Systems Approach to Creating FRP to Meet 2009 International Building Code Requirements for Interior Composites

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Introduction

In a giant leap forward for the Fiber Reinforced Polymer (FRP) industry, the 2009 update to the International Building Code (IBC) now explicitly permits FRP in building construction, both interior and exterior, allowing FRP to compete with wood, aluminum, steel, concrete and gypsum board. Since most FRP materials contain flammable hydrocarbon resins, the IBC code requires that for interior use FRP must be fire tested and meet both flame-spread and smoke-obscuration criteria. IBC Chapter 8 specifies those criteria, and IBC Chapter 26 enforces them by requiring that FRP components carry an IBC-sanctioned Label that indicates that the material has passed the required fire tests. These Labels are affixed only when the material becomes Listed with an independent product safety testing organization that has certified the fire test results. These include Underwriters Laboratory, Southwest Research Institute, Intertek and others.

The details of exactly how a Listing is accomplished are specified by the testing laboratory, and may be simplified for FRP fabricators by the existence of an "umbrella" Listing by a resin manufacturer who pre-qualifies a manufacturing regimen with the testing lab. Once an FRP component acquires its own Listing and is issued the Label identifying the testing laboratory, architects and professional engineers may then call out the credentialed FRP in construction plans.

The purpose of this article is to explain a methodology (systems approach) for fire-hardening FRP materials so that they can meet both flame spread and smoke obscuration specifications required by IBC. If a fabricator follows these recommendations, Listing and Labeling should be achievable.

The Smoke Problem

The construction industry has long recognized that the petro-resinous binder common to all FRP composite materials is naturally flammable. For applications where property loss has been the major issue, FRP flammability, measured as flame spread rate, has been significantly reduced by the incorporation of bromine compounds in the resin. Pound for pound, bromine remains the most cost effective fire retardant for FRP resins. The result of adding bromine to a resin is that when it is subjected to high heat it burns inefficiently, hence slowly, which accounts for its great success at reducing flame spread. However, an unfortunate side effect of this inefficient burning is the production of large quantities of dense and acrid smoke. In human-occupied spaces, that smoke creates the double jeopardy of visually impeding rapid exit from a burning building while also creating a suffocating atmosphere. More fire victims are killed by smoke inhalation than by burning; that's why smoke issues are so important for meeting the prescribed regulatory code. Fire testing clearly shows that FRP materials with bromine additives cannot come close to passing the smoke obscuration criterion set by the IBC.

So, the question raised by the new IBC rules is: Can FRP materials using currently available low-cost resins be made to pass both flame and smoke tests?

Solving the Problem Using a Systems Approach

The answer to that question is emphatically *YES!* A new way to attack the smoke generation problem is a combination of discrete steps that can be combined into a "systems approach" to attack both the fire and smoke problems at the same time. First, there are several modifications to commodity resins that can reduce smoke generation and help quench flame. Then, there is a fire-retardant-coated surfacing veil that can be applied during the manufacture of any FRP lay-up that has also been shown to greatly reduce both flame spread and smoke production. By coupling the use of this veil with the resin modifications, almost any low cost resin can be made to pass the IBC chapter 8 criteria. Here are the recommended steps to achieve this goal:

- Use a low cost, high viscosity general-purpose resin (GPR) containing less than 27% styrene.
- To reduce the viscosity of the resin so it will easily accept a high loading of ATH, add methyl methacrylate (MMA). MMA will not generate sooty black smoke as does styrene monomer.
- Add 25 to 150 parts Aluminum Trihydrate (ATH) as needed to reduce flame spread.
- To further reduce viscosity, fire-retarding liquid phosphorus plasticizers can provide powerful solvency and are excellent viscosity reducers for highly filled polyester resins. For example, Supresta's Phosflex compounds that act as wetting agents and flow modifiers in very low concentrations. Liquid phosphate plasticizers are available in a wide range of compound compositions.
- Glass reinforcements play a substantial role in fire testing in two ways. Firstly, high glass content reduces the resin percentage, which reduces fuel for any potential fire. Testing shows that composites with less than 38% glass content are unlikely to pass the IBC smoke requirement, regardless of how the GPR is modified. Secondly, the glass reinforcements provide a blocking effect that delay***s*** and interfere***s*** with the decomposition process . Woven roving near the surface can provide this "basket strength" while the resin chars. Mats should be avoided as they generally absorb a disproportionate quantity of resin, i.e., fuel. However, there are new high density mats and stitched woven roving mats that are a considerable improvement over earlier mats.
- Finally, add the specially-coated fiberglass veil that has been shown to slow both burning and smoke generation. During manufacture, when the lay-up is wet out with GPR, the intumescent veil is subsumed and becomes embedded at the surface of the resultant part. This provides the finished FRP composite with an inter-laminate surface layer, analogous to an intumescent coating but impervious to chipping or cracking since the actual surface is the native GPR. These intumescent veils are moderately priced when compared to the expense and inefficiencies of acrylic polyester or phenolic resins.

Here's a summary of the make-up of a resin using the above recommendations:

Constituent	Parts
Low Cost GPR (<27% Styrene)	100.00
MMA (Methyl Methyacrylate)	5.00 to 14.00
ATH (General Purpose or Coated)	50.00 to 150.00
Viscosity Reducer (Ex.: Phosflex 4)	0.50 to 1.50

The following are standard additives that vary depending upon fabrication method:

Pigment dispersion	1.50 to 3.00
Mold Release	1.00 to 1.50
UV Inhibitor	0.30 – 0.50
Peroxide Initiator(s)	0.75 to 2.50

IBC Testing for Flame Spread and Smoke

The required test method that measures the critical fire and smoke characteristics of interest to the IBC for interior applications is ASTM E-84, Standard Test Method for Surface Burning Characteristics of Building Materials, also called NFPA 255 and UL 723. The E-84 test is often referred to as the "tunnel test" and it measures and reports two observations during a specimen's exposure to an open flame source within an enclosed tunnel-shaped chamber: flame propagation and smoke obscuration.

The test specimen is approximately 2 feet in width x 24 feet in length, and is mounted as the roof of the tunnel. A gas burner at one end supplies flame to the roof, while air is vented at the opposite end by a metering fan that regulates the volume of air that passes through the tunnel. The test run time is 10 minutes.

The **IBC** rates materials according to ASTM E-84 performance into the following classes:

A: Flame Spread Index (FSI) 0-25; Smoke Developed Index (SDI) 0-450

B: Flame Spread Index (FSI) 26-75; Smoke Developed Index (SDI) 0-450

C: Flame Spread Index (FSI) 76-200; Smoke Developed Index (SDI) 0-450

Although the Flame Spread Index (FSI) can vary from 0 to 200, in all cases the smoke (SDI), must be less than 450. A typical composite, especially those containing bromine, can not attain this required smoke number. Also note that when FRP materials are used as facing for cored panels, an additional test, the "room corner test" (NFPA 286: Standard Methods of Fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth) is required.

The values for FSI and SDI are derived from a comparison of the test sample's results with those acquired from a red oak flooring sample. Red oak burns vigorously but with little smoke production. There are other observations made during the test, such as Time to Ignition, Maximum Flame Front Advance, as well as related characteristics. However the FSI and SDI are the crux of the test.

Below is a chart of E-84 Flame Spread and Smoke Development graph results from three pultruded flat sheet samples, all using low-cost polyester GPR with a glass reinforcement content between 49 to 51%.

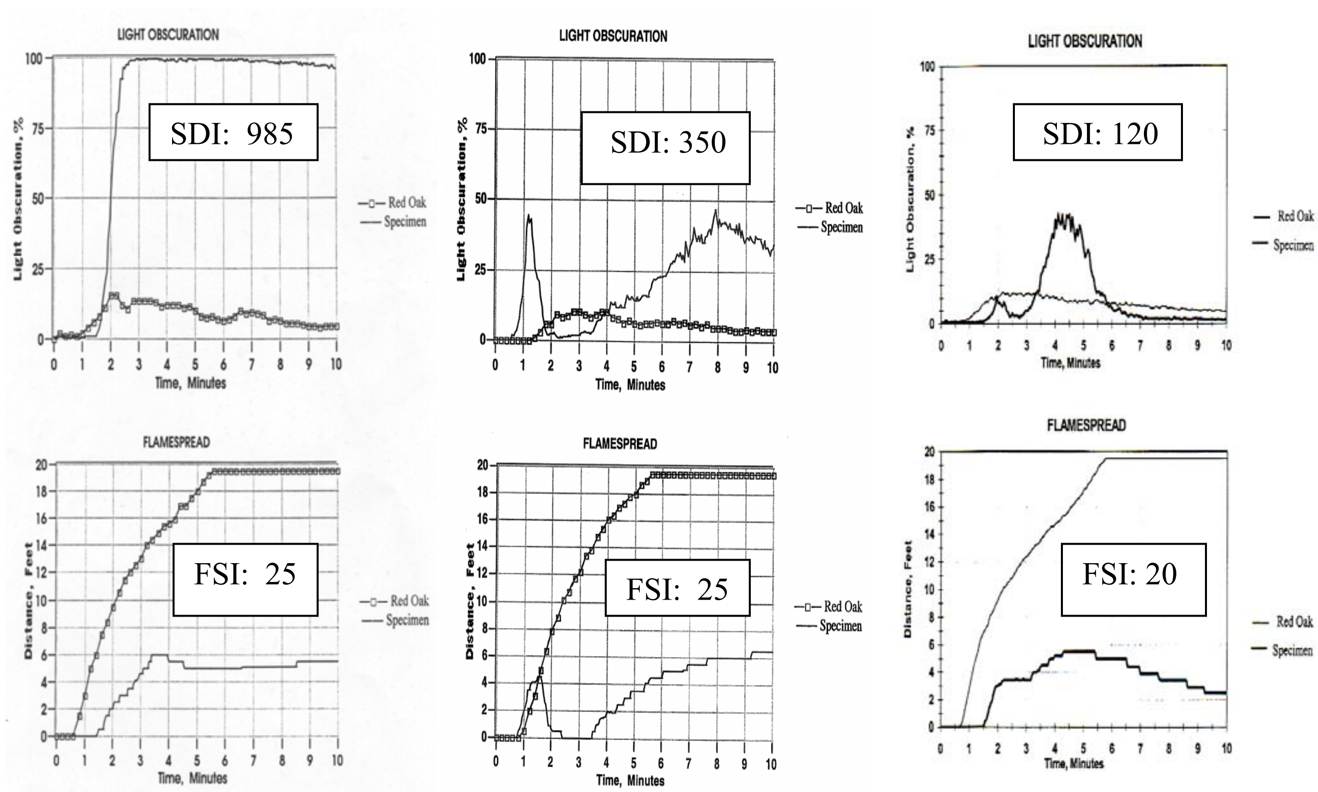
Sample (1) Fire retarded with decabromodiphenyl ether (DBDPE) and antimony oxide, and containing glass reinforcements, calcium carbonate and a polyester veil.

Sample (2) Fire retarded using the "systems approach" with MMA, ATH, and glass reinforcements with an intumescent veil.

Sample (3) Fire retarded using the "systems approach" with MMA, ATH, Fyrol, and glass reinforcements with an intumescent veil containing 20% expandable graphite.

Figure 1: Three ASTM E-84 FSI and SDI Results on Pultruded Polyester Resin Panels

Sample (1) **Sample (2)** **Sample (3)**



Brominated Panel | ATH & Intumescent Veil Panel | ATH & Intumescent / Graphite Veil Panel

- IBC / ASTM E 84: No Rating - | **- IBC / ASTM E 84: Class A -** | **- IBC / ASTM E 84: Class A -**

Sample (1) is a brominated panel that does very well with flame spread, recording a 25 FSI. However it is abundantly clear that it fails miserably recording a 985 SDI. When the flame spread starts the smoke rockets to almost 100% obscuration – and stays there. The IBC would certainly withhold an interior rating from this panel.

Sample (2) is a panel with ATH and an intumescent veil. Note the smoke begins slightly before the flame spread. This is the water coming out from the ATH and the intumescent composition. The first spike is the surface resin flashing-off. The flame and smoke spiked between 1 and 2 minutes and but dropped back to the lowest reading shortly after 2 minutes. At 3 1/2 minutes the flame spread and smoke begin to rise because the panel being tested was supplied in strips. Buckling occurred causing the fire to infiltrate onto the backside. However at no time did the smoke obscuration reach 50% with the final FSI recording of 25 and SDI of 350. This is clearly an E-84 IBC Class A material that can be applied to an interior of any building.

Sample (3) is a panel with ATH and an intumescent veil that is complemented with 20% expandable graphite. At 1 1/2 minutes the flame spread and smoke begin together. The smoke obscuration subsides to nearly zero, and begins to increase at approximately 3 minutes, dropping back to nearly zero beginning at 6 minutes. The smoke remains at nearly zero until the conclusion of the test. The flame spread remained low, never reaching the 6-foot mark on the 24-foot test panel. The result is a remarkable FSI of 20 and SDI of 125. The intumescent / graphite veil provides superior low smoke characteristics and clearly illustrates what can be done with a low cost resin. Additionally, the flame diffusion characteristics and the expansion of the graphite additive make this veil ideal for more demanding applications where burn-through resistance is needed, as in NFPA 286 as well as NFPA 285: Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Non-Load-Bearing Wall Assemblies Containing Combustible Components.

Cone Calorimeter for Low-cost Screening Tests

Because E-84 testing requires a relatively large sample and is somewhat costly to perform, many fire engineers recommend first qualifying smaller samples using the Cone Calorimeter, ASTM E-1354, Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter. The Cone requires only a 4-inch-square specimen, and actually produces more detailed analyses of the tested material than E-84 does. The Cone exposes the test sample to high radiant heat while monitoring and analyzing the combustion gases as well as monitoring and recording mass, time and temperature readings and other combustion characteristics in real-time.

The following table (Figure 2) of four ASTM E-1354 Cone Calorimeter test results compares a non-fire retarded, unfilled FRP placard to previously detailed placards of a brominated FRP and two intumescent veils that follow the "systems approach" . All specimens have an approximate 50% fiberglass content (by weight) and are manufactured with low cost polyester resin.

Figure 2: 50 kW/m^2 Cone Calorimeter Test Results and ASTM E 84 Flame & Smoke Comparisons

Sample Description & Test Number	Cone Time to Ignition (seconds)	Cone Peak Heat Release Rate (kW/m²)	Cone Average Heat Release Rate (kW/m²)	Cone Peak Smoke Production Rate (m²/sec.)	Cone Average Smoke Production Rate (m²/sec.)	ASTM E-84 Flame Spread Index (FSI)	ASTM E-84 Smoke Development Index (SDI)
Standard Neat PE Resin & Glass Reinforcements No FR Additives Note: For reference only.	47	249	113	0.124	0.031		
Sample (1) Pultruded Brominated Resin Panel w/ Polyester Veil	65	185	85	0.221	0.071	25	985
Sample (2) Pultruded Panel w/ATH & Intumescent Veil (Veil Wt.: 33.0 g/ft²)	50	160	66	0.054	0.017	25	350
Sample (3) Pultruded Panel w/ ATH & Expandable Graphite Intumescent Veil (Veil Wt.: 37 g/ft)	63	47	21	0.008	0.005	20	125

The first specimen listed is an unfilled polyester resin with woven glass reinforcements that was Cone tested and used as a baseline for comparison only to modified placards. This placard shows poor Peak Heat

Release Rate (PHRR) at 249 kW/m² and an Average Heat Release Rate (AHRR) of 113 kW/m² indicating it burned vigorously and has the propensity to spread flame. The smoke numbers indicate the placard composition would not pass the ASTM E-84 Class A requirement of <450 SDI.

The second panel specimen (Sample 1) was a brominated polyester resin with glass reinforcements that was tested to ASTM E-1354 and ASTM E-84. This panel was formulated for a low E-84 Flame Spread Index (FSI) but not a low Smoke Developed Index (SDI). As you can see from the Cone numbers, the bromine / antimony content was sufficient to keep the PHRR to 185 kW/m² and AHRR to 85 kW/m² which relates to a 25 FSI in the E-84 test. However, as mentioned earlier, bromine works as a flame retardant by producing large volumes of soot and particulate smoke. This provided an E-1354 Peak Smoke Production Rate (PSPR) at 0.221 m^2/s and Average Smoke Production Rate of 0.071 m^2/s, and an E-84 SDI of 985.

The third panel specimen (Sample 2) was a pultruded panel that was produced using the ATH resin formulation described above. In the Cone test the PHRR and AHRR were noticeably lower at 160 kW/m² and 66 kW/m² verses 185 kW/m² and 85 kW/m² for the brominated panel. The smoke was also significantly lower with PSPR and ASPR of 0.054 m^2/s and 0.017 m^2/s verses 0.221 m^2/s and 0.071 m^2/s for the brominated panel. The improved performance of Sample 2 is also manifest in the E-84 results of FSI 25 and SDI 350. What this clearly illustrates is a dramatic reduction in the propensity or ability of the flat sheet to spread fire and generate smoke.

The fourth panel specimen (Sample 3) was a pultruded panel produced using the “systems approach” described above and a surfacing veil that was a combination of intumescent constituents with 20% expandable graphite. In the Cone test the PHRR and AHRR were significantly lower at 47 kW/m² and 21 kW/m² verses 185 kW/m² and 85 kW/m² for the brominated panel. The smoke was also dramatically lower with PSPR and ASPR of 0.008 m^2/s and 0.005 m^2/s verses 0.221 m^2/s and 0.071 m^2/s for the brominated panel. The improved performance of Sample 3 is also manifest in the E-84 results of FSI 20 and SDI 125. During the test the intumescent / graphite veil grew into a thick felt-like expansion providing an insulating barrier to protect the laminate below the surfaceThis is remarkable when one considers it was achieved with a low cost styrenated polyester GPR.

A New Way to Achieve an E-84 Class A Interior Finish

Commodity building composites that meet E-84 Class A compliance can be relatively inexpensive and uncomplicated to manufacture. There is nothing exotic or mysterious about it. The “systems approach” methodology benefits from commonplace fabrication practices and readily available raw materials. The only new variation is utilizing one of the intumescent veils that will provide both excellent fire inhibition and smoke suppression. As verified by E-84 Class A passage in numerous tests, the intumescent veil markedly reduces the propensity of a composite to combust and generate smoke when exposed to an open flame or high radiant heat. This is a simple low cost solution to an expensive and complex problem.