Fire Protection for Marine Composite Construction

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Introduction

Composite materials are being used for boats and ships of ever-increasing size. Yachts over 50 meters and the 70 meter Swedish Visby class corvette are examples of how design and fabrication methods have improved. However, unlike steel and aluminum, composite materials are combustible during shipboard fires. Regulatory agencies have put limitations on the size of vessels that can be built with composite materials primarily because of concern over fire safety. Resin systems have the greatest influence over how a laminate will perform in a fire.

The recreational, commercial and naval maritime industries all have different regulations regarding the use of composite materials for construction. Regulations vary with fire threat; size and complexity of the vessel; ship operational parameters; risk to passengers and crew; and liability issues. As regulatory agencies move towards "performance-based" standards, fire test methods are often cited in lieu of specifying certain allowable materials. Small-scale test methods are the least expensive and afford the greatest level of scientific sampling. Large-scale tests more accurately simulate actual fires and synergistic effects of material systems, but are usually cost prohibitive.

Recent research and development projects sponsored by the U.S. Navy and the Department of Transportation under the MARITECH program have provided insight into how composite material systems perform in fires and what fire protection systems seem to be the most promising. When fire threats are small, additives can be mixed with conventional resin systems to produce "fire retardant" blends. Insulation is used to protect composites when a severe fire threat is perceived.

Fire Parameters

In order to understand all the fire tests, regulations, and fire protection systems, it is helpful to categorize events associated with fires under the following broad terms:

- Time-to-Ignition and Flame Spread;
- Structural Integrity; and
- Smoke Production.

In the early stages of a fire, the key factor that influences the fire safety of a composite laminate is the time it takes to ignite. Fire scientists like to relate this to the size of the fire that the specimen is exposed to. Once a surface has ignited, safety becomes a function of how fast the flame will spread. Researchers at the National Institute of Standards and Technology (NIST) Building and Fire Research division conducted pioneering research into the ignitability and flame spread of composite laminates in the 1980s.

Assuming that a fire can be contained to a single compartment, the next concern is structural integrity. Because composites are such good insulators, fires often don't spread to adjacent compartments. When a British minehunter suffered an engine room fire that lasted several hours, fuel that was in a composite day tank failed to ignite. However, containment of fires can raise the compartment temperatures to the point where structural collapse of bulkheads and decks is a concern. Unlike ignitability and flame spread, the selection of sandwich core material can significantly influence structural integrity at elevated temperatures.

Smoke during a fire can be the biggest problem on a ship, much as it is in building fires. Most fire fatalities are from carbon monoxide poisoning. Visibility during fires is also an issue, both for people trying to evacuate and firefighters trying to extinguish the blaze. Some composites will burn "blacker" than others, although the source of the fire and other furnishings produce an overwhelming amount of smoke on their own. There has been some concern that fire retardant additives may have toxic properties during fires, but carbon monoxide exposure seems to override all other threats.

Fire Threats

Now that we're scared to death and will never barbecue again over our transoms, lets take a look at what are the real fire threats and their significance. A center-console runabout obviously doesn't have to withstand an Exocet missle hit. For recreational boats, the biggest threat is from the engine room or systems associated with the propulsion plant.

The second highest risk comes from the galley. Cooking appliances typically have their own safety systems, such as metal shielding and remote cut-off switches. What often can't be accounted for is human error on the part of crew or passengers. Some commercial gaming vessels have small trash can fires on a daily basis that go unreported.

For naval vessels, the fire threat is much more significant, as are mitigation and protection systems. Although a surface combatant is exposed to more fire threats than a commercial vessel of the same size, all of the crew on a warship are potential fire fighters. On the other hand, passengers on commercial ships must be evacuated during serious fires. Table 1 is an overview of non-combat naval fire threats.

Table 1 Non-Combat Fire Source Data for Naval Combatants

FIRE SOURCE	Surface Ships[1]		Submarines[2]	
	1983 - 1987		1980 - 1985	
	Number	Percent	Number	Percent
Electrical	285	39%	100	61%
Open Flame/Welding	141	19%	23	14%
Flammable Liquid/Gas	0	0%	13	8%
Radiant Heat	102	14%	8	5%
Matches/Smoking	40	5%	1	1%
Explosion	7	1%	1	1%
Other	89	12%	0	0%
Unknown	68	9%	18	11%
TOTAL:	732	100%	164	100%
[1]Navy Safety Center Database, Report 5102.2				
[2]NAVSEA Contract N00024-25-C-2128, "Fire Protection Study," Newport News Shipbuilding				

From the non-combat data presented in Table 1, it should be noted that 90% of the reported fires were contained to the general area in which they were started. 75% of the fires were extinguished in under 30 minutes. Most fires occurred in engineering spaces.

Fires onboard surface ships are usually classified by the severity of a time/temperature profile. Fire scientists like to quantify the size of a fire in terms of overall energy output (kW). The following is a rough relationship between fire type and size:

- Trash can fire: 10 - 50 kW
- Room fire: 50 - 100 kW
- Post-flashover fire: > 100 kW
- Small smoldering fire: 2 - 10 kW

A post-flashover fire would represent an event such as the incident on the ***USS STARK***, where Exocet missile fuel ignited in the space. This fire lasted over 24 hours and left even the steel structure twisted.

Regulations by Industry

The majority of boats built with composite materials are for recreational use. The U.S. Coast Guard and the American Boat and Yacht Council (ABYC) have regulations that cover ventilation of boats with gasoline engines; galley stoves; and fire fighting equipment. Structural fire protection is not addressed, as these vessels are relatively small. Fires should be readily detected and extinguished or evacuation can be accomplished rather easily.

Larger “megayachts” may have more numerous cabins and possibly may be offered for charter with paying passengers. Classification societies, such as the American Bureau of Shipping (United States), Lloyd’s Register of Shipping (United Kingdom) and Det Norske Veritas (Norway) as well as the Marine Safety Agency (United Kingdom) do address the issue of structural fire protection for yachts over 80 feet. Most of the classification societies are following the lead of the Marine Safety Agency (MSA) for yachts. Yachts over 50 meters in length generally must adhere to more stringent regulations similar to rules for passenger vessels. Some key areas of the MSA regulations for yachts *under* 50 meters include:

- Engine rooms should be gas tight; capable of preventing the passage of smoke and flame at the end of the 60 minute standard fire test and should be insulated where necessary with a suitable non combustible material;

- Ventilation to engine rooms and fuel supplies must be capable of remote cut-off;

- All underdeck compartments shall be provided with a satisfactory means of escape. In the case of accommodation areas, two means of escape from each public space or main compartment should be provided;

- Where the hull, bulkheads, and main deck are constructed of materials other than steel, evidence of precautions taken to reduce the passage of flame should be submitted for consideration to the Administration;

- The stowage of gasoline that may be used for auxiliary boats, cars, jet-skies, etc. is regulated as is fire protection methods and isolation from electrical equipment;

- A fire detection and fire alarm system should be fitted. The system should consist of smoke, heat or other suitable detectors fitted in the machinery space and galley as a minimum.

The U.S. Coast Guard is charged with inspecting commercial vessels to ensure that structure, stability, fire protection and equipment are safe. National standards are contained within the Code of Federal Regulations and international regulations are prescribed by the International Maritime Organization. Recent initiatives have focused on bringing domestic regulations in line with international standards.

The commercial designer is primarily concerned with the following general restrictions and excerpts from the Code of Federal Regulations (see appropriate Code of Federal Regulation for detail):

- Subchapter T - Small Passenger Vessels: Use of low flame spread (ASTM E 84 <100) resins;

- Subchapter K - Small Passenger Vessels Carrying More Than 150 passengers or with overnight accommodations for 50 - 150 people: must meet SOLAS requirement with hull structure of steel or aluminum conforming to ABS or Lloyd's;

- Subchapter I - Cargo Vessels: Use of incombustible materials - construction is to be of steel or other equivalent material; and

- Subchapter H - Passenger Vessels: SOLAS requires noncombustible structural materials and insulated with approved noncombustible materials so that the average back face temperature will not rise above designated values.

Some "K vessels" may be high speed ferries that can alternatively comply with the international High Speed Craft (HSC) Code, which does make provision for composite construction. The HSC Code classifies structure with the confusing terminology "fire-restricting" or "fire-resistive." "Fire-restricting" applies to all hull, superstructure, structural bulkheads, decks, deckhouses and pillars. Flame spread and combustibility are areas of concern for these structures. Areas of major and moderate fire hazard must have "fire-resistive" boundaries that comply with a SOLAS-type furnace test with loads. These decks and bulkheads must exhibit burn through resistance and maintain structural integrity during fires.

The U.S Navy currently does not have a definitive standard that covers the fire performance of composite materials on surface combatants. The general policy is to provide an equal level of safety to steel construction. Small boats and the specialized minehunter class are exceptions to this. Although some prototype composite structures have been deployed in the fleet, the use of composite structure or components in manned spaces has been limited. The military spends an inordinate amount of time maintaining and replacing corroded metallic structure and would love to increase the use of composites to reduce life-cycle costs and manning requirements. Additionally, increased stealth and mission requirements for the 21st century surface combatant will require the use of composite materials, especially for deckhouse structure.

MIL-STD 2031 for Submarines

The requirements of MIL-STD-2031 (SH), "Fire and Toxicity Test Methods and Qualification Procedure for Composite Material Systems used in Hull, Machinery, and Structural Applications inside Naval Submarines" are summarized here. The foreword of the standard states:

> *"The purpose of this standard is to establish the fire and toxicity test methods, requirements and the qualification procedure for composite material systems to allow their use in hull, machinery, and structural applications inside naval submarines. This standard is needed to evaluate composite material systems not previously used for these applications."*

Table 2 summarizes the requirements outlined in the new military standard. It should be noted that to date, no polymer-based systems have been shown to meet all the criteria of MIL-STD-2031 (SH).

Table 2. MIL STD 2031 Test Methods and Acceptance Criteria

Test	Description	Criteria	ASTM Test Method
Oxygen-Temperature Index (%)	The minimum concentration of oxygen in a flowing oxygen nitrogen mixture capable of supporting flaming combustion of a material.	Minimum % oxygen @ 25°C 35 % oxygen @ 75°C 30 % oxygen @ 300°C 21	ASTM D 2863 (modified)
Flame Spread Index	A number or classification indicating a comparative measure derived from observations made during the progress of the boundary of a zone of flame under defined test conditions.	Maximum 20	ASTM E 162
Ignitability (seconds)	The ease of ignition, as measured by the time to ignite in seconds, at a specified heat flux with a pilot flame.	*Minimum* 100 kW/m^2 Flux 60 75 kW/m^2 Flux 90 50 kW/m^2 Flux 150 25 kW/m^2 Flux 300	ASTM E 1354
Heat Release Rate (kW/m^2)	Heat produced by a material, expressed per unit of exposed area, per unit of time.	*Maximum* **100 kW/m^2 Flux** Peak 150 Average 300 secs 120 **75 kW/m^2 Flux** Peak 100 Average 300 secs 100 **50 kW/m^2 Flux** Peak 65 Average 300 secs 50 **25 kW/m^2 Flux** Peak 50 Average 300 secs 50	ASTM E 1354
Smoke Obscuration	Reduction of light transmission by smoke as measured by light attenuation.	*Maximum* D_s during 300 secs 100 D_{max} occurrence 240 secs	ASTM E 662
Combustion Gas Generation	Rate of production of combustion gases (e.g. CO, CO_2, HCl, HCn, NO_x, SO_x, halogen, acid gases and total hydrocarbons.	**25 kW/m^2 Flux** *Maximum* CO 200 ppm CO_2 4% (vol) HCn 30 ppm HCl 100 ppm	ASTM E 1354
Burn Through Fire Test	Test method to determine the time for a flame to burn through a composite material system under controlled fire exposure conditions.	No burn through in 30 minutes	DTRC Burn Through Fire Test
Quarter Scale Fire Test	Test method to determine the flashover potential of materials in a room when subjected to a fire exposure.	No flashover in 10 minutes	Navy Procedure
Large Scale Open Environment Test	Method to test materials at full size of their intended application under controlled fire exposure to determine fire tolerance and ease of extinguishment.	Pass	Navy Procedure
Large Scale Pressurable Fire Test	Method to test materials using an enclosed compartment in a simulated environment under a controlled fire exposure.	Pass	Navy Procedure
N-Gas Model Toxicity Screening	Test method to determine the potential toxic effects of combustion products (smoke and fire gases) using laboratory rats.	Pass	Navy Procedure

Test Methods

ASTM 1354, Cone Calorimeter

It is very difficult to simulate actual fires in a laboratory environment. Geometries of a compartment and air movement don't often conform to the standard conditions needed for a repeatable test. Fire scientists like to categorize the size of fires using guidelines such as the following:

- Small smoldering fire: 2 - 10 kW
- Trash can fire: 10 - 50 kW
- Room fire: 50 - 100 kW
- Post-flashover fire: > 100 kW

Small-scale tests are the most affordable types of tests where several samples can be evaluated and averaged. However, systems such as sandwich laminates may have significant edge effects that influence small-scale tests. The Cone Calorimeter is emerging as the internationally accepted small-scale fire test method. Sample size is 100 by 100 mm (4 by 4 inches) and heat exposure is provided by a cone shaped heater. Figure 1 shows the test apparatus. Samples are weighed and smoke analyzed during the test to indicate how much to sample contributes to the fire. Ignitability is also measured. This test has proven useful for screening resin systems, but is not useful for sandwich laminates or fire protection systems.

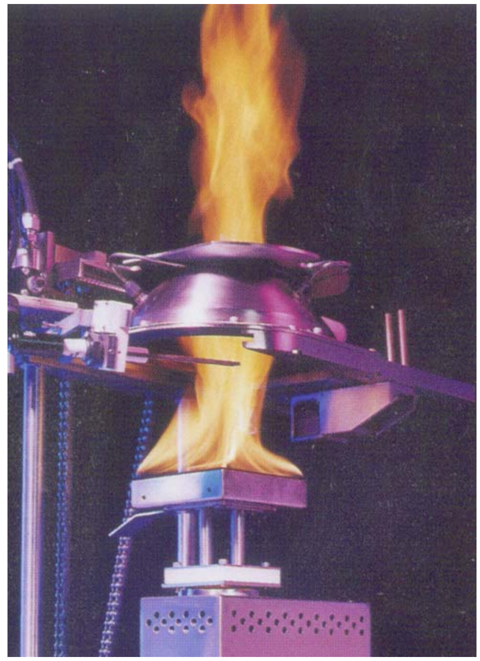

Figure 1 Cone Calorimeter

ASTM E 1317-90, Standard Test Method for Flammability of Marine Finishes

A description and background contained in the test standard provide insight as to why this test may be appropriate for intermediate-scale evaluation of shipboard composite material systems. The test method describes a procedure for measuring fire properties associated with flammable surfaces finishes used on noncombustible substrates aboard ships. The International Safety of Life at Sea (SOLAS) Convention requires the use of marine finishes of limited flame spread characteristics in commercial vessel construction.

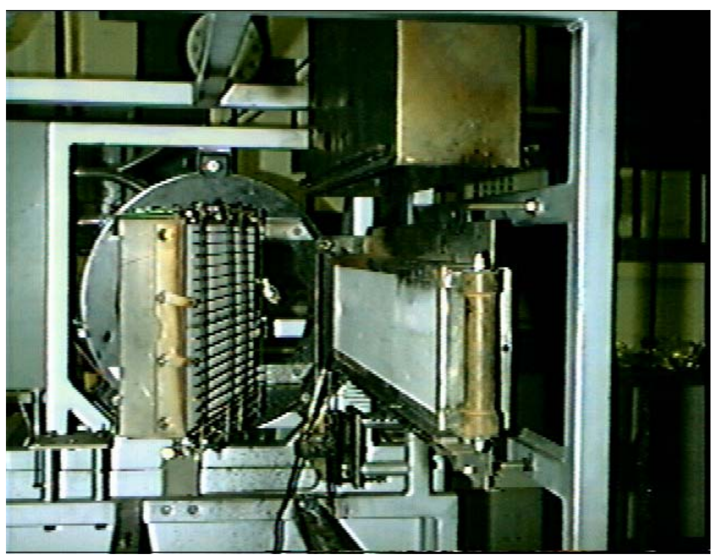

Figure 2 LIFT Test Arrangement

The increased understanding of the behavior of unwanted fires has made it clear that flame spread alone does not adequately characterize fire behavior. It is also important to have other information, including ease of ignition and measured heat release during a fire exposure. The International Maritime Organization (IMO) has adopted a test method, known as IMO Resolution A.564(14), which is essentially the same as the ASTM test method [4-38].

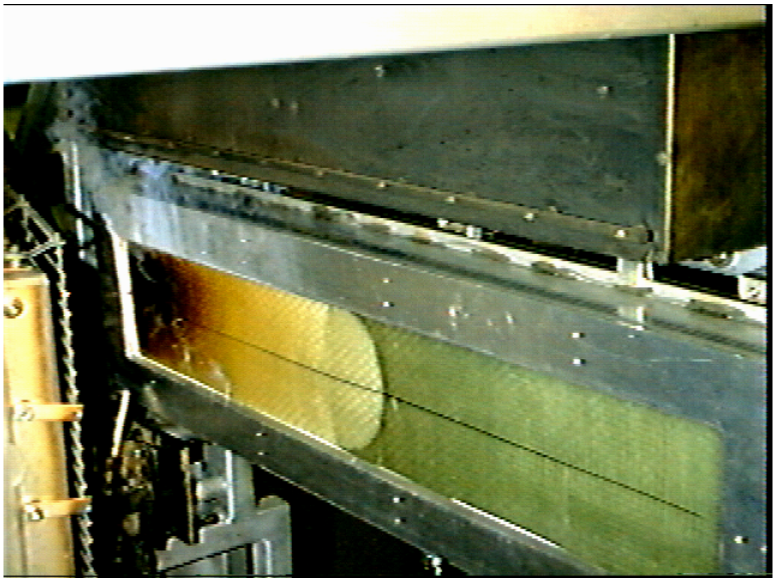

Figure 3 Flame front Measurement during LIFT Test

The test equipment used by this test method was initially developed for the IMO to meet the need for defining low flame spread requirements called for by the Safety of Life at Sea (SOLAS) Convention. The need was emphasized when the IMO decided that noncombustible bulkhead construction would be required for all passenger vessels. These bulkheads were usually faced with decorative veneers.

International Maritime Organization (IMO) Tests

IMO Resolution MSC 40(64) outlines the standard for qualifying marine materials for high speed craft as fire-restricting. This applies to all hull, superstructure, structural bulkheads, decks, deckhouses and pillars. Areas of major and moderate fire hazard must also comply with a SOLAS-type furnace test (MSC.45(65)) with loads, which is similar to ASTM E 119.

Figure 4. 300kW Burner for ISO 9705 Test

IMO Resolution MSC 40(64) on ISO 9705 Test

Tests should be performed according to the standard ISO 9705 Room/Corner Test. This standard gives alternatives for choice of ignition source and sampling mounting technique. For the purpose of testing products to be qualified as “fire restricting materials” under the IMO High-Speed Craft Code, the following should apply:

- Ignition source: Standard ignition source according to Annex A in ISO 9705, i.e. 100 kW heat output for 10 minutes and thereafter 300 kW heat output for another 10 min. Total testing time is 20 minutes; and

- Specimen mounting: Standard specimen mounting, i.e. the product is mounted both on walls and ceiling of the test room. The product should be tested complying to end use conditions.

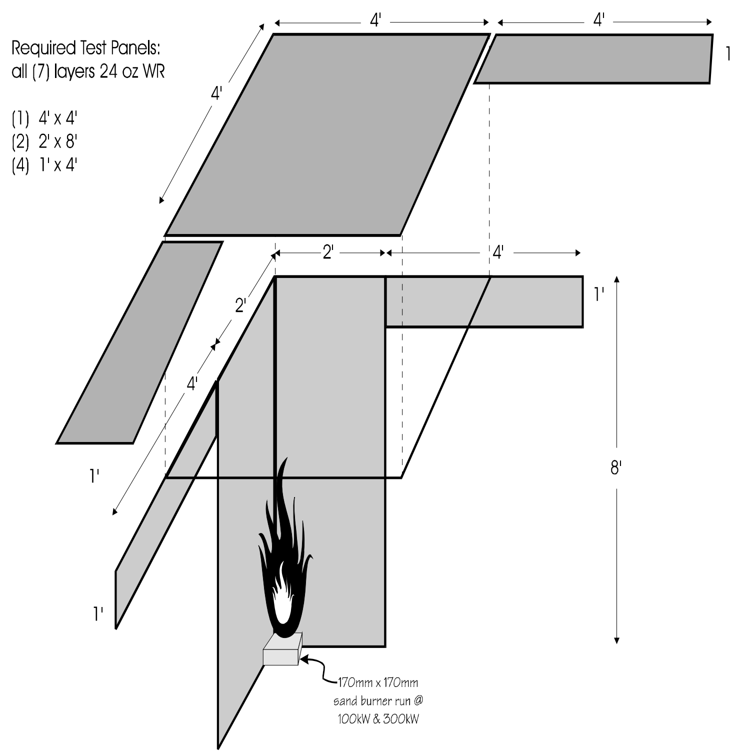

Figure 5. ISO 9705 Arrangement with Reduced Sample Size using Two 4 x 8 foot Sheets

3-Foot E 119 Test with Multiplane Load

In the U.S., the ASTM E 119 test is the generally accepted standard method for evaluating and rating the fire resistance of structural-type building fire barriers. The method involves furnace-fire exposure of a portion of a full-scale fire barrier specimen. The furnace-fire environment follows a monotonically-increasing, temperature-time history, which is specified in the test method document as the standard ASTM E 119 fire. The test method specifies explicit acceptance criteria that involve the measured response of the barrier test specimen at the time into the standard fire exposure, referred to as the fire resistance of the barrier design, that corresponds to the desired barrier rating. For example, a barrier design is said to have a three-hour fire-resistance rating if the tested specimen meets specified acceptance criteria during at least three hours of a standard fire exposure. The fire-resistance rating, in turn, qualifies the barrier design for certain uses. Here the term “qualifies” is intended to mean that the barrier design meets or exceeds the fire-resistance requirements of a building code or other regulation.

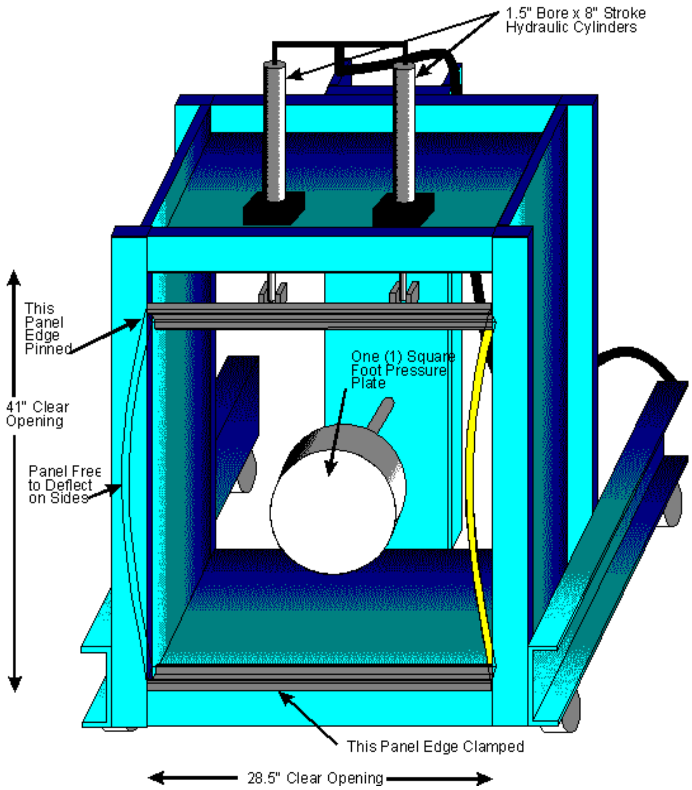

Figure 6. Multiplane Loading Jig for 3’ Samples

U.S. Coast Guard regulations for fire protection and the International Conventions for Safety of Life at Sea of 1948, 1960 and 1974, require that the basic structure of most vessels be of steel or “material equivalent to steel at the end of the applicable fire exposure.” The ASTM E 119 fire curve is used as the applicable fire exposure for rating SOLAS decks and bulkheads. These provisions place the burden of proving equivalency on designers who use noncombustible materials other than steel, where structural fire provisions apply. The 1974 SNAME T&R Bulletin 2-21 [4-39] provides Aluminum Fire Protection Guidelines to achieve these goals for aluminum.

Approaches to Fire Protection
When utilizing composite materials for marine construction, there are several approaches to satisfying fire protection requirements. One approach is to use a resin that by itself has very good fire performance requirements. Conventional structural resin systems (polyester, vinyl ester and epoxy) can be modified with fire retardant additives. Additives will not improve these resins to the point where the IMO HSC Code requirements can be met, but USCG "*T*" vessels can be constructed with fire retardant resins. The additives generally degrade physical properties of the laminate, may influence processing variables and can actually increase smoke production in severe fires.

Phenolic resins do offer the potential to pass the IMO's ISO 9705 test and approach 30 minute endurance ratings in E 119 fires. These resins may not be as tough as the high-end structural resins in use today and are generally more difficult to process.

Another approach to meeting fire protection requirements involves insulating the structure with "batted" materials, such as mineral wool or refractory products. This method provides a high degree of thermal protection, but relies on mechanical attachment methods to hold the insulation in place. Labor costs associated with insulation installation and the added weight of these systems are key drawbacks.

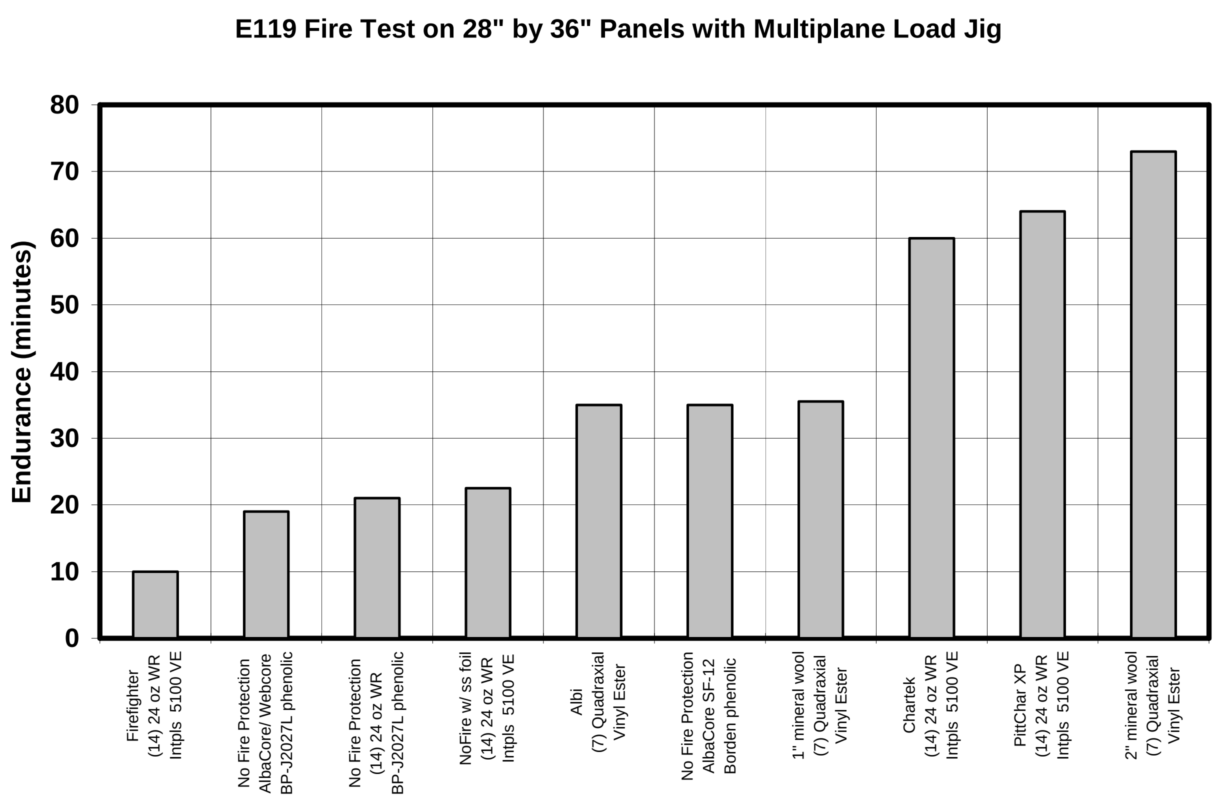

Figure 7 Burn-Through Resistance of Various Fire Protection Schemes

Fire protection can also be achieved through the use of intumescent coating systems, which are activated by exposure to fire and expand to form a protective char layer. These products fall into two broad categories: water-based and epoxy-based. The epoxy products (Pitt-Char from PPG and Chartek from Textron) are very durable products developed for the offshore industry. Unfortunately, the epoxy systems produce smoke levels that are in excess of values specified by the IMO ISO 9705 test. The water-based intumescent coatings (Firefighter, NoFire and Albi products) work well to limit flame spread with little smoke production and are generally more reasonably priced. However, one would be concerned about the durability of these products in a marine environment. Application thickness are much less than the epoxy products, so minimal burn-through resistance (ASTM E 119/SOLAS test) is achieved. Figure 7 shows some comparison fire endurance times for various composite panels subjected to in-plane and out-of-plane loads.

Several panels were tested that had no fire protection. The Albi Core products were sandwich laminates that had phenolic resin skins and Albi Core, which is a syntactic core made with phenolic resin and glass microspheres by Isorca. A solid E-glass/phenolic panel was also tested. It should be noted that this is a very severe test with high heat fluxes (up to 100 kW/m^2) and high loads (1000 lbs in-plane and 250-500 lbs out-of-plane).

Figure 8 shows a proposed configuration that would provide one hour of structural fire protection to a conventional sandwich composite laminate. A combination of intumescents, fire-retardant foam, spray mineral fibers and air space is utilized. The “I”-beams supporting the suspended ceiling would ideally be non-conductive, as would be possible with phenolic pultrusions. At this time, such a profile would have to be fabricated on a custom basis.

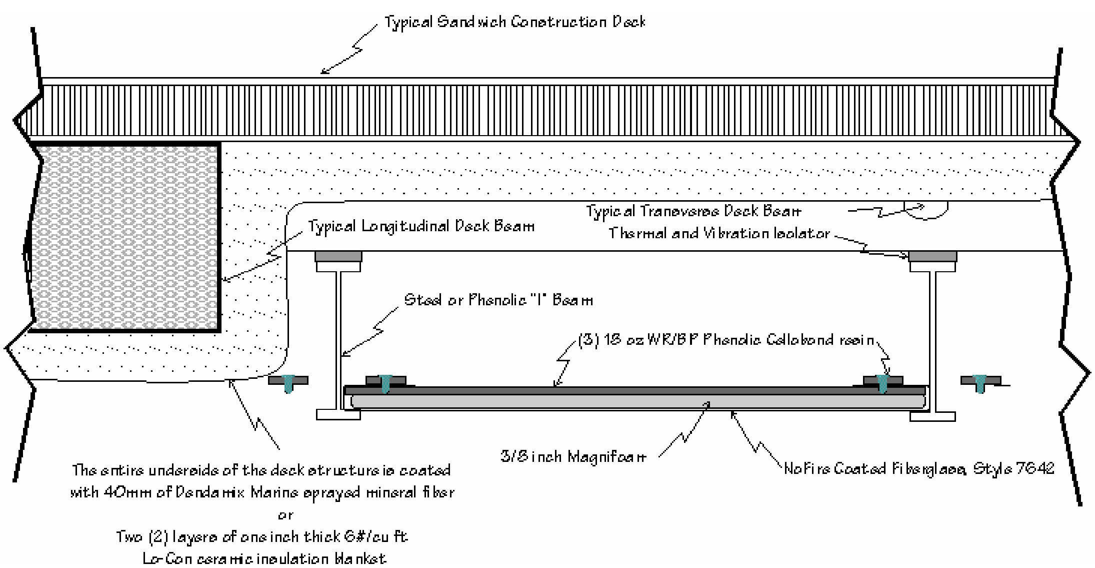

Figure 8. Typical “A-60” Composite Construction Deck

Summary

There is a wide range of fire threats available to composite material construction for boats and ships. At the most basic level, even a polyester laminate will not support combustion on its own without an external flame source. Composite material construction requires structural fire protection when protecting against the most severest of threats, such as on a surface combatant in a damage control situation.

When performing a fire risk assessment of a vessel, keep in mind the composition of the passengers and the vessel route information for determining safe harbors and evacuation time estimates. Larger vessels, such as passenger ships with 150 or more people, would require more time to evacuate than a typical fast ferry. Therefore, a bulkhead with a 60 minute fire rating for the passenger vessel may only require 30 minutes for the fast ferry.

Although there are many fire performance parameters to consider when doing a fire risk assessment for composite construction materials, the following fire tests should be considered for screening and qualification:

Small fires - ignitability; smoke - Cone Calorimeter

Medium fires - heat release; flame spread - Cone & LIFT; ISO9705

Large Fires - structural - E119, UL1709

Special fire protection against small fires is generally not needed for composite construction, although some care should be excersized in the engine room and galley areas. Fire retardant resins usually meet criteria for vessels with small fire risk.

To protect against medium scale fires, composite materials require some sort of fire protection. Water-based intumescents may meet the criteria for interior applications. When composite materials are being considered as structural elements on ships and large yachts, the issue of elevated temperature structural integrity comes into play.

Composite materials offer a tremendous advantage to the marine designer with their ability to be tailored to specific engineering requirements. Composite deck and bulkhead systems offer superior insulation and mechanical damping characteristics when compared to a stiffened metal plate construction. When fire protections schemes are employed to protect surface skins, the resulting composite system is fire hardened with optimal containment properties. For further information, please download the Adobe Acrobat file: *"Fire Performance"* from the web site ***www.marinecomposites.com***.