

## Abstract

Wood-plastic composites are becoming more important as a material that fulfills recycling needs. In this study, fire performance tests were conducted on several compositions of wood and plastic materials using the Ohio State University rate of heat release apparatus. Test results included five-minute average heat release rate in  $\text{kW/m}^2$  (HRR avg) and maximum heat release rate in  $\text{kW/m}^2$  (HRR max). As expected, the general trend was an increase in the values of HRR avg and HRR max with increasing concentrations of polypropylene or high density polyethylene.

# Heat Release Rate of Wood-Plastic Composites

Nicole M. Stark, Robert H. White, and Craig M. Clemons  
USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin

## Introduction

There is a growing trend in industry to move towards using recycled materials in various products. As a result, several different uses for recycled materials are being examined by both the government and the private sector. One type of material currently being studied at the USDA Forest Service, Forest Products Laboratory (FPL), is a wood-plastic composite (1-2). These composites encompass a wide variety of materials and fabrication technologies.

In this paper, wood-plastic composites refer to synthetic polymers (the thermoplastics polypropylene or high density polyethylene) combined with a lignocellulosic, such as wood flour, wood fiber, or paper. Other components, such as thermosetting resins and stabilizers, may be present in small amounts. Because each component can come from recycled materials and the composite itself may be recyclable, wood-plastic composites could fill the need of an industry requiring recycled or recyclable materials. Wood fibers and plastics represent a significant portion of municipal solid waste, about 45 percent and 8 percent by weight, respectively (3). Products from wood-plastic composites could provide invaluable uses for these "waste" materials.

Composite materials in which the wood fiber is combined with a synthetic polymer may have beneficial characteristics contributed from each component. Wood-plastic composites currently have several applications and numerous possibilities. The building industry has experimented with the use of these products for decking materials. The automotive industry is beginning to use some of these products for interior paneling in automobiles.

To help meet the demand for these new materials, testing has to be done to determine their applicability for certain uses. The FPL has performed experiments to determine the mechanical properties of these materials (4). However, little information is available on their fire performance. The purpose of this study was to obtain fire performance data for several types of wood-plastic composites. This was done by producing several composites of known composition and obtaining rate of heat release data using the Ohio State University (OSU) test apparatus (5) at FPL (6-7). The OSU apparatus is advantageous for

preliminary work because it is a bench-scale test that provides heat release results that are useful for fire growth modeling and prediction of flame spread performance.

## Preparation and Test Methods

### Sample Preparation

Two types of wood-plastic composites were produced by using different processes to combine the wood component with the synthetic polymer. Melt-blended materials were made by mixing the polymer and the lignocellulosic filler in a high kinetic energy mixer (K-mixer\*) until the polymer was melted and the filler was evenly distributed. Air-laid materials were made by weaving a wood fiber and dry polymer fiber together to form a mat. Melt-blended materials are usually greater than 50 percent synthetic polymer, and the wood component is dispersed in the polymer component. In contrast, air-laid materials are typically less than 50 percent polymer, and the polymer is initially dispersed in the wood component. After the initial combination, materials produced using both methods are hot pressed. In this preliminary study, we produced both types of these materials and tested them with several different percentages of polymer.

For the melt-blended materials, we used two polymers: polypropylene (PP) and recycled high density polyethylene from milk bottles (HDPE-MB). The wood component used as the filler was either recycled newspaper (ONP) or wood flour (WFO). The main component of the wood flour was pine. Each polymer was added to each filler at 50 percent, 60 percent, and 80 percent on a weight basis. As a result, we had 12 different compositions of melt-blended material.

A K-mixer consists of a barrel with an impeller inside. The impeller rotates at a high speed and generates heat as a result of the kinetic energy. The heat melts the polymer, and the impeller disperses the wood fiber. The rpm's of the impeller, the temperature at which the material can be dumped, and the flow rate of cooling water through an outside jacket can all be

\*The use of trade or firm names in this publication is for reader information and does not imply endorsement by the US Department of Agriculture of any product or service.

controlled. The rpms varied during each individual batch in the K-mixer. The K-mixer was sometimes run initially at a high rpm to melt the polymer, then lowered to ensure good dispersion, then increased to obtain the proper temperature for release of material. This was particularly important with a high fiber concentration (40 percent or 50 percent) where additional residence times are needed to ensure proper dispersion of the fiber.

After the material was blended in the K-mixer, we pressed the material to form 12.7 mm (0.5 in) thick boards. To avoid air pockets, the boards were pressed slowly in a hot steam press using little pressure. We used two retaining rings to prevent the material from pressing outward. The outer ring was 12.7 mm (0.5 in) thick and controlled the thickness of the specimen. The inner ring was slightly thinner and had a smaller diameter. The outer ring contained the material and allowed flashing of excess material. Teflon-coated metal cauls were used to prevent sticking of the composite material. Preliminary OSU tests on specimens of various thickness revealed that the 12.7 mm (0.5 in) thickness was appropriate to obtain heat release data for the desired length of time. The 100 by 150 mm (4 by 6 in) specimens were cut from the circular samples removed from the press.

For the air-laid material, the wood fiber (WFi) was hemlock and the synthetic polymers were either polypropylene (PP) or virgin high density polyethylene (HDPE). The PP was added to the wood fiber in weight percentages of 10, 30, and 50 percent. The virgin HDPE was added to the wood fiber and 10 percent phenolic resin in weight percentages of 10,30, and 50 percent.

We produced the air-laid material by first forming a mat consisting of the wood fiber and a dry polymer granule matrix. The wood fiber can be thought of as being woven together by a special needling process. The polymer gets caught in the woven fibers and the result is a mat. The mat is pressed in a hot press during which time the polymer melts and the polymer and/or the resin added holds the wood fibers together to produce the resulting board.

### Fire Testing

We tested the materials in an OSU or ASTM E906 apparatus (5) to obtain their heat release rate (HRR) characteristics. The apparatus had been modified to use the oxygen consumption method to determine the HRR (6-7). Some initial samples were tested in a vertical configuration. This proved to be impractical because the material would melt and drip before the data could be recorded. As a result, the specimens were tested in a horizontal configuration. A 35 kW/m<sup>2</sup> heat flux was produced by controlling the power to the four electric heater elements. This corresponds to approximately 18.3 kW/m<sup>2</sup> directed at the specimen surface after the radiant heat flux produced from the heater elements is reflected towards the specimen by a stainless steel reflector, 1.3 mm (0.05 in) thick. The heat flux was kept constant regardless of any deformation of the material that may change the initial exposed surface area. A gas pilot flame was positioned over the center of the specimen so that the tip of the flame just touched the surface of the specimen. We terminated the tests after 700 to 800 seconds of exposure. The

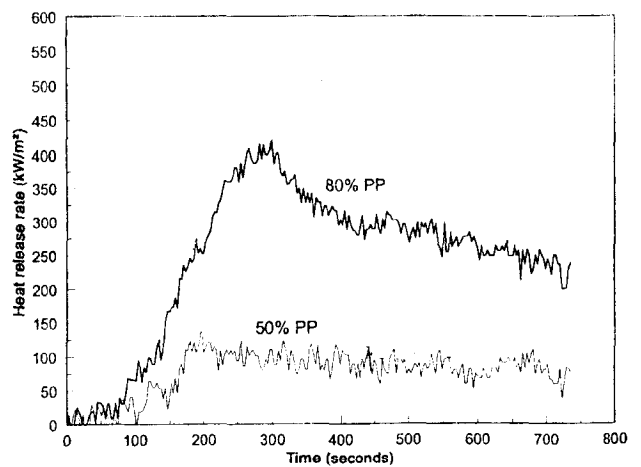


Figure 1. HRR as a function of time for WFo/PP melt-blended composites.

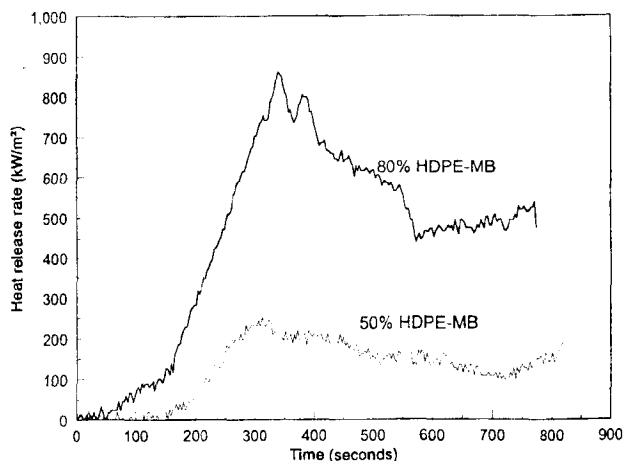


Figure 2. HRR as a function of time for WFo/HDPE-MB melt-blended composites.

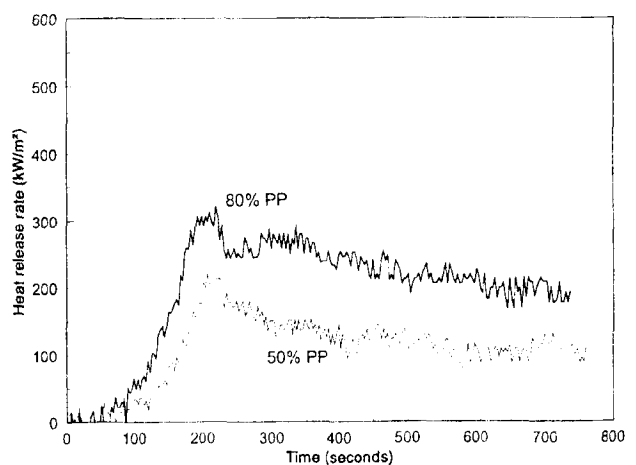


Figure 3. HRR as a function of time for ONP/PP melt-blended composites.

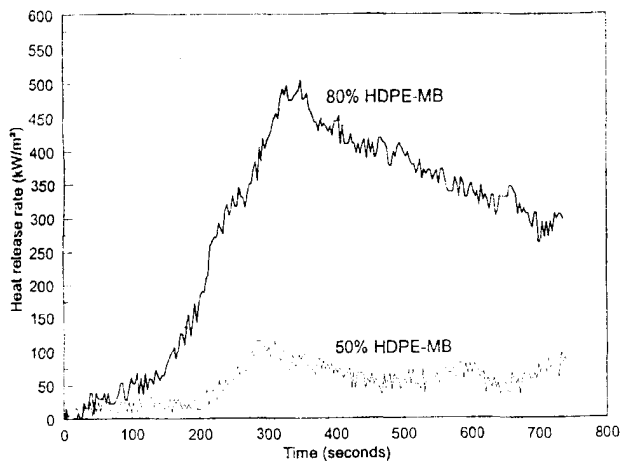


Figure 4. HRR as a function of time for ONP/HDPE-MB melt-blended composites.

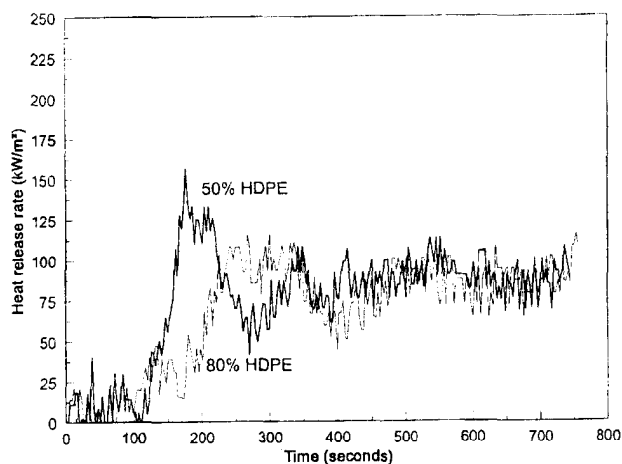


Figure 5. HRR as a function of time for hemlock/HDPE air-laid composites.

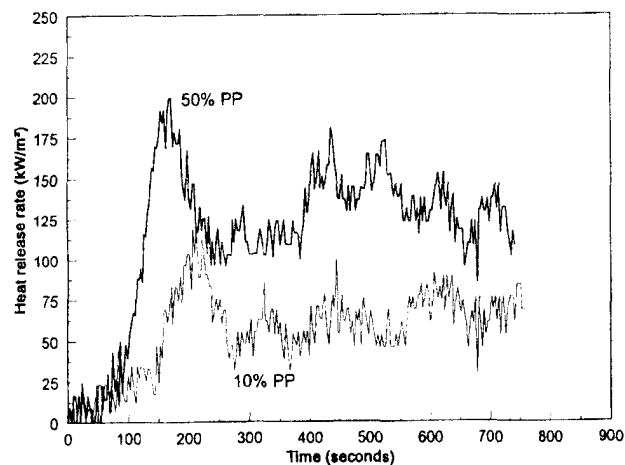


Figure 6. HRR as a function of time for hemlock/PP air-laid composites.

calculated results were HRR in kW per square meter of exposed surface area as a function of time.

Three replicates of each composition were tested. The specimens were 100 by 150 mm (4 by 6 in.) and 12.7 mm (0.5 in.) thick. Each specimen was wrapped in two layers of aluminum foil and mounted in a horizontal holder with a 12.7-mm (0.5 in.) layer of Kaowool insulation as a backing. The samples were conditioned at 23°C (73°F) and 50 percent relative humidity. In addition to the wood-plastic systems previously discussed, we tested two species of solid-wood specimens: hemlock and pine. Hemlock is the fiber used in the air-laid composites. Pine is the main component in the wood flour used in the melt-blended composites. We also tested specimens made from two of the synthetic polymers, HDPE-MB and PP, as pure polymer. The pure polymer specimens were formed using the melt-blend method.

## Results

Our initial results were expressed as HRR of exposed area as a function of time. To express the results as a single number, we report the initial peak HRR or the average HRR.

### HRR as a Function of Time

Representative HRRs ( $\text{kW/m}^2$ ) for the different types of composite specimens are shown in Figures 1-6. The tests were normally terminated between 700 and 800 seconds. According to ASTM E 906, normal test duration should be 10 minutes (600 seconds). For the duration of the tests, there was essentially one peak in most curves for the composite specimens. For the tests using the solid-wood samples, there was an initial peak at around 100 seconds followed by a second peak at around 500 seconds (Figure 7). The second peak is generally associated with temperature increase on the unexposed surface of the sample. Representative HRR curves for the synthetic polymer specimens are also reported in Figure 7. In the pure PP tests, there was a single peak present. In one of the two pure PP tests, it appears that the peak was obtained just as the test was terminated. In the two pure HDPE-MB tests, the HRR curve was still increasing when the test was terminated.

### Peak and Average HRRs

The heat and smoke release rate curves were analyzed to obtain the: a) average HRR over five minutes after an initial increase in HRR in  $\text{kW/m}^2$  (HRR avg) and, b) initial peak HRR in  $\text{kW/m}^2$  (HRR max). With these calculated values, data for the wood-plastic composites can be compared with each other as well as to data from solid-wood and synthetic polymer specimens. For the composite materials, the average of the coefficient of variation for the HRR data is 12 percent. The values of HRR avg and HRR max for each composite system are presented as a function of synthetic polymer composition (percent) (Figures 8-11). Results for the two air-laid materials and one of the four melt-blended materials are shown. The numerical values of HRR avg and HRR max for the solid-wood and synthetic polymer specimens plus their corresponding standard deviations are reported in Table I.

## Discussion

### HRR

General trends for the HRR of melt-blended composites indicate that, as the amount of polymer in the composite increases, HRR avg and HRR max also increase (Figures 8-11). The highest HRR's were obtained with composites of 80 percent synthetic polymer. In particular, the HRRs for the wood flour/80 percent HDPE-MB was significantly greater than all the other specimens. For average HRR, the four 80 percent synthetic polymers were among the five highest. For initial peak HRR, the four 80 percent synthetic polymers were among the seven highest. (Two of the others were the pure synthetic polymer.) In the case of HRR for air-laid composites, the same general result was observed. The values of HRR avg and HRR max increased with increasing polymer concentration, although the increase was not as large as the observed increase with the melt-blended materials with a higher percentage of synthetic polymer. In the ranking of average and peak HRR, almost all the materials with a 50 percent or less polymer content were not significantly different.

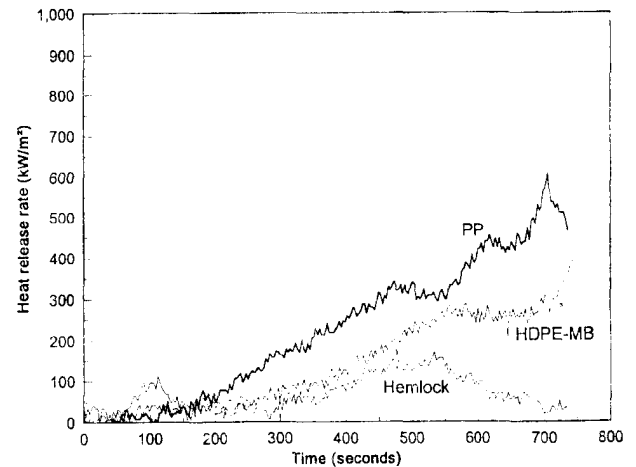
Results for the solid-wood specimens (Table I) were generally consistent with the literature. Tran (8) reported a five-minute average HRR of approximately 100 kW/m<sup>2</sup> for white pine tested in a cone calorimeter following the ASTM E1354 testing method (9) with a heat flux of 20 kW/m<sup>2</sup>. After the completion of this study, FPI replaced its OSU apparatus with a cone calorimeter. In cone calorimeter tests of pine and hemlock specimens using 20 kW/m<sup>2</sup> heat flux, values for HRR avg were 106 and 102 kW/m<sup>2</sup>, respectively. The respective values for HRR max were 133 and 127 kW/m<sup>2</sup>. Except for the HRR avg for hemlock, which was 112 percent greater, the cone calorimeter results were about 25 percent greater than the OSU calorimeter results. The OSU and cone calorimeters are different in ways that can affect the results, such as the gas pilot flame above the specimen in the OSU tests compared with an electric spark igniter in the cone calorimeter.

In our tests of 25-mm-thick samples, the respective values for HRR avg and HRR max were 132 and 504 kW/m<sup>2</sup> for PP and 51 and 378 kW/m<sup>2</sup> for HDPE-MB. The value for the HRR max for HDPE-MB was not a true peak value, because the HRR was still increasing when the test was terminated. The HRR avg values calculated using the OSU test for pure polymer specimens were low. The peak was not figured into the five-minute average because it did not occur within five minutes from ignition of the specimen.

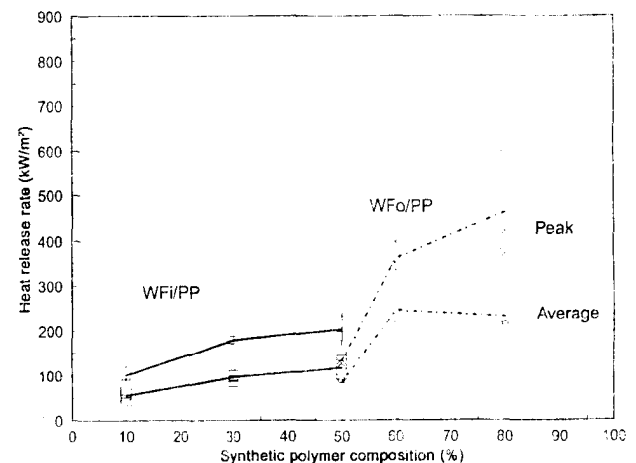
In cone calorimeter tests of HDPE-MB specimens 11 mm thick, we obtained HRR avg and HRR max values of 152 and 366 kW/m<sup>2</sup>, respectively. Hirschler (10) cited peak HRR values of 1170 and 913 kW/m<sup>2</sup> for 6 mm thick samples of polypropylene and polyethylene exposed to a 20 kW/m<sup>2</sup> heat flux. Scudamore and others (11) reported mean values for peak HRR of 377 and 453 kW/m<sup>2</sup> for 3 mm thick samples of PP and 6-mm-thick samples of HDPE, respectively, exposed to a heat flux of 20 kW/m<sup>2</sup>. The values for average HRR for more than three minutes were 130 and 137 kW/m<sup>2</sup> for the PP and HDPE, respectively. Using a heat flux of 50 kW/m<sup>2</sup>, Elliot and others (12) tested medium density polyethylene (MDPE) for a range of thicknesses from 1 to 10 mm. The thicker samples had

**Table 1. Values of HRR avg and HRR max with their Corresponding Uncertainties (shown in [ ]) for Solid-Wood and Synthetic Polymer Specimens**

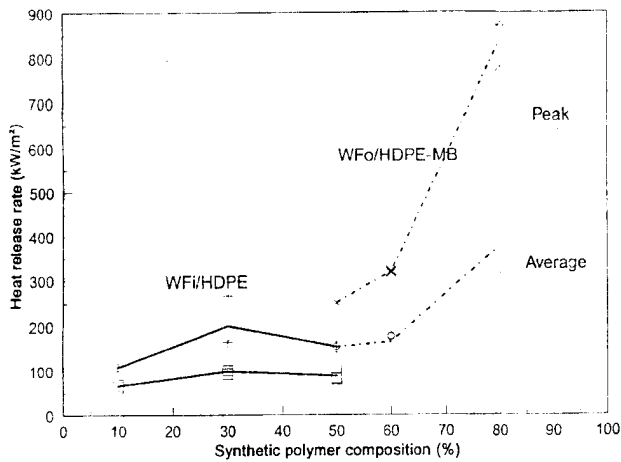
Material	HRR avg (kW/m <sup>2</sup> )	HRR max (kW/m <sup>2</sup> )
PP	132 [7]	504 [145]
HDPE-MB	51 [1]	378 [23]
Pine	86 [16]	109 [12]
Hemlock	48 [2]	99 [17]



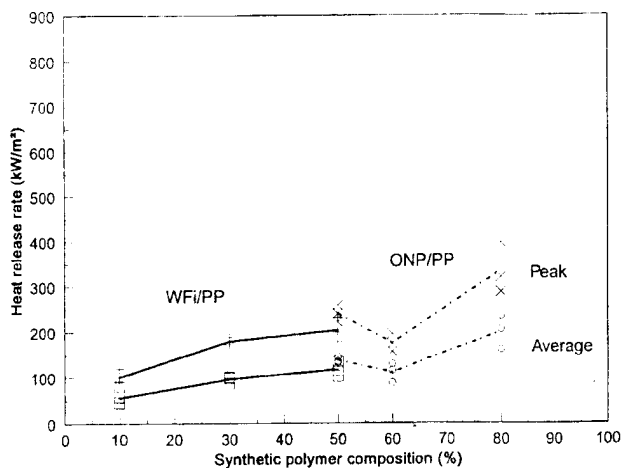
**Figure 7. HRR as a function of time for solid hemlock, PP, and HDPE-MB.**



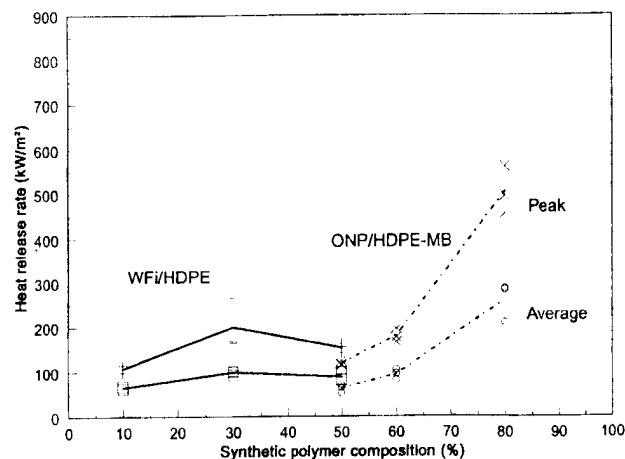
**Figure 8. HRR as a function of synthetic polymer composition for wood fiber or wood flour composites containing PP.**



**Figure 9.** HRR as a function of synthetic polymer composition for wood fiber or wood flour composites containing HDPE.



**Figure 10.** HRR as a function of synthetic polymer composition for wood fiber or ONP composites containing PP.



**Figure 11.** HRR as a function of synthetic polymer composition for wood fiber or ONP composites containing HDPE.

higher peak HRRs but they occurred later in the tests. For thermally thick samples, the HRR would increase slowly for a period before increasing rapidly to a peak when the remaining sample had become thermally thin. In their test of 10-mm-thick MDPE, the HRR was around 500 kW/m<sup>2</sup> at 350 seconds before increasing to a peak of around 1.550 kW/m<sup>2</sup> at 450 seconds. This literature data is consistent with the premise that the low HRRs (average and peak) we obtained for the 25 mm thick samples of pure synthetic polymers were due to the slow initial burning of the synthetic polymers and the termination of the tests before the peak HRR was obtained.

The expectation was that solid-wood samples (hemlock and pine) would produce the lowest values and pure synthetic polymers (HDPE and PP) would produce the highest values, with the composite values somewhere between. This was not the case. The two wood samples were among the group of low HRRs that were not significantly different, but so were the pure HDPE-MB samples for the five-minute average (second lowest). As previously discussed, the problem appeared to be the prolonged burning of the pure synthetic polymer samples [Figure 7]. Both the synthetic polymers had peak HRR's among the top seven specimens. The peak HRR for pure PP was greater than the 80 percent PP specimens. In a way, the results for the composites were a composite of the pure materials—the early peak HRR of the wood and the higher heat content of the polymers.

Additional tests need to be done at higher heat flux levels. The heat flux used in these tests (18 kW/m<sup>2</sup> on the surface) was a fairly low heat flux level. Most HRR testing is done with heat flux levels of 35 or 50 kW/m<sup>2</sup>. Data from this report are an initial set of fire performance data. Additional extensive testing using a wider range of materials and exposures are possible with the cone calorimeter. Fire retardant treatments can be used to reduce heat release and flame spread.

## Application of Results

Heat release rate is a critical factor in predicting the contribution of a burning material to the growth of a fire. However, it is not the fire performance response that is currently used to regulate materials. In North America, regulation of building materials is generally based on the flame spread index (FSI) as determined in the 25 ft tunnel (ASTM E84)(13). The greater the FSI, the faster or further the flames travel down the specimen, which is the ceiling of the tunnel. In building codes, regulations are based on the three classes of Class I, 0-25; Class II, 26-75; and Class III, 76-200. The HRR can be used to predict the FSI. Although a more complete predictor also includes the thermal properties and ignition temperature (14), HRR alone has been used as a predictor of FSI.

Although a good correlation was not available to use with our tests of the composites in the OSU apparatus using a heat flux of 20 kW/m<sup>2</sup>, available correlations suggest that most of the materials examined would likely meet a Class III rating if tested according to ASTM E84. The exception would be the composites with 80 percent PP or HDPE-MB and the wood flour composites with 60 percent pp or HDPE-MB. A correlation of FSI compared with a five-minute HRR in OSU was described in a previous study on solid wood in a vertical orientation (15). The correlation indicated that, with a heat flux

of 25 kW/m<sup>2</sup>, a Class III rating is obtainable if an average HRR is between 60 and 160 kW/m<sup>2</sup>. Stevens and others (16) developed a correlation between the peak HRR in the cone calorimeter and the ASTM E84 FSI for thermoset resin systems (FSI of 15 to 45) using a heat flux of 50 kW/m<sup>2</sup>. Flame spread indexes of 25 and 75 corresponded to peak HRRs of 180 and 430 kW/m<sup>2</sup>, respectively. In unpublished tests of wood specimens (FSI of 150 to 250) in the cone calorimeter using a heat flux of 50 kW/m<sup>2</sup>, we found that FSIs of 75 and 200 corresponded to peak HRRs of 205 and 350 kW/m<sup>2</sup>, respectively. Although greater heat flux generally results in higher peak HRR, the effect is not consistent for different materials (8, 10-11). Note that there are problems conducting the ASTM E84 flame spread test with materials that melt and drip when exposed to heat.

Other fire performance tests could be performed on the same materials. Future studies need to focus on tests needed for specific applications. Both the compositions examined and the tests performed can be tailored to fit a particular application as these materials may be used in a wide variety of applications. For composites with poor performance in HRR or flame spread, the effectiveness of fire retardants in these materials should be investigated.

## Conclusions

In this study, the values for HRR avg and HRR max increased with increasing polymer concentration in a particular composite system. Composites containing more than 60 percent polymer and particularly 80 percent polymer have large HRRs. The flame spread index determined for most specimens in this study would be categorized as a Class III rating. At higher concentrations of polymer, the flame spread index may be above the Class III rating. Depending on specific applications, additional fire performance tests are needed.

## References

1. Forest Products Laboratory, "Recycling research progress at the Forest Products Laboratory," Gen Tech Rep FPL-GTR-86, US Dept of

Agriculture, Forest Service, Forest Products Lab, Madison, WI, 1995, 19 p.

2. B. English, C.M. Clemons, N. Stark, and J.P. Schneider, "Waste-Wood-Derived Fillers for Plastics," Gen Tech Rep FPL-GTR-91, US Dept of Agriculture, Forest Service, Forest Products Lab, Madison, WI, 1996.
3. J.J. Balatinez and R.T. Woodhams, *J of Forestry*, **91** (11) 22 (1993).
4. C. Gonzalez, C.M. Clemons, G.E. Meyers, and T.M. Harten, "Effects of Several Ingredient Variables on Mechanical Properties of Wood Fiber-Polyolefin Composites Blended in a Thermokinetic Mixer," *Proc Material Research Society Symp*, **266**, (1992).
5. ASTM Designation: E906-83, "Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products," *Annual Book of ASTM Standards*, **4.07**, 807 (1994).
6. H.C. Tran, *Fire and Materials* **12**, 143 (1988).
7. H.C. Tran, "Modifications to An Ohio State University Apparatus and Comparison with Cone Calorimeter Results," in *Heat and Mass Transfer in Fires*, J.G. Quintiere, L.Y. Cooper, eds., *Proc of the AIAA/ASME Thermophysics and Heat Transfer Conf*, Seattle, WA, ASME, NY, **141**, 131 (1990).
8. H.C. Tran, "Experimental Data on Wood Materials," in *Heat Release in Fires*, V. Babrauskas and S.J. Grayson eds., Elsevier Applied Science, London and New York, p. 357-372 (1992).
9. ASTM Designation: E1354-94, "Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter," *Annual Book of ASTM Standards*, **4.07**, 1106 (1994).
10. M.M. Hirschler, "Heat Release from Plastic Materials," in *Heat Release in Fires*, V. Babrauskas and S.J. Grayson eds., Elsevier Applied Science, London and New York, p. 373-422 (1992).
11. M.J. Scudamore, P.J. Briggs, and F.H. Prager. *Fire and Materials*, **15**, 65 (1994).
12. P.J. Elliot, R.H. Whiteley, and J.E.J. Staggs. "Steady State Analysis of Cone Calorimeter Data," *Proc Fire and Materials, Int'l Conference*, Interscience Communications Ltd, London, **4**, 35, (1995).
13. ASTM Designation: E84-94, "Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products," *Annual Book of ASTM Standards*, **4.07**, 385, (1994).
14. M.A. Dietenberger, O. Grexa, R.H. White, M.Sweet, and M. Janssens. "Room/Corner Tests of Wall Linings with 100/300 kw Burner," *Proc Fire and Materials, 4th Int'l Conference*, Interscience Communications Ltd, London, **4**, 53 (1995).
15. S.L. LeVan and H.C. Tran, "The Role of Boron in Flame-Retardant Treatments," *Proc First Int'l Conf on Wood Protection with Diffusible Preservatives*, Margaret Hamel, ed., **1**, 39 (1990).
16. M.G. Stevens, V. Voruganti, R. Rose. "Correlation of Small Scale Fire Tests to ASTM E84 Tunnel Performance for Thermoset Resin Systems," *Proc Fire and Materials, Int'l Conference*, Interscience Communications Ltd, London, **4**, 319 (1995).

## Biography



Nicole Stark received a BS in chemical engineering from the University of Wisconsin/Madison in 1995. She began her career at the Forest Products Laboratory in the fire safety of wood products research unit and is currently involved with the performance designed composites group with a focus on non-traditional composites such as waste wood fiber reinforced thermoplastics.

*The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin. This article was written and prepared by US Government employees on official time, and it is therefore in the public domain and not subject to copyright.*

