CONE CALORIMETER TESTS OF WOOD COMPOSITES

Robert H. White, Forest Service Forest Products Laboratory, USA
& Kuma Sumathipala, American Wood Council, USA

ABSTRACT

The cone calorimeter is widely used for the determination of the heat release rate (HRR) of building products and other materials. As part of an effort to increase the availability of cone calorimeter data on wood products, the U.S. Forest Products Laboratory and the American Wood Council conducted this study on composite wood products in cooperation with the Composite Panel Association and APA-The Engineered Wood Association. We tested the specimens in accordance with ASTM E 1354 and used a heat flux of 50 kW/m^2. The twenty-nine commercial wood composites included untreated and fire-retardant-treated (FRT) particleboards, untreated and FRT medium density fiberboards, untreated high density fiberboards, untreated plywoods, and untreated oriented strand boards. Such FRT composites are made to have a Class A flame spread rating when tested in the ASTM E 84 tunnel test. Fire retardant treatment of the wood products reduced the initial HRR, reduced the mass loss rate, increased the residual mass fraction, resulted in lower average effective heat of combustion values, and usually resulted in longer ignition times. For the untreated specimens, the results for residual mass fraction at the end of the test ranged from 0.13 to 0.28 with a mean result of 0.23. In contrast, the results for the FRT samples ranged from 0.33 to 0.39 with a mean result of 0.36. In the case of the 300 s HRR averages, the range was 118 to 218 kW/m^2 for the untreated composites and 58 to 100 kW/m^2 for the FRT composites.

INTRODUCTION

As part of an overall effort to increase the availability of cone calorimeter data on wood products, the U.S. Forest Service Forest Products Laboratory (FPL) and the American Wood Council (AWC) conducted this study on composite wood products in cooperation with the Composite Panel Association (CPA), APA-The Engineered Wood Association, and member companies of these organizations. The cone calorimeter is a widely used small-scale test for the determination of the heat release rate (HRR) of building products and other materials. In addition to the measurement of the HRR due to combustion, the cone calorimeter also provides data on the times for ignition and visible smoke production.

The fire performance characteristics measured in the cone calorimeter are measures of the relative flammability of the wood products. Although the cone calorimeter is a small-scale test, the results correlate well with test results from large-scale fire tests [1] and are used to predict the combustion behavior of materials in a real fire. In cooperation with the AWC, the FPL created an on-line database of data files for cone calorimeter tests conducted at FPL and reported in one or more of its publications (http://www.fpl.fs.fed.us/products/products/cone/introduction.php).

The ASTM E84 flame spread test [2] is the most common test used to regulate the flammability of building materials in the U.S. Available data in the public domain for the ASTM E84 flame spread index of wood products are tabulated in an AWC publication [3] and are discussed in a technical note of APA-The Engineered Wood Association [4]. Cone calorimeter data has been used to predict the flame spread index in the E84 tunnel test [1,5,6].

This project was limited to samples of commercial composite wood products. Several studies on cone calorimeter testing of wood-plastic composites were reviewed in a recent publication [7]. Testing of commercial and experimental wood composites in the cone calorimeter has been done previously at FPL [8-14]. Tests on commercial wood composites included tests on plywood, particleboard, oriented strandboard (OSB), hardboard, waferboard and fire-retardant-treated (FRT) plywood [11,13]. Results presented in the FPL Research Paper [11] are thermophysical and fire properties needed for fire modeling. Data files for these materials are included in the on-line FPL cone calorimeter database.

The wood-based composites tested in this project included particleboard, medium-density fiberboard (MDF), high density fiberboard (HDF), plywood and OSB (Table 1). All materials tested were commercial products obtained from the manufacturers. The wood-based composites tested included particleboard and MDF products treated with fire-retardant (FR) chemicals as well as the untreated products.

METHODS

We tested the 100 mm by 100 mm specimens in the cone calorimeter at the FPL in accordance with the procedures in ASTM International test method E 1354-08a [15]. The FPL cone calorimeter is a Combustion Analysis System (AutoCal), Model No. Cone 2A, manufactured by Atlas Electric Devices Company of Chicago, IL. The FPL apparatus was purchased in 1995. In 2008, the FPL cone calorimeter was modified and upgraded with Windows-based data acquisition software and new data acquisition hardware. The upgrade was done by FireScience, Inc of Lake Villa, IL. Tests conducted for this project (i.e. tests numbered 1488 or greater), the data collection and calculations were done using the FireScience software (Cone Calorimeter IIa ver. 4.10).

Specimens were exposed in the horizontal orientation with the conical radiant electric heater located 25 mm above the specimen. The specimens were tested in the optional retainer frame but without the wire grid. As specified in the standard, the sides and bottom of the specimens were wrapped in aluminum foil and the specimen rested on a ceramic fiber blanket. The heater was set for a heat flux intensity of 50 kW/m^2 and the spark igniter was used. Visual observation of the length of time required to create a steady flame was recorded. The 4 seconds criteria for observing the time for sustained ignition of the specimen was used. Three replicate samples were tested.

In the cone calorimeter test; the HRR, specimen mass, and smoke obscuration are determined as a function of time. HRR was calculated from the measurements of the depletion of oxygen during the test. Specimen mass was measured from a load cell beneath the specimen. Obscuration of a laser beam in the exhaust duct was recorded as a measure of the visible smoke development from the burning specimen. Average specific extinction area was computed from smoke obscuration and mass loss data for duration of the test. With retainer frame, the exposed surface area of the specimen was 0.008836 m^2, which was used to express the results per unit surface area. These results were reported as a function of time. The data scans are taken at 1 second intervals. The data recorded included those specified in the ASTM International standard E1354, or the corresponding International Organization for Standardization (ISO) 5660-1 and ISO 5660-2 standards [16].

Statistical analysis was done with SAS for Windows, SAS 9.2, of SAS Institute, Cary, NC.

MATERIALS

Wood composites included in this study included untreated and FRT particleboards, untreated and FRT MDF, untreated HDF, untreated plywood, and untreated OSB (Table 1). Specimens were supplied to FPL by the cooperators in 2008 and 2009. The cone calorimeter tests were conducted in 2009 and 2010. Prior to testing, the specimens were conditioned at 50 % RH and 23^{o}C.

Several of the particleboard and MDF were made with FR chemicals. Such FRT particleboards and MDF are made to have a Class A flame spread rating. A Class A flame spread rating requires a flame spread index of 25 or less in the ASTM E84 tunnel test. Manufacturers' literature for some of these

1. List of materials tested

Material Number	Description [1]	FPL Test No.	Thickness mm (in.)	Density as tested [2] kg/m^3
Untreated Particleboards				
1	Grade D2 – Mobile home decking, urea-formadehyde resin, southern yellow pine	1624	19 (3/4)	867 (12)
2	M3i, "NAF [3]", contained BASF M20HB pMDI and 0.17% Hexion FMA wax.	1630	19 (3/4)	720 (5)
3	M2, "NAF", contained BASF M20HB pMDI and 0.17% Hexion FMA wax.	1637	13 (1/2)	724 (10)
4	PBU, "NAF", contained BASF M20HB pMDI and 0.19% Hexion FMA wax.	1627	19 (3/4)	692 (11)
5	Premium Flooring, "NAF", contained BASF M20HB pMDI and 0.25% Hexion FMA wax.	1640	9 (3/8)	742 (16)
6	Industrial Particleboard, UF resin, Southern yellow pine, density Industrial PB – 48.2	1625	19 (3/4)	777 (6)
7	ANSI M-3 grade specifications, Made in western U.S. plant. Manufactured with three layer panel construction process.	1617	19 (3/4)	727 (18)
8	Grade LD1, Urea-formadehyde, 50% hardwood (maple, birch), 50% softwood (spruce)	1643	38	474 (2)
9	Grade M2, urea-formadehyde, 50% hardwood (maple, birch), 50% softwood (spruce)	1635	12	696 (8)
FRT Particleboards				
10	FRT, "NAF", meets ANSI M-2 specifications.	1615	19 (3/4)	737 (2)
11	FRT, with urea formaldehyde resin.	1622	19 (3/4)	733 (10)
12	FRT, UF resin, Southern yellow pine. density PB – 51.1	1633	19 (3/4)	798 (15)
Untreated Medium Density Fiberboards				
13	Standard grade, manufactured in western U.S. plant.	1619	19 (3/4)	707 (18)
14	Standard grade, manufactured in southern U.S. plant. Sold under same name as Material No. 13	1621	19 (3/4)	726 (21)
15	Methylene Diphenyl Diisocynate (MDI) adhesive, made from hardwood species	1628	19 (3/4)	725 (6)
16	UF adhesive, made from hardwood species	1632	19 (3/4)	686 (5)
FRT Medium Density Fiberboards				
17	FRT, "NAF", manufactured in a southern U.S. plant.	1620	19 (3/4)	728 (34)
18	FRT, urea formaldehyde resin, from southern U.S. plant.	1616	19 (3/4)	654 (27)
19	Made with pine furnish and MUF resin	1631	19 (3/4)	663 (10)
20	FRT, manufactured in a western U.S. plant.	1618	19 (3/4)	761 (6)
21	FRT, "NAF", manufactured in a southern U.S. plant.	1623	19 (3/4)	602 (12)
High Density Fiberboards				
22	ANSI grade 230, Urea Formaldehyde, made from Mixed Hardwood (mostly maple and birch), Avg. Properties: Density 999 kg/m^3, Surf. Dens. 1204 kg/m^3, Core Dens. 873 kg/m^3	1638	5	958 (6)
23	ANSI grade 230, type standard, Urea Formaldehyde, Mixed Hardwood (mostly maple and birch), Avg. Properties: Density 912 kg/m^3, MOR 6330 psi, IB 247 psi, Surf. Dens. 1043 kg/m^3, Core Dens. 808 kg/m^3.	1639	3	816 (11)
Untreated Plywoods				
24	White fir, PF adhesive	1641	9 (3/8)	449 (16)
25	SYP species PF adhesive	1642	9 (3/8)	598 (28)
Untreated Oriented Strand Boards				
26	SYP and hardwood species, PF/ISO adhesive	1634	11 (7/16)	720 (36)
27	Quaking aspen & hardwoods species [includes jack pine, red pine, balsam poplar,white birch, and/or red maple]. PF/PF adhesive.	1636	11 (7/16)	639 (72)
28	Aspen, PF/ISO.	1629	18 (23/32)	576 (46)
29	SYP & hardwood species, PF/ISO	1626	18 (23/32)	646 (11)

[1] Description information provided by the supplier of the test specimens.

[2] These density values were calculated from the mass and thickness measurements made on the 100 by 100 mm samples at the time of the cone calorimeter test. Means and (standard deviations) are listed.

[3] "NAF" indicates no urea formaldehyde resin was added to the board.

FRT products provided some additional information on the flame spread index and the smoke developed index obtained in the E 84 tests. Material nos. 10 and 11 are fire-rated particleboards with a Class A rating based on a flame spread index of 20 and smoke developed index of 25. Per manufacturer's literature, material no. 17 is a fire-rated MDF with a Class A rating based on a flame spread index of 15 and smoke developed index of 95 in the ASTM E84 test. Material no. 18 is also a fire-rated MDF with a Class A rating based on a flame spread index of 15 and smoke developed index of 95 in the ASTM E84 tunnel test. The corresponding untreated product is Material no. 14. Material no. 20 has a Class A rating based on a flame spread index of 20 and smoke developed index of 40 in the ASTM E84 tunnel test. The corresponding untreated product MDF is Material no. 13. Material no. 21 is fire-rated MDF with a Class A fire rating based on a flame spread index of 15 and smoke developed index of 95 in the ASTM E 84 test.

With respect to material nos. 2 through 5, there are four groups of "NAF" particleboard samples, all of which are made with three liquid constituents, pMDI, water and a small amount of wax sizing. The four groups include ¾ inch M3i, (ANSI A208.1-2009 nomenclature), ½" M2 grade, ¾ inch PBU grade and 3/8 Inch Premium Flooring grade – No standard. (NAF = No Urea Formaldehyde Added Particleboard). These boards were made with the following species, (Ponderosa pine, Idaho White pine, Lodgepole pine) – generally 20%, Grand fir 40%, Douglas-fir 22%, Western red cedar 16% and 2% hardwood – mostly Alder. Plywood trim was not used so there is no PF resin in the boards. These panels consistently generate 0.00 ppm formaldehyde in the large chamber test.

RESULTS

The primary results from the cone calorimeter test are the curves for mass loss, heat release rate and smoke obscuration as a function of time. For reporting purposes, these curves were reduced to single numbers via individual results such as the recorded peaks or calculated averages.

Heat Release Rate and Ignition

Results for ignitability include the *times for sustained ignition* (s) and the *times for the peak heat release rate* (s) (Table 2). For the untreated composite products, the ignition times ranged from 13.8 s to 47.5 s with a mean of 32.8 s (st. dev.= 7.8). For the FRT composites, the ignition times ranged from 46.4 to 61.9 s for the FRT particleboard (mean of 52 s, st. dev.= 6) and 27 to 968 s (mean of 495 s, st. dev.= 419 s) for the FRT MDF. For some of the FRT MDF, the observation of sustained ignition was only recorded very late in the tests (Table 2). For the untreated composites, the linear regression between times for sustained ignition and density had a R^2 of 0.52.

The HRR measurements result in curves for the HRR as a function of time (Figures 1-7). The curves generally exhibited a sharp initial peak heat release rate. Curves for several of the untreated particleboard are illustrated in Figure 1. The initial peak of each curve is generally accredited to the rapid HRR for uncharred wood, which is reduced once the protective char layer forms as the result of the thermal degradation of the wood. The times for the initial peak heat release rate (PHRR) ranged from 31 s to 157 s for the untreated composites (mean of 63.5 s, st. dev.= 16.4) and 46 s to 82 s (mean of 63.4 s, st, dev.= 11.3) for the FRT composites. Selected HRR curves for the three FRT particleboards are shown in Figure 2. The linear regression of times for PHRR as a function of FR treatment and density had a R^2 of only 0.15 with only density being significant factor.

A HRR curve for an untreated MDF panel and curves for three of the five FRT MDF products are illustrated in Figure 3. As with the particleboards, the FR treatments resulted in reductions in the HRR, particularly the initial PHRR. There were some variations in the effectiveness of the FR treatments as exhibited in the HRR curves. As noted earlier, all the FRT MDF boards were rated for Class A flame spread index in the ASTM E84 tunnel test. The two materials (No. 17 and 18) with lower HRR corresponded to reported FSI of 15 while the one (No. 20) with slightly higher HRR had a reported FSI of 20. Curves of the cumulative heat released can also be used to illustrate the effectiveness of the FR treatment.

Figure 1

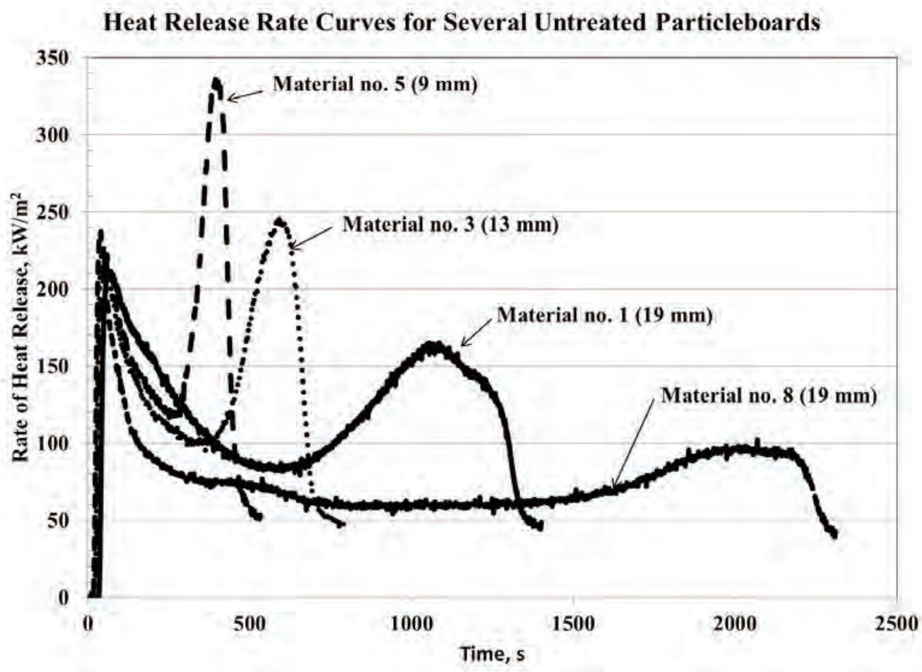
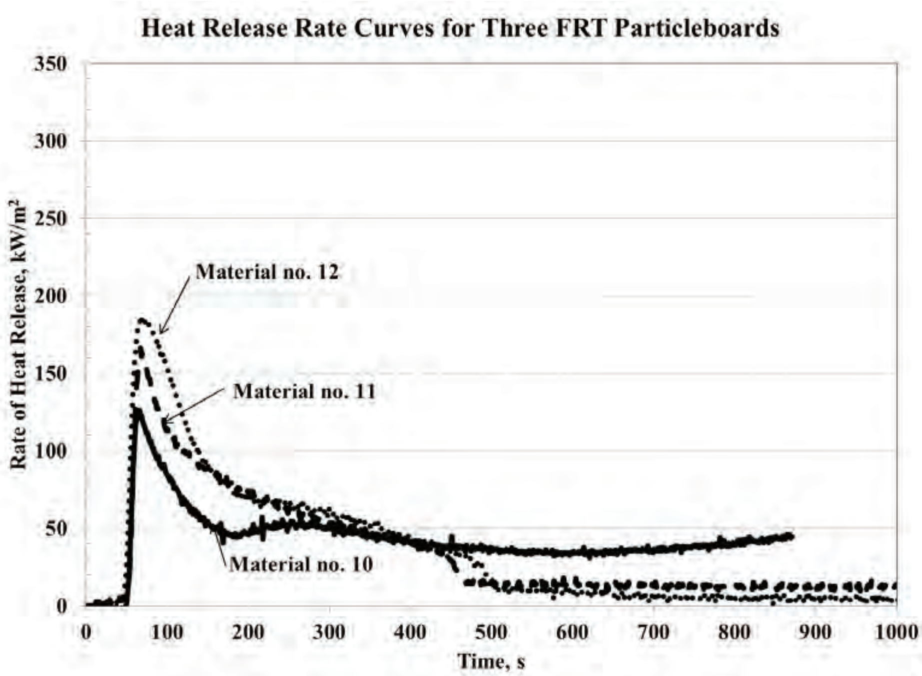


Figure 2



The two untreated HDF products were 3 and 5 mm thick. With the thin 3 mm product, the second peak in the HRR curve started before there was much of a reduction in HRR as exhibited in the thicker panels (Figure 4). The second peaks in the HRR curves reflected the thermal wave reaching the back side of the specimen which results in increased temperature since the back surface is on an insulated blanket.

Figure 3

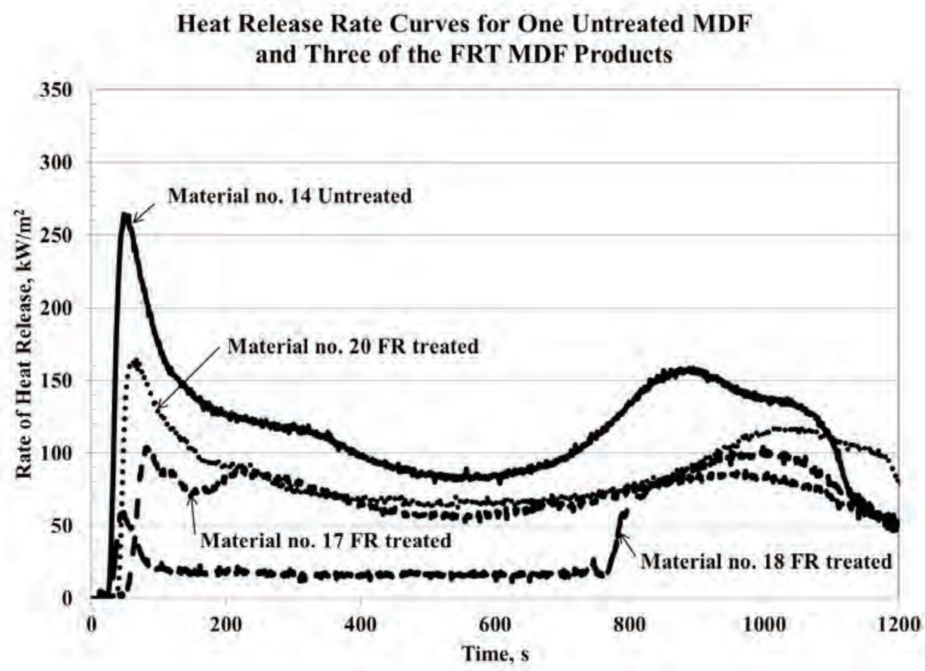
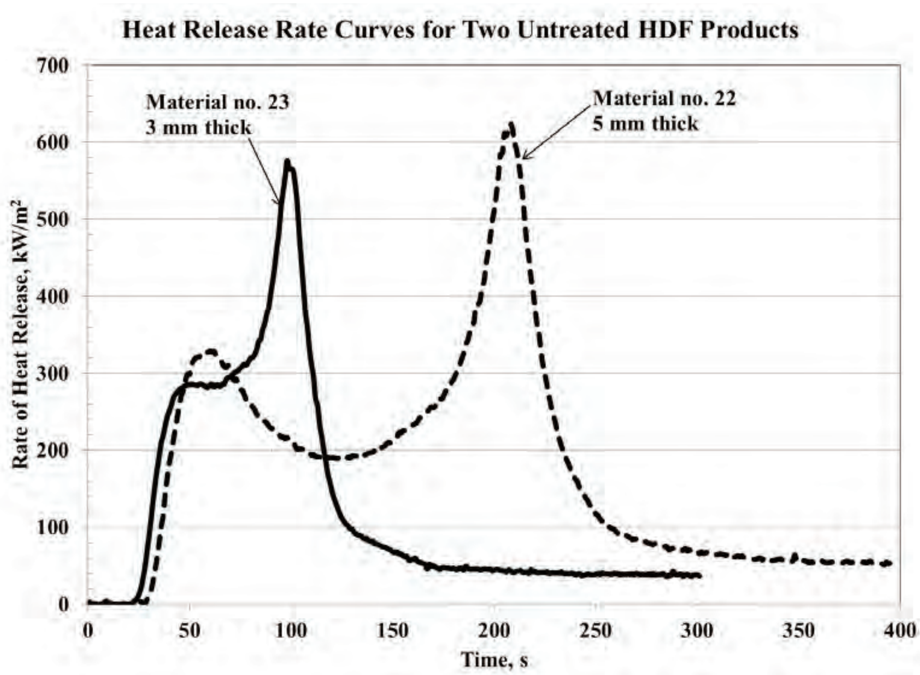


Figure 4



For reporting purposes, the HRR curve was reduced to single numbers (Table 2) including the *initial peak heat release, rate (*PHRR, kW/m^2*)* and *average heat release rate* averaged over 60s, 180s, and 300 s (AHRR-60, AHRR-180, AHRR-360, kW/m^2) from the time of sustained ignition.

2. Cone calorimeter results related to ignition and the rate of heat release

Material Number[1]	Times for Sustained Ignition[2]	Initial Peak heat release rate[2]	Time of Peak Heat Release Rate[2]	Average Heat Release Rate 60 seconds[2]	Average Heat Release Rate 180 seconds[2]	Average Heat Release Rate 300 seconds[2]
	s	kW/m^2	s	kW/m^2	kW/m^2	kW/m^2
Untreated Particleboards						
1	44.8 (1.4)	225 (7)	78 (5)	180 (6)	176 (2)	158 (2)
2	39.0 (1.0)	212 (2)	73 (5)	172 (4)	161 (3)	147 (4)
3	31.5 (1.0)	227 (3)	57 (1)	180 (3)	158 (3)	138 (4)
4	35.5 (1.7)	202 (2)	65 (4)	167 (2)	156 (3)	143 (3)
5	34.2 (2.2)	227 (5)	66 (5)	181 (6)	160 (5)	148 (6)
6	41.1 (1.5)	256 (8)	70 (2)	202 (4)	185 (3)	162 (1)
7	47.1 (0.7)	213 (2)	76 (4)	175 (2)	160 (2)	140 (1)
8	24.9 (2)	238 (3)	48 (4)	179 (3)	140 (1)	119 (2)
9	32.8 (1)	261 (3)	57 (8)	213 (16)	169 (1)	142 (1)
FRT Particleboards						
10	55.3 (6.2)	118 (7)	71 (6)	85 (6)	66 (3)	61 (5)
11	53.6 (6.2)	151 (23)	69 (3)	114 (13)	92 (3)	79 (3)
12	47.4 (1.0)	183 (4)	70 (1)	147 (5)	107 (3)	89 (2)
Untreated Medium Density Fiberboards						
13	35.1 (1.8)	248 (2)	67 (8)	191 (5)	160 (4)	140 (3)
14	37.5 (0.7)	264 (2)	63 (2)	208 (3)	168 (3)	148 (4)
15	30.7 (0.8)	254 (4)	57 (3)	192 (4)	157 (2)	140 (1)
16	32.3 (2.4)	290 (2)	58 (2)	217 (6)	168 (3)	145 (4)
FRT Medium Density Fiberboards						
17	641 (300)	117 (11)	78 (7)	83 (6)	84 (14)	80 (14)
18	942 (22)	68 (11)	49 (1)	90 (8)	94 (3)	87 (2)
19	28.5 (1.4)	175 (2)	48 (3)	129 (3)	102 (2)	90 (2)
20	37.9 (3.5)	166 (2)	60 (6)	136 (2)	109 (3)	95 (4)
21	828 (46)	81 (32)	63 (13)	87 (6)	93 (7)	88 (8)
High Density Fiberboards						
22	40.0 (0.7)	324 (8)	70 (1)	239 (1)	253 (8)	218 (-)
23	33.4 (1.8)	289 (6)	61 (2)	239 (4)	198 (8)	-
Untreated Plywoods						
24	18.2 (6.3)	193 (52)	44 (14)	134 (24)	118 (4)	141 (7)
25	24.8 (9.3)	227 (38)	87 (61)	146 (42)	175 (14)	204 (12)
Untreated Oriented Strand Boards						
26	26.9 (2.5)	198 (7)	59 (17)	161 (4)	161 (8)	150 (5)
27	28.5 (1.4)	242 (12)	54 (7)	191 (8)	174 (11)	169 (14)
28	18.6 (4.1)	226 (9)	46 (3)	178 (4)	158 (1)	141 (2)
29	31.6 (2.8)	202 (6)	77 (8)	161 (7)	162 (3)	150 (4)

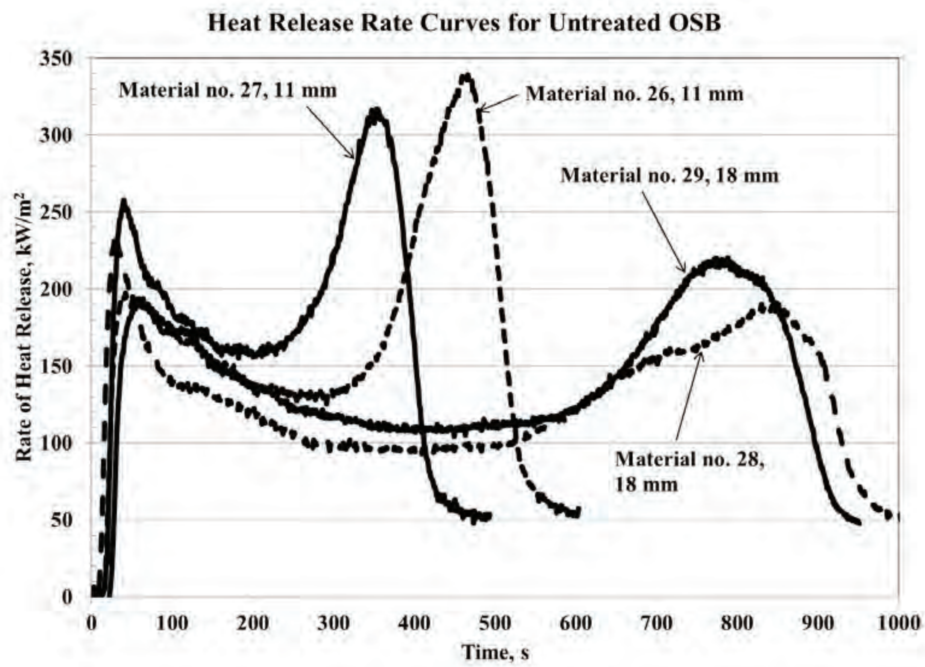
[1] See Table 1.
[2] Means and (standard deviations) of three replicates.

The FR treatment generally reduces the heat release rate. For the untreated composites, the PHRR ranged from 154 to 329 kW/m^2 (mean of 239 kW/m^2, st. dev.= 36 kW/m^2) while the FRT particleboards had PHRR that ranged from 59.4 to 186 kW/m^2 (mean of 132 kW/m^2 , st. dev.= 43). In the case of the AHRR-300, the range was 118 to 218 kW/m^2 for the untreated composites and 58 to 100 kW/m^2 for the FRT composites. For the untreated composites, the linear regression of the AHRR-60 with density resulted in a R^2 of 0.33.

There is a time delay for the recording of the oxygen concentrations by the oxygen analyzer. Thus, a time shift of the heat release rate data is made relative to the mass loss and smoke production data. The time delay directly affects the times for peak heat release rate and its comparison to the observed times for sustained ignition. In previous projects, we had the time shift for the oxygen analyzer set for 12 s longer than what was used in the data reported in this paper. New calibration of the time shift resulted in the adjustment to a value 12 s shorter. This adjustment resulted in observed times for sustained ignition closer to the start of the heat release rate curve rather than closer to the times for the peak heat release rate. For the untreated specimens tested, the initial peak heat release rate occurred on average 31 s (st. dev. = 16 s) after the observation of sustained ignition.

As the thermal wave reaches the back of the specimen, the rate of mass loss and the heat release rate increases to a second peak HRR. As the flow of pyrolysis gases decreases, oxygen is better able to get to the surface of the specimen and there is more oxidation of the char layer. The effective heat of combustion associated with char oxidation is higher than that for combustion of the volatile gases. The time for the second peak HRR often (Figures 1 and 4) reflects the relative thickness of the specimens. This was also observed in the HRR curves (Figure 5) of the untreated OSB specimens (Material nos. 26-29) which had thicknesses of 11 and 18 mm.

Figure 5



Mass Loss and Effective Heat of Combustion

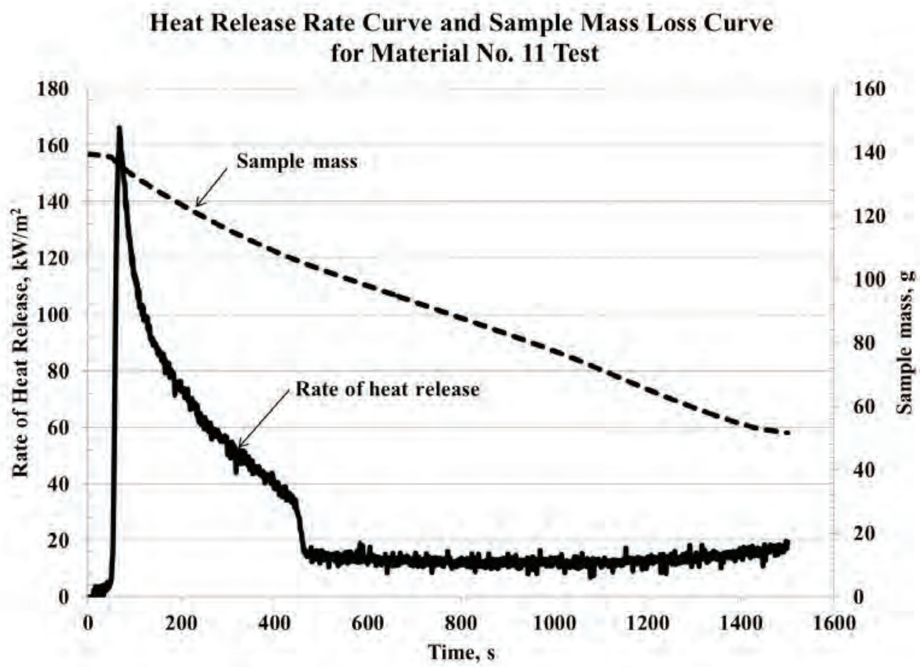
For mass loss, the results included the *initial mass* (g), *sample mass loss* (g/m^2), *average mass loss rate* for period of 10 to 90% mass loss (AMLR, g/m^2 s), and *residual mass fraction at termination of test* (residual mass as fraction of the initial mass) (RMF, -) (Table 3). The results expressed on a per m^2 basis were calculated using an exposed surface area of 0.008836 m^2. The tabulated results (Table 3) are the means and standard deviations for the three replicates of each sample.

The mass at time of sustained ignition for the specimens was also recorded. It was a mean reduction of only 0.74 g (st. dev. = 0.23) from the initial specimen mass for the untreated specimens. In contrast, three of the FRT MDF had considerable mass loss at time of sustained ignition. For these three products, the times for the observation of sustained ignition did not occur until much later in the test.

For the untreated specimens, the results for RMF at the end of the test ranged from 0.13 to 0.28. The mean result for the untreated specimens was 0.23 (st. dev. = 0.03). In contrast, the results for the FRT samples ranged from 0.33 to 0.39 with a mean result of 0.36 (st. dev. = 0.02). Higher RMF is associated with many FR treatments for wood products in that the chemicals shift the thermal degradation reactions to one of less volatile flammable gases and a higher residual char content. This mechanism is also reflected in the lower AMLR for the FRT samples, untreated mean of 12.2 g/m^2 s (st. dev.= 3.1) vs. 7.6 g/m^2 s (st. dev.= 0.7). The linear regression of AMLR as a function of FR treatment and density had a R^2 of 0.52 with both parameters being significant factors. In the case of just the untreated specimens, the regression of AMLR as a function of density had a R^2 of 0.26.

Beyond the lower heat release rate with the treated sample, the flames extinguished at 480 s in a test of a FRT particleboard even though there was continued mass loss. This resulted in a sharp drop in the heat release rate curve (Figure 6). A spark igniter facilitates the initial ignition of the combustible gases in the cone calorimeter test. The igniter is removed once sustained flaming occurs. If the flames extinguishes in less than 60 s after turning off the spark, it is re-inserted and left in for the duration of the test. The cone calorimeter only measures the heat release rate if there is combustion of the volatile gases since it uses oxygen depletion to measure heat release rate.

Figure 6



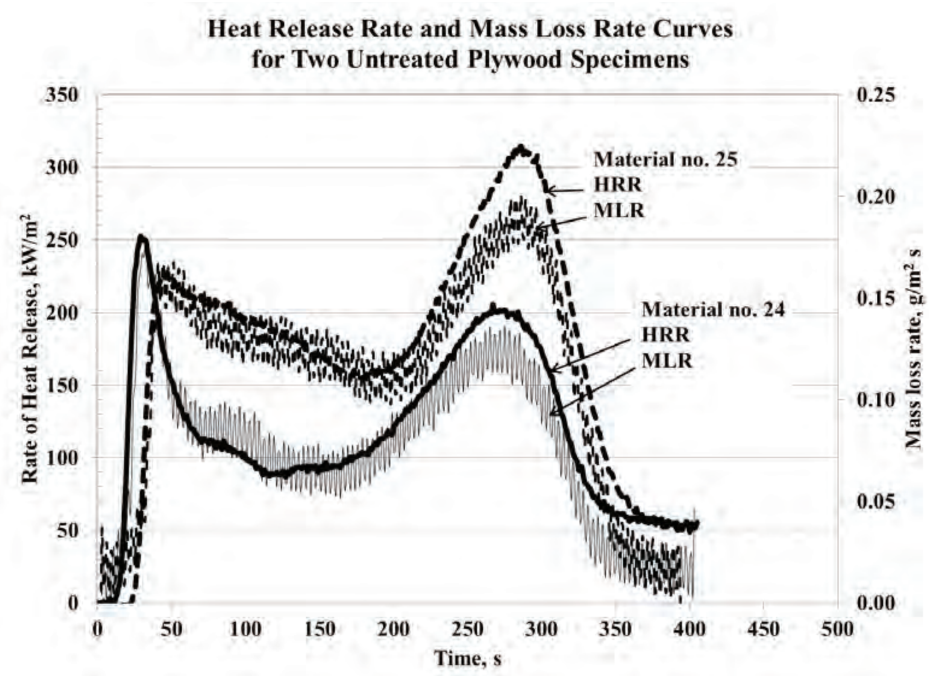
The *average effective heat of combustion* (AEHOC, MJ/kg) for the test duration (Table 3) was also calculated. The AEHOC was calculated by dividing the total heat released by the mass loss. For the untreated samples, the AEHOC ranged from 11.17 to 16.26 MJ/kg with a mean value of 12.8 MJ/kg (st. dev.= 0.98). For the FRT composites, the AEHOC ranged from 3.51 to 10.42 MJ/kg and the mean value was 7.0 MJ/kg (std. dev.= 2.2 MJ/kg).

In the case of the two untreated plywood products (Material nos. 24 and 25), the differences in the heat release rates reflected the differences in the mass loss rate (Figure 7). To reduce the noise in the mass loss rate data, the curves in Figure 7 for the mass loss rate are rolling 5 s averages of the readings taken at 1 s intervals. The AMLR of these two untreated plywood materials were different (10.8 vs. 16.1 g/m2s while their AEHOC were similar (both 13.9 MJ/kg) (Table 3).

Visible Smoke

Results for visible smoke production include the *average specific extinction area* (ASEA, m^2/kg). For the untreated composites, results for the ASEA ranged from 30 m^2/kg to 181 m^2/kg with a mean value of 99 m^2/kg (st. dev.= 37). Consistent with very little mass loss before ignition, nearly all (mean value of 98%) of the total smoke production rate for the untreated composites occurred after the time for sustained ignition. Results for the ASEA of the FRT composites ranged from 4.2 m^2/kg to 108 m^2/kg with a mean value of 44 m^2/kg (st. dev. = 36). Also consistent with the mass loss data prior to ignition and delayed ignition, more visible smoke was reported as occurring prior to ignition with some of the FRT specimens.

Figure 7



CONCLUDING REMARKS

The heat release rate curves for the wood composites reflect the normal HRR curves for wood with the initial peak heat release rate followed by period of reduced HRR until the temperature on the back surface of the specimen starts to increase. At that point, the HRR increases to a second peak consistent with the faster thermal degradation and higher heat release associated with char oxidation. Fire retardant treatment of the wood products reduces the initial heat release rates, reduces the mass loss and increases the residual mass fraction, results in lower average effective heat of combustion values, and usually results in longer ignition times and less visible smoke.

ACKNOWLEDGMENT

The cone calorimeter tests were conducted by Anne Fuller, cone calorimeter operator at the Forest Products Laboratory. Samples were supplied by Composite Products Association, APA-The Engineered Wood Association, and their member companies. Funding was supplied by American Wood Council.

2. Other cone calorimeter results

Material Number[1]	Initial mass[2]	Sample Mass Loss[2]	Average Mass Loss Rate 10%-90%[2]	Residual Mass Fraction[2]	Average Effective Heat of Combustion[2]	Average Specific Extinction Area[2]
	g	g/m^2	g/m^2s	-	MJ/kg loss	m^2/kg
Untreated Particleboards						
1	166.2 (2.4)	14.2 (0.2)	10.77 (0.12)	0.24 (0.003)	12.10 (0.10)	95.7 (8.0)
2	139.1 (1.0)	12.1 (0.2)	10.67 (0.15)	0.23 (0.01)	12.67 (0.16)	111.9 (1.4)
3	92.9 (1.3)	8.2 (0.2)	11.83 (0.40)	0.22 (0.02)	12.94 (0.22)	135.5 (15.4)
4	133.9 (2.0)	11.5 (0.1)	10.33 (0.15)	0.24 (0.004)	12.49 (0.36)	125.7 (18.9)
5	71.8 (1.5)	6.2 (0.16)	13.97 (0.65)	0.24 (0.005)	13.41 (0.02)	150.5 (27.6)
6	147.7 (1.0)	13.0 (0.9)	10.45 (0.35)	0.22 (0.05)	12.44 (0.30)	108.1 (30.6)
7	139.9 (3.4)	12.0 (0.2)	9.83 (0.12)	0.24 (0.01)	11.27 (0.12)	46.4 (13.0)
8	179.4 (0.6)	15.5 (0.1)	6.43 (0.21)	0.24 (0.004)	11.90 (0.13)	35.6 (5.2)
9	88.1 (1.0)	8.0 (0.2)	12.03 (0.32)	0.20 (0.02)	12.28 (0.38)	67.2 (1.7)
FRT Particleboards						
10	140.1 (0.4)	10.0 (0.1)	7.67 (0.21)	0.37 (0.004)	6.82 (0.87)	14.2 (14)
11	139.2 (1.9)	10.0 (0.2)	6.97 (0.47)	0.36 (0.02)	5.31 (2.25)	16.6 (16.6)
12	154.3 (2.9)	10.7 (0.2)	6.47 (0.15)	0.39 (0.01)	3.98 (0.46)	82.8 (8)
Untreated Medium Density Fiberboards						
13	136.6 (3.4)	11.7 (0.1)	10.20 (0.53)	0.24 (0.02)	12.09 (0.35)	73.5 (12.4)
14	140.4 (4.0)	11.7 (0.5)	10.16 (0.36)	0.26 (0.01)	11.75 (0.30)	65.2 (18.1)
15	140.2 (1.11)	12.1 (0.1)	12.13 (0.21)	0.24 (0.01)	11.79 (0.12)	87.2 (22.1)
16	135.0 (1.0)	11.6 (0.3)	10.50 (0.26)	0.24 (0.02)	12.03 (0.34)	59.7 (10.5)
FRT Medium Density Fiberboards						
17	129.9 (6.0)	9.4 (0.6)	8.20 (0.36)	0.36 (0.01)	8.69 (0.13)	29.1 (14.7)
18	125.4 (5.2)	9.1 (0.4)	7.53 (0.15)	0.36 (0.01)	5.30 (0.45)	81.8 (17.9)
19	128.2 (2.0)	9.6 (0.3)	7.87 (0.21)	0.34 (0.01)	10.01 (0.36)	14.6 (9.8)
20	148.4 (1.2)	11.0 (0.2)	8.63 (0.23)	0.34 (0.01)	9.45 (0.27)	18.4 (11.6)
21	118.4 (2.4)	8.6 (0.3)	7.63 (0.32)	0.36 (0.01)	6.31 (0.75)	91.0 (26.2)
High Density Fiberboards						
22	52.7 (0.3)	4.8 (0.2)	21.27 (0.21)	0.20 (0.04)	14.05 (0.31)	75.7 (7.6)
23	27.2 (0.4)	2.6 (0.02)	16.13 (2.41)	0.14 (0.02)	15.22 (1.06)	84.3 (6.5)
Untreated Plywoods						
24	40.4 (1.4)	3.5 (0.1)	10.77 (0.64)	0.23 (0.02)	13.87 (0.16)	88.6 (4.3)
25	56.9 (2.6)	5.2 (0.4)	16.07 (1.62)	0.20 (0.02)	13.86 (0.12)	115.9 (18.6)
Untreated Oriented Strand Boards						
26	83.9 (4.2)	7.2 (0.2)	14.50 (0.17)	0.24 (0.02)	13.33 (0.13)	161.4 (16.9)
27	72.5 (8.1)	6.5 (0.6)	15.27 (0.49)	0.22 (0.01)	13.48 (0.17)	130.3 (7.6)
28	109.5 (8.8)	9.8 (0.9)	11.17 (0.15)	0.21 (0.01)	12.81 (0.13)	118.2 (8.9)
29	123.9 (0.8)	10.7 (0.2)	11.57 (0.06)	0.24 (0.01)	12.93 (0.20)	142.0 (15.8)

[1] See Table 1.
[2] Means and (standard deviations) of three replicates.

REFERENCES

1. Dietenberger MA, White RH. 2001. Reaction-to-fire testing and modeling for wood products. In: Proc. 12th Annual BCC Conference on Flame Retardancy, Business Communications Co, Norwalk, CT. p. 54-69.
2. ASTM International, 2010. Standard test method for surface burning characteristics of building materials. ASTM E 84-10, ASTM International, West Conshohocken, PA.
3. American Wood Council. 2010. Flame spread performance of wood products. Design for Code Acceptance No. 1. AWC, Leesburg, VA.
4. APA The Engineered Wood Association. 2011. Flame spread index of APA performance-rated wood structural panels. Technical topics TT-010B. APA, Tacoma, WA. 1 p.

5. Janssens ML. 1992. Modeling the E 84 tunnel test for wood products. In: Proc. First Intl. Fire and Materials Conf., Interscience Communications Ltd., London, UK. p. 33-42.
6. White RH, Dietenberger MA. 2004. Cone calorimeter evaluation of wood products. In: Proc. 15th BCC Conf. on Flame Retardancy, Business Communications Company, Inc., Norwalk, CT. p. 331-342.
7. White RH, Stark NM, Ayrilmis, N. 2011. Recent activities in flame retardancy of wood–plastic composites at the forest products laboratory. In: Prof. 22nd Annual BCC Conf. on Flame Retardancys, BCC Research, Wellesley, MA. p. 248-259.
8. White RH, Winandy JE. 2006. Fire performance of oriented strandboard. In: Proc. 17th Annual BCC Conf. on Flame Retardancys. BCC Research, Norwalk, CT. p. 297-309.
9. White RH, Forsman J, Erickson JR. 2008. Aspen flakeboard treated with disodium octaborate tetrahydrate. In: 19th Proc. Annual BCC Conference on Flame Retardancy, BCC Research, Wellesley, MA. p. 238- 249.
10. Winandy JE, Wang Q, White RH. 2008. Fire-retardant-treated strandboard: properties and fire performance. *Wood and Fiber Science* 40(1):62-71.
11. Dietenberger MA, Grexa O, White RH. 2012. Reaction-to-fire of wood products and other building materials: Part II, Cone calorimeter tests and fire growth models. Res. Paper FPL-RP-670. Forest Products Laboratory, Madison, WI. 58 p.
12. Ayrilmis N, Kartal SN, Laufenberg TL, Winandy JE, White RH. 2005. Physical and mechanical properties and fire, decay, and termite resistance of treated oriented strandboard. *Forest Products Journal* 55(5):74-81.
13. Dietenberger M, Grexa, O. 1999. Analytical model of flame spread in full-scale room/corner tests (ISO9705). In: Proc. Fire and materials `99, Interscience Communications Limited, London, UK. p. 211-222.
14. Dietenberger, MA. 2004. Ignitability of materials in transitional heating regimes In: Proc. 5th Wood & Fire Safety Conf., Faculty of Wood Sciences and Technology, Technical University of Zvolen, Slovak Republic. p. 31-41.
15. ASTM International. 2008. Standard test method for heat and visible smoke release rates for materials and products using an oxygen consumption calorimeter. ASTM E 1354-08a, ASTM International, West Conshohocken, PA.
16. International Organization for Standardization. 2002. Reaction to fire tests- heat release, smoke production, and mass loss rate - Part 1: heat release rate (cone calorimeter method). ISO 5660–1:2002 and Part 2: Smoke production rate (dynamic measurement). ISO 5660-2:2002. ISO, Geneva, Switzerland.

FIRE AND MATERIALS 2013

Thirteenth international conference

San Francisco, California
USA

28th - 30th January

Published by

interscience communications

London, UK

www.intersciencecomms.co.uk

Proceedings of the Fire and Materials 2013 Conference

held at the Hyatt Hotel Fisherman's Wharf Hotel, San Francisco, California, USA
28-30 January 2013

A conference organised by
Interscience Communications Ltd
West Yard House
Guildford Grove, Greenwich
LONDON SE10 8JT
England

Fire and Materials 2013

pp 816
with 178 tables and 520 illustrations