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How Does Laminate Construction Affect Fire Performance of FRP Composites

By

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Abstract

In the North American construction market, the most widely cited fire test for qualifying material for use as interior and exterior finish material is based on the ASTM E-84 tunnel test. This test was developed in the late 1940s. There is quite a variation in the test results when running a composite panel. A study was done to determine the effect of glass content and panel thickness on the flame spread and smoke index. Another study was also conducted to determine how glass content affects the results of ASTM E1354 Cone Calorimeter Test. It was found that the sample thickness of the panel had a very large effect on the smoke index. This effect is being investigated. It was also seen that glass content can have an affect on flame spread index and smoke values. Information will also be shown on the round robin tests that ASTM has performed showing the reproducibility of the test within a testing lab and between different testing labs. These results indicate that when choosing a material for an application, the thickness and glass content of the laminate needs to be considered to verify that the system will meet the required test results for the application.

Introduction

Fiber reinforced composites are very versatile materials that can be designed to meet mechanical property requirements and even have different properties in different sections of the article being made. There are many components and properties that must be taken into account when designing a composite part. These include resin selection, the fiber reinforcement, fiber direction, fiber content, core materials and thickness. It is commonly known that these all play a part in the mechanical properties of the composite. One property that has not been reviewed in detail is how the change in the laminate construction will affect the behavior of the composite in fire tests. The most common test used by the construction industry for applications where composites are used is ASTM E-84-03a "Standard Test Method for Surface Burning Characteristics of Building Materials."1 This is commonly referred to as the tunnel test. The first tunnel for testing material was developed in 1927 by Underwriters Laboratories (UL) to test chemically impregnated wood. The test was refined and in August, 1950, Underwriters Laboratories published the first test method based on the Steiner Tunnel as Standard UL723. The National Fire Protection Association adopted the method as NFPA 255 in 1955.The American Society for Testing and Materials adopted the test as a tentative standard in 1950 and formally adopted it in 1961. There have been many revisions over the years to better standardize the test between the different testing labs and make the results more reproducible.

This test is currently listed as the standard test used for qualifying materials for interior finish materials in the model building codes. The Flame Spread Index (FSI) considers both the ignition time and the distance that the flame front travels during the 10-minute test. The FSI is a relative number to an FSI of 0 for cement board, and an FSI equal to 100 for select grade red oak. The FSI number is always rounded to the nearest multiple of five. A Class I or Class A Flame Spread Index refers to a FSI of ≤ 25. Class II or Class B refers to a laminate with a FSI of 30-75. Class III or Class C refers to a FSI of 80-200. Anything with a FSI over 200 is not classified. Some interior applications require a Smoke Developed Index (SDI) rating as well. This is also based on red oak being a SDI of 100. The SDI rating for interior finish materials in the building codes is ≤ 450. Some applications, for example exterior of buildings or industrial equipment, use the ASTM E-84 flame spread index, but they do not always have a smoke requirement.

This paper will investigate the affect that the laminate construction has on the ASTM E-84 flame spread index and smoke developed index as well as the cone calorimeter test results. The factors that will be investigated will be the resin content, panel thickness, and type of glass fiber.

ASTM E13542 cone calorimeter test is used to model fire performance in larger scale tests. The paper will also investigate the affect of glass content on the cone calorimeter test results. A model was developed by Stevens 3, 4 and presented previously at this conference that was able to use cone calorimeter test data to predict the ASTM E-84 flame spread index and smoke developed index. This will be used to determine if model could predict the results of the panels at different glass contents.

Experimental

The ASTM E-84 tunnel test is a surface burn test. The test measures the resistance to flame propagation and the amount of smoke generated during the test. It requires a specimen 24 feet (7.3 meters) long and 20 inches (0.56 meters) wide to cover the roof of a tunnel that measures 24-feet (7.3 meters) long by 17½ -inch (0.44 meters) wide by 12-inches (0.31 meters) high. A natural or methane gas flame (37.3 MJ/m3) is applied to one end of the panel with an average airflow velocity of 240 ± 5 feet/minute (73.2 ± 1.5 meters/minute) in the tunnel. Pictures of the test equipment are shown in Figures 1 and 2. FSI considers both the ignition time and the distance that the flame front travels during the 10-minute test. The distance that the flame travels along the panel is tracked by the operator. The FSI is a relative number to a FSI of 0 for cement asbestos board, and having an FSI equal to 100 for select grade red oak. The FSI number is always rounded to the nearest multiple of five. SDI is also measured during the test. This is measured using a photometer in the duct work at the end of the tunnel. The photometer system consists of a lamp and photocell that is mounted on a horizontal section of the 16-in. (406-mm) diameter vent pipe at a point where it is preceded by a straight run of pipe at least 12 diameters or 16 ft (4.88 m) and not more than 30 diameters or 40 ft (12.19 m) from the vent end of the chamber, and with the light beam directed upward along the vertical axis of the vent pipe. The photoelectric cell of which the output is directly proportional to the amount of light received shall be mounted over the light source. The light source is checked for linearity on a periodic basis. SDI is measured by dividing the total area under the sample curve by the total area obtained for the red oak calibration curve and multiplied by 100. Red oak is given a SDI of 100 and cement board is given an SDI of 0. This value is rounded to the nearest 5 if the smoke is < 200 and to the nearest 50 if it is greater than 200.

Two resins were used to do the first study on laminate construction. The first was a brominated epoxy vinyl ester resin with antimony pentoxide and the second was a brominated unsaturated polyester resin. They were both promoted to cure at room temperature with methyl ethyl ketone peroxide catalyst. The panels were then post cured at 250°F (121°C) for 8 hours.

The first sets of laminates were prepared using the hand lay-up process with both the brominated epoxy vinyl ester resin with antimony pentoxide and the brominated unsaturated polyester resin. Three panels 22 inches (56 cm) wide and 8 feet (244 cm) long were prepared for each test set. Panels were made using 3 and 6 layers of 1.5 oz/ft2 chopped strand E-glass mat at about 28% glass, 2 layers of 2.0 oz/ft2 chopped strand mat at 30% glass, and 2 and 4 layers of 24 oz/yd2 woven roving at about 55% glass content.

Only the brominated epoxy vinyl ester resin was used to prepare panels by the vacuum infusion process. Three panels were prepared for each set that were 22 inches (56 cm) wide and 8 feet (244 cm) long. All three panels were stacked on top of each other with a layer of peel ply in between each panel. This way all three panels were infused at the same time. The first series of panels were made using 3, 6, and 9 layers of 1.5 oz/ft2 chopped strand E-glass mat. These panels had a glass content of about 60 percent. The other series of panels were made using 1 and 2 layers of 96 oz/ft2 bi-directional stitched glass mat. The glass content for these panels was 70 percent by weight. These panels were post cured at 250°F (121°C) for 8 hours before testing the panels.

A second experiment was run that had panels made with 4 different brominated epoxy vinyl ester resins that had different levels of fire retardancy. Panels were prepared by hand lay up process with 3 layers of chopped strand glass mat at 25 to 28 percent glass and with 4 layers of woven roving glass which had a glass content of about 60 percent. All of these panels were about 0.12 inches (3 mm) thick. This was to determine if the glass content in the laminate would affect the ASTM E-84 flame spread or smoke index on materials that typically listed as having a higher flame spread index. Cone calorimeter testing was also conducted on these laminates to see how the glass content affected the test data.

Results and Discussion

ASTM has conducted round robin testing on six materials with various flame spread and smoke developed index at 11 testing labs. Multiple tests were run on each material at all 11 laboratories. The flame spread index within the laboratory (repeatability) for all of the materials tested had a relative standard deviation of 18 percent. The reproducibility of the FSI between laboratories was much higher with a relative standard deviation of about 30 percent. The precision testing was also done on the smoke developed index. This was not reported in the ASTM test procedure. Doing the analysis on the material that had approximately a 450 SDI gave a relative standard deviation between laboratories of about 31 percent. Testing is currently underway to determine if the precision of the test data for the FSI and SDI have improved in recent years. The reproducibility will translate into a value range for an average FSI at 25 of ± 7 for a 68 percent confidence level and a ± 14 for a 95 percent confidence level on the result. The range for a SDI of 450 would be ± 140 for a 68 percent confidence level and ± 280 for a 95 percent confidence level.

All panels were tested at the same testing facility. A summary of the FSI test data for the first set of panels tested are shown in Figures 3 and 4. This graph in Figure 3 plots the FSI value versus the panel thickness.

This data would indicate that the thickness of the test panel has no effect on the measured FSI. All of the FSI values were within the standard deviation of the test. It should also be noted the different types of glass and the various glass contents did not affect the FSI as shown in Figure 4. The first set of laminates tested had an FSI value between 15 and 25.

It was expected that the higher glass content laminates should have had a lower flame spread index. To determine if this is the case, a second set of panels were prepared that have typical flame spread index values in a laminate with 25 percent glass ranging from 20 to 50. Panels were made at 25 percent glass and 60 percent glass. The test results are shown in Figure 5. This does show that when the flame spread index of the laminate is greater than 30 on a 25 percent glass panel, going to 60 percent glass significantly reduces the flame spread index. When the flame spread index of the laminate is <25, the reduction seen by going to 60 percent glass is within the standard error of the test. That is why in the first of experiments that was run it did not show up as reducing the flame spread index.

The data for the SDI are shown in the graphs labeled Figure 6, 7 and 8. The graphs of the SDI versus panel thickness shows that the laminate construction can have a large effect on the smoke developed index value. It appears that the glass content of the panel and the thickness of the panel can affect the SDI value. This was seen in both sets of experiments that were run. Looking at the flame spread distance and smoke curves that are recorded during the test gives some insight into the reason why these two parameters affect the SDI value. The curves for the light obscuration and flame spread distance over time during the test for a thin and thick panel are shown in Figures 9 and 10. On the thinner panels it shows the flame front traveling along the panel for the certain time period and then the front starts receding. When the flame front starts receding, the percent light obscuration starts to decrease, which means less smoke is being given off. The total amount of resin in the panel seems to be the controlling factor on the SDI value. The SDI will probably maximize at different thicknesses depending on the resin content of the panel. As seen in Figure 8, higher glass content in the panel will give a lower smoke value for the same thickness of the panel.

Cone calorimeter testing was also conducted on the second set of panels at both 50 kW/m2 and 100 kW/m2 heat fluxes. This data is in Table 1. The only value that showed any significant difference between the 25 and 60 percent glass content laminates was the Total Heat Release rate. By going from 25 percent glass to 60 percent glass, the Total Heat Release rate was reduced by 30 – 50 percent. The predictive model was used to determine if it could predict the E-84 values from this cone calorimeter data. The results are shown in Figure 11 and 12. The model predicted the flame spread index values and the smoke values well. This confirms that the cone calorimeter can be used as a screening test for predicting how a laminate will perform in the ASTM E-84 test.

Conclusions

The laminate construction has an effect on the ASTM E-84 FSI and SDI values. The effect of the glass content of the FSI value increased as the FSI value increased. When the FSI value was less than 25, the difference seen going from 25 to 60 percent glass was hard to see because of the normal test variation. The thickness of the laminate and the resin content appear to have a very significant effect on the SDI values. The SDI values for the same resin system varied in this test from 250 to 1000 depending on the glass content and the thickness of the laminate. This needs to be considered when looking at test data for meeting a specific code. Some code organizations require that the test panels be run on the minimum and maximum thicknesses that they will be used at and with similar construction to how they will be used. This study would indicate that this is not a bad practice since the thickness and glass content can affect the flame spread and smoke index values.

Fabricators should also be aware of this when they are looking at information provided from suppliers. If the test data was run on a laminate that is not of similar thickness and glass content that will be used in the application, then the part may give a significantly different smoke value compared to the reported test data.

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REFERENCES

1. Standard Test Method for Surface Burning Characteristics of Building Materials, ASTM E-84-03a, Annual Book of ASTM Standards

2. Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products using an Oxygen Consumption

Calorimeter, ASTM E1354-04a, Annual Book of ASTM Standards

3. Stevens, M. G., V. Voruganti, and R. Rose. “Correlation of Small Scale Fire Tests to ASTM E-84 Tunnel Performance for Thermoset Resin Systems.” Proceedings of the 4th international Fire and Materials Conference, November, 1995, pp. 319-327.

4. Stevens, M. G. “Cone Calorimeter as a Screening Test for ASTM E-84 Tunnel Test.” Proceedings of Composites 2000. Annual conference of Composites Fabricators Association, October 2000.

Figure 1 - ASTM E-84 Tunnel Test

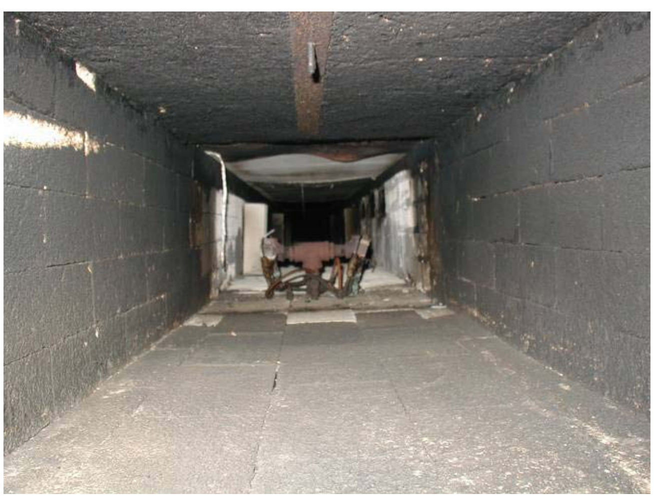

Figure 2 - ASTM E-84 Tunnel Test Burner

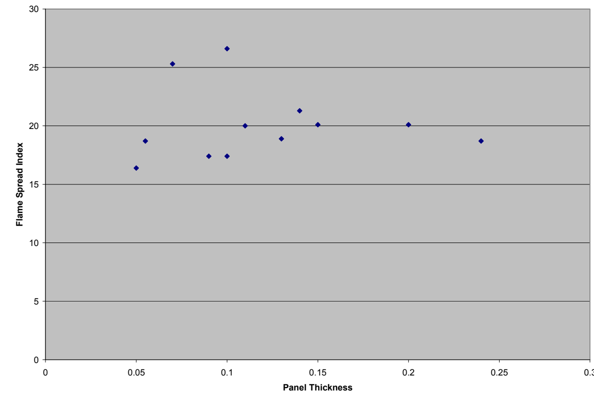

Figure 3 - Affect of thickness on Flame Spread Index

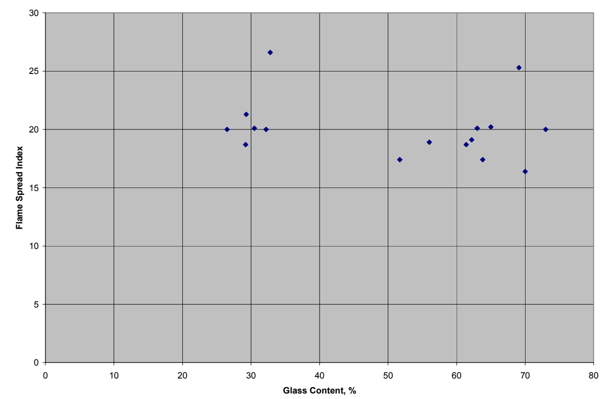

Figure 4 - Affect of glass content on Flame Spread Index

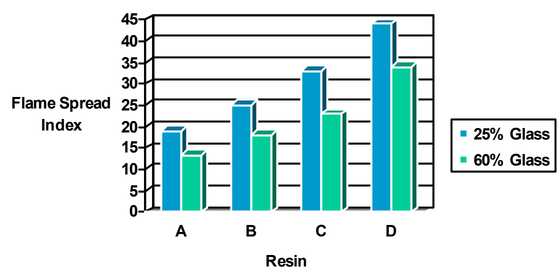

Figure 5. Affect of Glass Content on Flame Spread Index for second set of experiments.

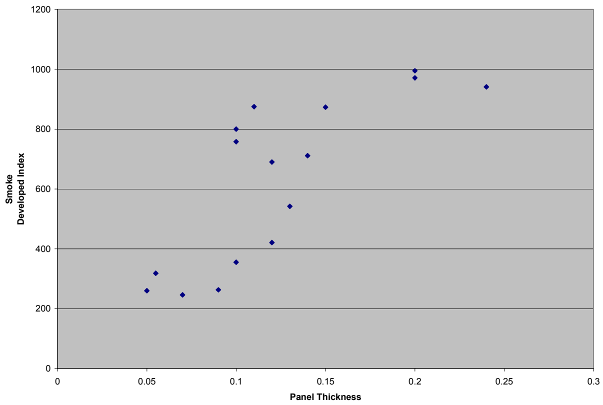

Figure 6 - Affect of Panel thickness on Smoke Developed Index.

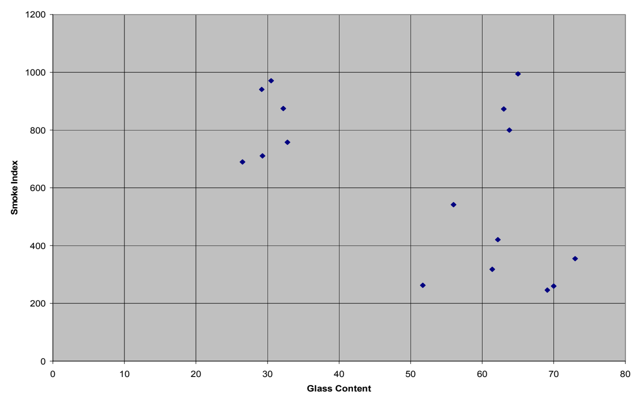

Figure 7 - Affect of Glass Content on Smoke Developed Index.

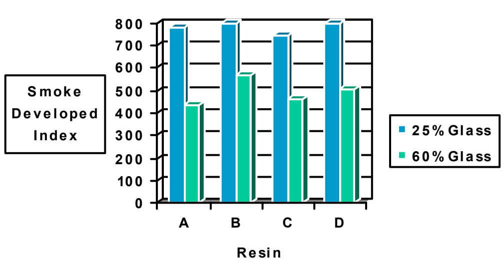

FIGURE 8. Affect of Glass Content on ASTM Smoke Developed Index for second set of experiments.

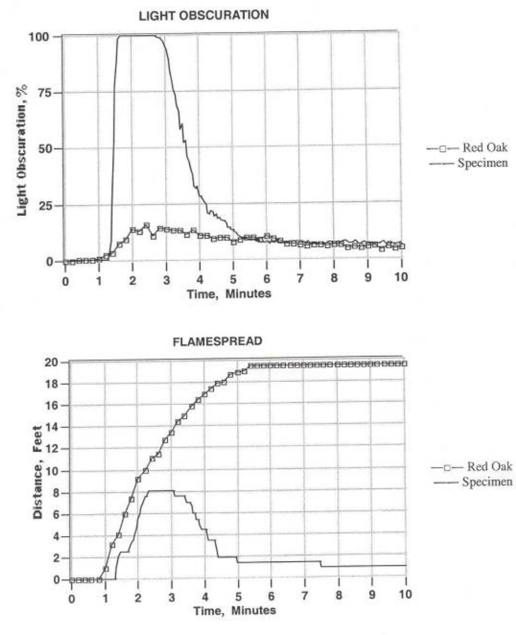

Figure 9 - ASTM E-84 Test curves for 0.1 inch thick panel with 73% glass

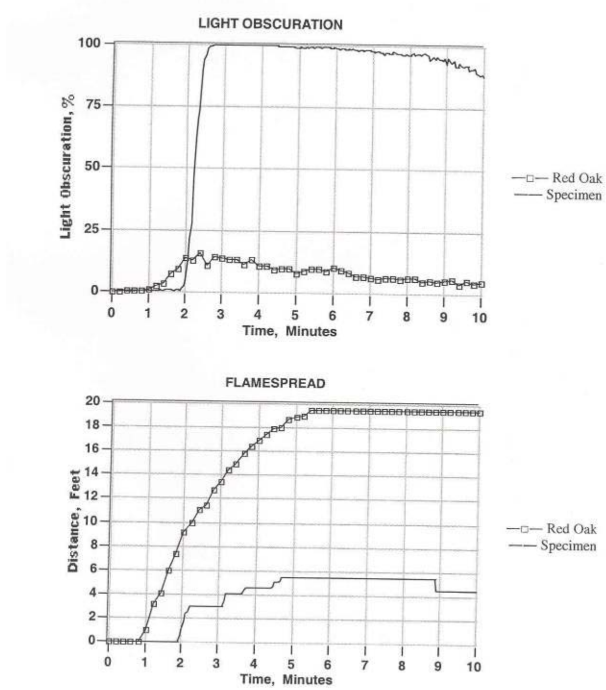

Figure 10 - ASTM E-84 Test curves for 0.2 inch thick panel with 65% glass.

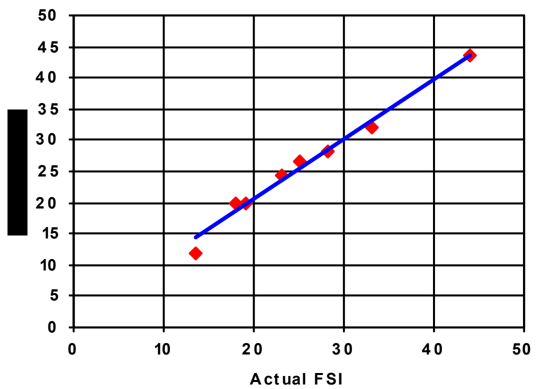

Figure 11. Comparison of Predicted and Actual FSI Values

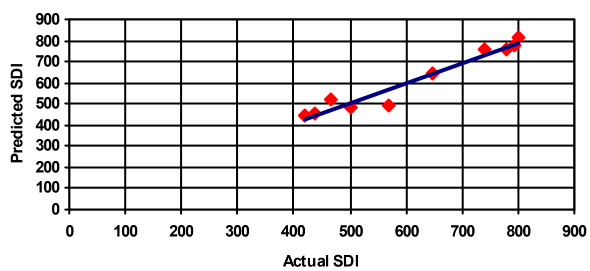

Figure 12. Comparison of Predicted and Actual SDI Values

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