derek Novak, American Bureau of Shipping, Senior Engineer
Dr. George Steele, NGSS - Newport News, Research Engineer

Executive Director Ship Structure Committee: LT Eric Cooper, U.S. Coast Guard

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American Society of Naval Engineers	Captain Dennis K. Kruse (USN Ret.)
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Bath Iron Works	Mr. Steve Tarpy
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Edison Welding Institute	Mr. Dave Edmonds
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Int'l Ship and Offshore Structure Congress	Dr. Alaa Mansour
INTERTANKO	Mr. Dragos Rauta
Massachusetts Institute of Technology	Mr. Dave Burke / Captain Chip McCord
Memorial University of Newfoundland	Dr. M. R. Haddara
National Cargo Bureau	Captain Jim McNamara
Office of Naval Research	Dr. Yapa Rajapaksie
Oil Companies International Maritime Forum	Mr. Phillip Murphy
Tanker Structure Cooperative Forum	Mr. Rong Huang
Technical University of Nova Scotia	Dr. C. Hsiung
United States Coast Guard Academy	Commander Kurt Colella
United States Merchant Marine Academy	Dr. C. B. Kim
United States Naval Academy	Dr. Ramswar Bhattacharyya
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University of Maryland	Dr. Bilal Ayyub
University of Michigan	Dr. Michael Bernitsas
University of Waterloo	Dr. J. Roorda
Virginia Polytechnic and State Institute	Dr. Alan Brown
Webb Institute	Dr. Kirsi Tikka
Welding Research Council	Dr. Martin Prager
Worchester Polytechnic Institute	Dr. Nick Dembsey
World Maritime Consulting, INC	VADM Gene Henn, USCG Ret.
Samsung Heavy Industries, Inc.	Dr. Satish Kumar

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SSC 391 and below are available on the SSC CD-ROM Library. Visit the National Technical Information Service (NTIS) Web Site for ordering information at URL:
http://www.ntis.gov/fcpc/cpn7833.htm

SSC Report Number	Report Bibliography
SSC 441	Fire Degradation, Failure Prediction and Qualification Methods for Fiber Composites R.J. Asaro, M. Dao, 2005
SSC 440	Deterioration of Structural Integrity Due to Chemical Treatment of Ballast Water S. Tiku, 2005
SSC 439	Comparative Structural Requirements For High Speed Crafts K. Stone, 2005
SSC 438	Structural Optimization for Conversion of Aluminum Car Ferry to Support Military Vehicle Payload, R.Kramer, 2005
SSC 437	Modeling Longitudinal Damage in Ship Collisions A.J. Brown, JAW Sajdak 2005
SSC 436	Effect of Fabrication Tolerances on Fatigue Life of Welded Joints A. Kendrick, B. Ayyub, I. Assakkaf 2005
SSC 435	Predicting Stable Fatigue Crack Propagation in Stiffened Panels R.J. Dexter, H.N. Mahmoud 2004
SSC 434	Predicting Motion and Structural Loads in Stranded Ships Phase 1 A.J. Brown, M. Simbulan, J. McQuillan, M. Gutierrez 2004
SSC 433	Interactive Buckling Testing of Stiffened Steel Plate Panels Q. Chen, R.S. Hanson, G.Y. Grondin 2004
SSC 432	Adaptation of Commercial Structural Criteria to Military Needs R.Vara, C.M. Potter, R.A. Sielski, J.P. Sikora, L.R. Hill, J.C. Adamchak, D.P. Kihl, J. Hebert, R.I. Basu, L. Ferreiro, J. Watts, P.D. Herrington 2003
SSC 431	Retention of Weld Metal Properties and Prevention of Hydrogen Cracking R.J. Wong 2003
SSC 430	Fracture Toughness of a Ship Structure A.Dinovitzer, N. Pussegoda, 2003

CONVERSION FACTORS