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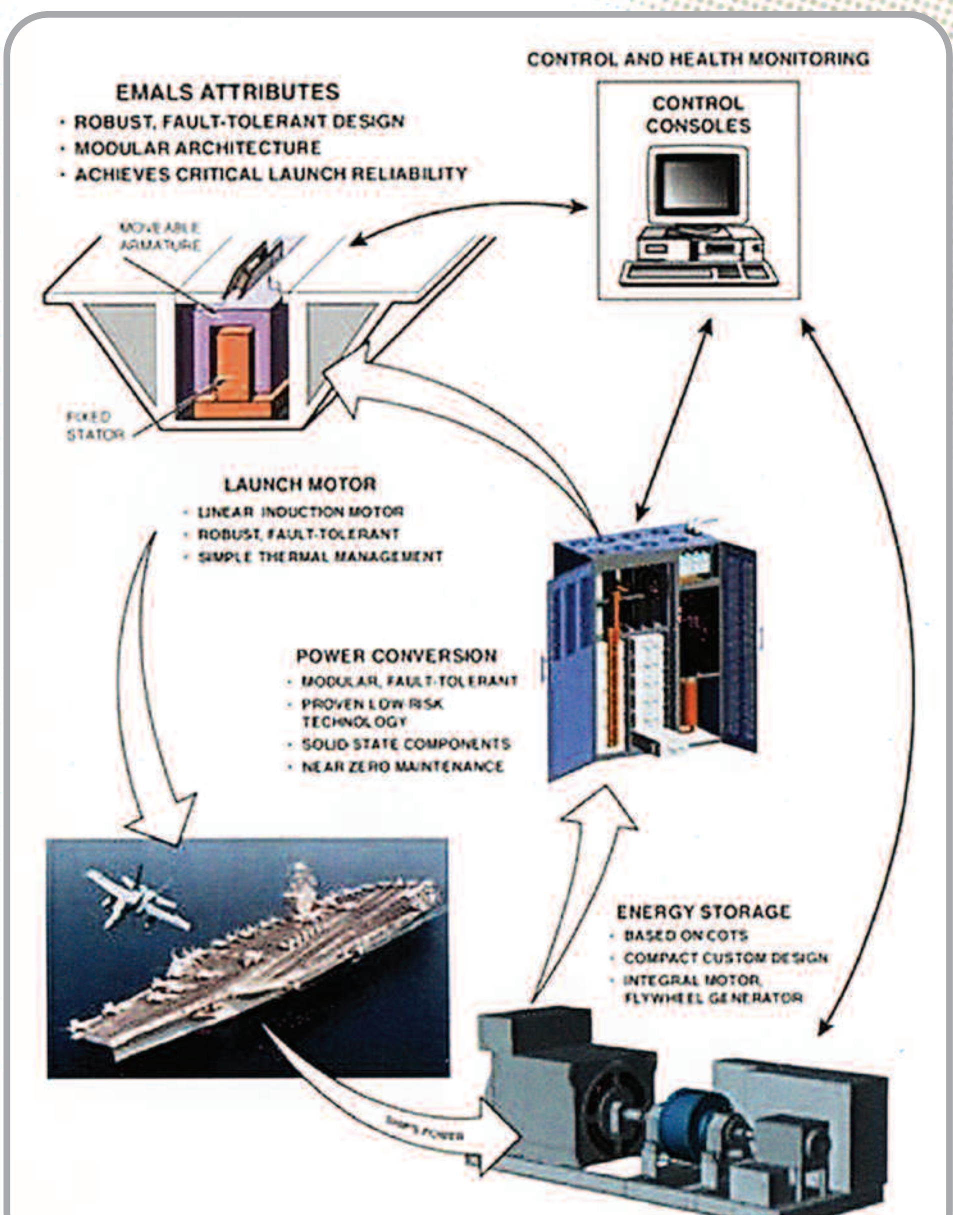
Flame Retardant Surface Mat

Low Smoke Polyester Pultrusions at Low Cost

By John Rowen

Pultrusion is a continuous composite manufacturing process that is efficient and economical for the production of high-strength structural components that compete directly with steel and aluminum parts. For many markets, composite parts have two major advantages over steel and aluminum—high strength-to-weight ratio and corrosion resistance. For example, the U.S. Navy is accelerating the incorporation of composite materials into the fleet in order to both reduce weight and decrease maintenance. Lower weight translates to improved ship stability, speed, range, payload capability and fuel efficiency. However, one serious concern is the flammability of composite materials.

Whether a fire is accidental or the result of hostile attack, those on board can't simply withdraw as if they were exiting a building. To address this concern, composite manufacturers have turned to bromine compounds as additives to their resins, with the result that flammability is reduced, but smoke production is increased. Other flame retardants are better at reducing



Courtesy of General Atomics

Fig. 1 The Electro-Magnetic Air Launch System (EMALS) design is a robust, highly reliable aircraft carrier launch system that will meet or exceed all Navy performance goals.

The Problem Defined

Pultruded polyester (PE) components are widely used in a variety of building applications such as I-beams and C-channels, tubes and angles used for walkway and handrail systems, decking, ballistic panels, and cable trays. Pultrusions are often specified for applications requiring high strength and light weight, but in particular for use in corrosive environments.

However, upon exposure to open flame or high radiant heat these materials can exhibit high surface flammability, smoke generation and toxicity (FST) characteristics. This is a particular problem when the end use is within a partially or entirely enclosed environment requiring egress. This fire hazard is subject to regulated life safety performance criteria set by local, state and Federal code governing authorities.

Current Solutions: Bromine and ATH

To address surface flammability, PE resins can be adjusted to have a significant degree of fire resistance (FR) by combining them with FR additives. Bromines, e.g., decabromodiphenyl ether oxide (DBDPE), are the most effective FR compounds in general use, especially when combined with the synergist antimony trioxide (ATO). However, under a fire load these brominated compounds produce large volumes of acrid particulate smoke and soot. Additionally, brominated FRs liberate decomposition byproducts such as hydrobromic acid (HBr) and other noxious species that can render the immediate environment biologically toxic, causing acute eye irritation and eventual asphyxia. Less toxic additives such as aluminum trihydrate (ATH) are preferable smoke, but they are less efficient and must be added in such great quantity that the strength of the part is compromised.

There is a novel method of fire hardening fiberglass composites using a fire-retardant-coated veil as the outer layer of a lamination schedule. Since only the surface is coated, the strength characteristics of the part remain the same, while fire is blocked from penetrating the interior of the part. Upon exposure to open flame or high radiant heat, the resultant manufactured product has surface flammability reduction comparable to a brominated resin manufacture, but with much less smoke and toxicity. For example, several Navy development programs that have benefited from the incorporation of this fire retarding (FR) and smoke-suppressing veil are the Electromagnetic Aircraft Launch System (EMALS)(**Fig. 1**) for aircraft carriers, the Light Weight Composite Stanchion (**Fig. 2**) for cargo ships, and the Very Light Weight Hatch (**Fig. 3**).

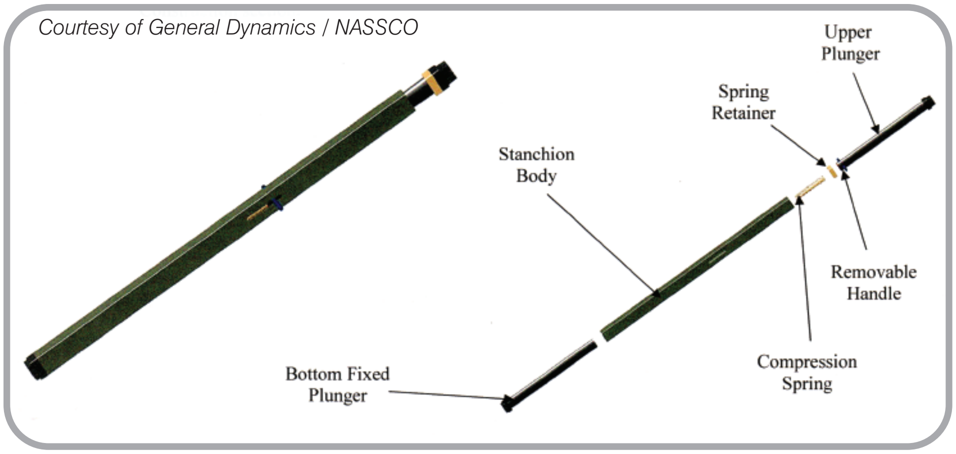


Fig. 2 Plunger actuated composite stanchion for the three hold types: Freeze/Chill (F/C), Specialty Cargo, and General Stowage.

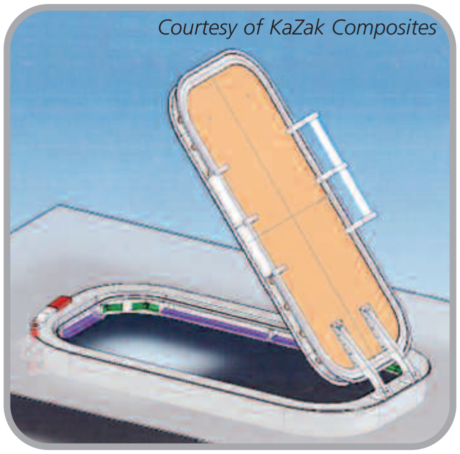


Fig. 3 The Very Light Weight Hatch (30" x 60") can be operated by one individual as opposed to three for the steel hatch, thus eliminating the requirement for a secondary scuttle hatch. Tested to the UL 1709 protocol.

Figure 4. Intumescent Coating ASTM E-662 Standard Test Method for Specific Optical Density of Smoke Generated by a Solid Material

OPTICAL DENSITY TEST RESULTS SUMMARY			
	NON-FLAMING	FLAMING	
Ds 1.5 min.	average:	0.6	3.9
Ds 4.0 min.	average:	0.4	30.1
Dm(corr)(20.0 min.)	average:	4.7	178.3

Figure – 4 contains the results of an ASTM E-662 test on a non-fire retardantPE resin / balsa / glass sandwich panel that had an Avtec intumescent coating applied to it. Generally, if the non-flaming and flaming average values at 20 minutes are added together and have a result below 200, the specimen will likely have an ASTM E-84 Class A Smoke of <450.

Figure 5. 50 kW/m2 Cone Calorimeter Test Results Comparing Three FR Mat Specimens to a Brominated Specimen

Sample /Test #	Placard Initial Mass(g)	Mass Correlated Conversion Factor	Correlated Total Smoke Release(g)	Correlated Average Smoke Production (g/m^2/s)	Duration of Test (s)	Peak Heat (kW/m^2) Release
Sample 1 "glass out" (glass against die)	80.7	1.00	20.01	.017	1198	91
Sample 2 "FR out" (FR against die)	81.6	.99	18.58	.019	1058	123
Sample 3 FR mat sandwich (two FR mats)	82.2	.98	14.95	.011	1349	110
Pultruded Bromine PanelPolyester Veil	40.6	1.99	52.26	.140	465	185

Note: the Brominated panel at the bottom of the chart released a 261% greater quantity of smoke (correlated 52.26gm) compared to the FR Mat – Sample 1 (20.01gm). Samples 2 and 3 illustrate contrasting results when the FR Mat is positioned in alternative orientations. Sample 2 had the FR side positioned as the surface i.e., glass rich side down. Sample 3 contained two FR Mats with the FR sides back to back forming a sandwich construction.

from a toxicity standpoint, however the required high loading levels significantly degrade the desirable physical characteristics of the pultrusion.

The Problem of Smoke Suppression: Acrylics and Phenolics

Clearly, smoke suppressant additives for PE resins have not evolved to match the effectiveness and sophistication of the fire retarding additives. The difficulty of chemically suppressing smoke created by the combustion of a cured resin is exacerbated by the complex interaction between the resin and the flame retardant agent. The total complexity has stymied the development of any universal smoke suppressing additive options. Some success has been achieved with thermosetting modified acrylic and phenolic resins, however, these resins have their own set of issues. Such as very high hydrated mineral, e.g., ATH, loading for acrylic, and voids due to liquid vapor byproducts in phenolic. Compared to PE, composites comprised of these resins have a reputation of exhibiting brittle physical characteristics.

What About Intumescent Coatings?

Painting PE laminates with intumescent FR coatings can dramatically reduce the ability of a laminate to combust or generate smoke. Intumescents are a family of fire protective coatings containing constituents that react under high heat to form a protective charred layer. Once the under-laminate is shut off from the atmosphere by a sturdy, carbonific barrier, the combustion process is greatly slowed. This layer both reduces surface ignitability, and reduces smoke by entrapment of the resultant smoke particles. **Fig. 4** shows the results of an ASTM E-662 ("The Standard Test Method for Specific Optical Density of Smoke Generated by a Solid Material") on a PE balsa cored sandwich panel coated with a fire-retardant paint. The results indicate low smoke production because the longer the exposure time, the more smoke and soot is packed into the coating, thus further shielding the laminate from ambient oxygen. This shielding results in a slow charring of the substrate rather than a more flammable, vigorous oxidation.

However attractive from a life safety viewpoint, a secondary over coating on pultruded parts has numerous drawbacks. It can require code regulated paint application and drying areas. Spray application necessitates over-spray, often resulting in a loss of more than 30 percent of coating material. Coatings can be scored, scratched or chipped at any point during the coating's life cycle. For all of these reasons, the coating option has not received much acceptance.

New Solution: Deliver Intumescents on a Surfacing Veil

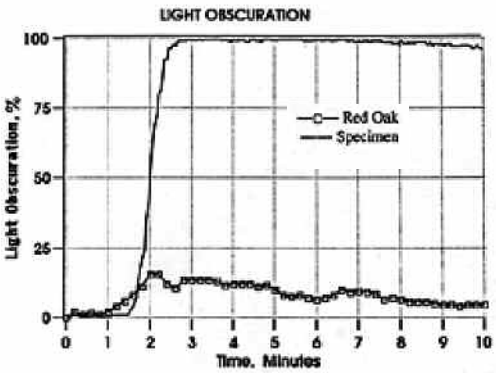
Using a veil or mat as a transport medium to deliver intumescent FR and smoke suppressing constituents to the surface of a pultrusion during a manufacturing process is a novel option. Surfacing veils, both glass and organic, have traditionally been employed to provide a resin-rich surface that enhances and maximizes the corrosion resistance and life cycle of a pultrusion. Augmenting that surfacing veil with FR agents on the underside provides an inter-laminate FR envelopment comparable to an intumescent secondary coating. Since the FR material is "wet out" by the PE resin, it becomes integral to the finished part, and cannot peel or chip. However, there remains the question of whether the PE resin on the surface will provide too much fuel to allow the finished part to pass a fire test. This and other issues were investigated by actual burn testing in the fire lab at Worcester Polytechnic Institute (WPI).

Cone Testing the Performance of Intumescent-Coated Mats

The Cone Calorimeter was used as the screening test apparatus because of its convenience and repeatability. Although the Cone instrument results don't predict specific E-84 results, better results on the Cone tests are highly correlated with better results on E-84 tests. ASTM E-1354 Cone Calorimetry enables fire safety engineers to measure the total quantity of particulate smoke released by weighing each specimen during exposure to high radiant heat. In addition, the apparatus calculates smoke release over time, and measures peak heat. Each specimen was subjected to 50 kW/m^2 of radiant heat.

The test run described in **Fig. 5** compares four samples; three are various configurations of FR mat-protected vacuum-bagged samples, and one is a bromine-protected pultrusion. The FR mat has both a glass rich surface and an intumescent surface, so it was decided to test with 1) Glass side out, 2) Intumescent side out, and 3) Two veil layers with the intumescent sides touching. For reasons of pultrusion die wear, it is desirable to run with the glass side against the die, so the three tests were chosen to determine whether one would sacrifice fire performance by choosing that orientation. The mass of Sample 1, glass side out, was designated to be the baseline for mass correlation. As can be seen in **Fig. 5**, Sample 1 did indeed perform well, with a very low smoke and peak heat as compared to the brominated panel, and comparable to the other FR mat samples. Even though the vacuum bagged specimens had lower glass

Figure 6a. Brominated Panel ASTM E-84-01 Smoke Developed Index Result



TEST DATA

UNROUNDED FSI:	23.4
UNROUNDED SDI:	984.0
FS*TIME AREA (Ft*Min):	45.6
SMOKE AREA (%*Min):	791.2

Figure – 6a contains the results of an ASTM E-84-01 test result preformed upon a commodity, PE pultruded flat sheet containing DBDPE.

content than the brominated pultruded placard, e.g., 41 percent verses 52 percent, what the table clearly illustrates is a dramatic reduction in the propensity of the part to generate smoke for all FR mat specimens. Based upon these and many other Cone tests, the results were deemed sufficient to justify the fabrication of pultruded test panels and formally test them to the E-84-01 protocol.

E-84 Comparison PE Pultrusions Protected by FR Mat Versus Bromine

The FR mat test specimen was an assembly of four 1-foot by 12-foot pultruded panels butted together to form a 2-foot by 24-foot specimen. The bromine-protected specimen comprised two 12-foot pultrusions 2 feet wide, butted end-to-end. The tests were run at Southwest Research Institute**.** **Figs. 6a and 6b** show the E-84-01 results for those two specimens. While both specimens had nearly identical flame spread indices (FSI), the bromine-protected panel had a smoke developed index (SDI) more than 250 percent higher than the FR mat panel. In fact, the accompanying graph shows the brominated panel producing nearly total visual obscuration throughout the test. The FR panel actually under performed its potential, since at 3.5 minutes into the test the panel strips buckled slightly and the burner flame penetrated the center seam of the assembly, combusting the back of the panel which was not protected by the FR Mat. Smoke was observed entering the tunnel chamber through the center seam, originating from the unprotected, organic veiled surface. At 8 minutes the phenomenon and obscuration subsided. Despite the sizable penalty the panel seams created, the specimen easily passed the Class A smoke requirement. Initial concern about the burn-off of the PE resin on the surface of the FR mat were confirmed by the early "spike" in the **Fig. 6a** graph, but that burning was only momentary. The net comparison of graphs in **Fig. 6a and 6b** clearly illustrates that the **FR Mat** dramatically reduces the capability of PE pultrusions to generate smoke when exposed to open flame.

In summary, the fire and smoke testing presented in this article validate that a low cost, general purpose pultruded product can meet not only the flame spread requirement of E-84 Class 1, but additionally satisquare-feety the Class A low smoke requirement. This combined Class 1/A certification is a prescribed requirement by regulatory code governing authorities for enclosed environments requiring life safety egress. Additionally, the testing results suggest that new and promising opportunities in markets dominated by aluminum and steel, such as infrastructure, e.g., bridges, tunnels, electrical transmission, marine terminals; energy, e.g., mining, gas and oil; and, transportation, e.g., rail, truck, ships, are now open to low-smoke pultruded products.

Subsequent application tests have verified that the FR mat will provide similar results when processed by filament winding, vacuum infusion and reinforced thermoplastic consolidation. For more details of these and other test results, you can log on to *www.avtecindustries.com*. CM

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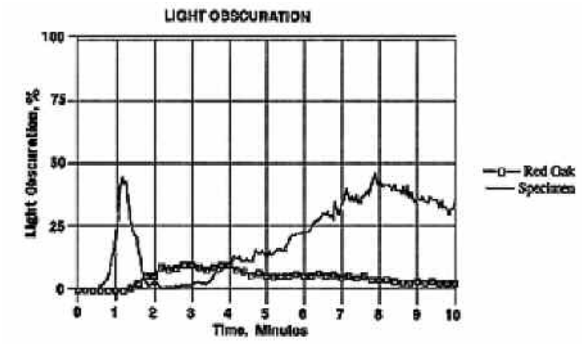
Figure 6b. Non-Brominated Panel ASTM E-84-01 Smoke Developed Index with FR Mat



TEST DATA

UNROUNDED FSI:	23.3
UNROUNDED SDI:	351.4
FS*TIME AREA (Ft*Min):	45.4
SMOKE AREA (%*Min):	206.2
FUEL AREA (°F*Min):	5109.2

Figure – 6b contains the smoke obscuration result, SDI, of an ASTM E-84-01 derived from a low cost, PE pultruded flat sheet containing ATH as well as the resultant FR Mat. The % Light Obscuration at no time exceeds 50%. The FR Mat provided the necessary smoke suppression to achieve an SDI Class A rating.