CONE CALORIMETER EVALUATION OF UNTREATED AND FRT WOOD COMPOSITES FOR FLOOR APPLICATIONS

Chen, Z., White, R. H., Cai, Z., Fu, F.

Abstract:

As part of an investigation of wood composites for floor applications, we conducted cone calorimeter tests on fire-retardant-treated and untreated plywood, medium density fibreboard, and veneer Fire retardant treatments included the inorganic chemicals ammonium polyphosphate, disodium octaborate tetrahydrate, aluminium hydroxide, and magnesium hydroxide The application of the chemicals to the plywood or veneer included as an additive to the adhesive, brush application on the veneer or plywood, and dip treatment of the veneer. The cone calorimeter test results indicated the extent to which the fire retardant treatments reduced the heat release rates, reduced the effective heat of combustion and increased the residual mass fraction

Key words: *plywood veneer, fiberboard, ammonium, polyposphate, disodium, octaborate tetrahydrate, aluminium hydroxide, magnesium hydroxide.*

INTRODUCTION

Plywood and medium density fiberboard (MFD) are widely used in a variety of applications including as flooring products. For some aplications, it is necessary to treat the wood composites with fire-retardant (FR) chemicals to satisfy fire performance requirements. In this project, we evaluated several inorganic chemical treatments for MDF, plywood and wood veneer. The application of the chemicals to the plywood or veneer included as an additive to the adhesive, brush application, and dip treatment of the veneer. The objectives of the present study were to provide some baseline cone calorimeter data for plywood and MDF treated with known Fr chemicals and comparative data for different methods of applying the FR chemicals.

The cone calorimeter test is widely used to evaluate the flammability characteristics of materials. The calculation of the heat released due to combustion is based on the oxygen consumption principle. Although the cone calorimeter is a small-scale test, the obtained results have been found to correlate well with those obtained from a large-scale fire test and are used to predict the combustion behavior of materials in a real fire. The heat release rate (HRR) measured by cone calorimeter is a very important parameter as it expresses the intensity of a fire.

METHODS

Specimens

The types of materials included MDF, plywood, and veneer. Specimens included untreated (UT) specimens and specimens with FR treatments applied to surface by brush, by soaking the veneer, and by the FR chemical being added to the adhesives. The FR inorganic chemicals included: (1) Ammonium polyphosphate (APP), $NH_4\ PO_3]_n$; (2) Disodium octaborate tetrahydrate (DOT), $Na_2B_8O_{13}.4H_2O$; (3) Aluminium hydroxide (or Alumina trihydrate) (ATH), $Al(OH)_3$; (4) Magnesium hydroxide (MDH), $Mg(OH)_2$; and a commercial fire retardant (CFR). The CFR treatment is a commercial ferric phosphate based formulation for flame retardancy applications.

MDF specimens were made from softwood fibres sprayed with a solution of APP powder to obtain 0, 10, 20, and 30 weight percentage gain (WPG). Moisture content of the fibres was controlled to 6%. The adhesive was a urea formaldehyde resin adhesive. These specimens were 13 mm thick and four replicates were tested. Density of the untreated MDF was 700 kg/m^3. A 12 mm thick commercial untreated MDF and a 14 mm thick commercial FR treated MDF were tested. Density of the untreated commercial MDF made with softwood fibre was 780 kg/m^3. For the commercial MDF, the softwood fibres were sprayed with a phosphide/nitride formulation, dried, and hot pressed in the commercial production line.

For the first group of 5 mm-thick three-ply poplar plywood specimens, the FR chemicals (APP, DOT, ATH, MDH and CFR) was added to the urea formaldehyde resin adhesive as a powder at a 30% WPG treatment level based on wet adhesive weight. For the second group of poplar plywood specimens, the veneer was dipped (i.e. soaked) in a saturated room temperature solution of the FR chemical. For treated Douglas-fir plywood specimens, the FR chemical was added to the plywood adhesive at a 30 wt% treatment level. The Douglas-fir plywood was 11 mm thick.

Pieces of veneers were treated with DOT or CFR by dipping (soaking) in a saturated solution of the FR chemical for one to 24 hours or brushing on one or more applications of the FR chemical solution to get the different treatment levels. The veneer specimens included 2 mm thick poplar veneer and 4 mm thick Douglas-fir veneer. To obtain the highest treatment level for the Douglas-fir veneer, the treatment included both the soaking and the brush application.

A single replicate of each chemical treatment/plywood (or veneer) combination was tested in the cone calorimeter.

Test methodologies

We tested the 100 mm by 100 mm specimens in the cone calorimeter at the Forest Service Forest Products Laboratory (FS-FPL) in accordance with the procedures in ASTM International test method E 1354-08a [2]. The FS-FPL cone calorimeter is a Model No. Cone 2A, Combustion Analysis System (AutoCal) manufactured by Atlas Electric Devices Company of Chicago, IL. Specimens were tested in the horizontal orientation using heat flux intensity of 50 kW/m^2 and the data were collected every second. In most cases, only one replicate was tested. Prior to testing, the specimens were conditioned at 50 % RH and 23°C The specimens were tested in the optional retainer frame but without the wire grid Ignitability was determined using a 4 seconds criteria for observing the time for sustained ignition of the specimen. With frame, the exposed surface area of the specimen was 0.008836 m^2, which was used to express the results per unit surface area.

In the cone calorimeter tests; the heat release rate, specimen mass, and specific extinction area were measured as a function of time. Heat release rate 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 data for duration of the test.

The data reported in this paper include the following measurements: *time for sustained ignition* (TSI,s); *heat release rate* (kW/m^2) including the *initial peak heat release rate* (PHRR) *average heat release rate* averaged over 60s (AHRR-60), 180s (AHRR-180), and 300 s (AHRR-300) from the time of sustained ignition; *time to PHRR* (tPHRR, s); total *heat released* for test duration (THR, MJ/m^2); *average effective heat of combustion* (AEHC, MJ/kg); initial mass (IMASS, g); *mass at time of sustained ignition* (MSI, g) (from ISO 5660-1 [7]; *residual mass fraction at termination of test* (residual mass as fraction of the initial

mass) (RMF, -); *average mass loss rate* for the peoiod of 10% to 90% mass loss (AMLR, g/s-m²); and average specific extinction area (ASEA, m²/kg).

RESULTS AND DISCUSSION

The results from the cone calorimeter tests are reported in Tables 1 to 6 and Figures 1 to 2. Results and tables are organized in sections on MDF, poplar plywood, Douglas-fir plywood, and varoous veneers.

FR-treated MDF

The APP-treated specimens included MDF made from fibres treated at 0, 10, 20, and 30 WPG (Table 1). APP is used as a fire retardant chemical in a wide range of applications including extinguishing forest fires [1] and intumescent paints [12].

Table 1. Results for untreated and treated MDF's.

Parameter	Units	APP Treatment Level[1]				Commercial Products[2]	
		0%	10%	20%	30%	UT	FRT
TSI	s	29	24	22	NSI[3]	41	55
PHRR	kW/m^2	217	152	132	96	743	414
tPHRR	s	42	31	26	20	44	54
AHRR- 60	kW/m^2	185	119	78	NSI[3]	217	174
AHRR-180	kW/m^2	145	91	38	NSI[3]	164	138
AHRR-300	kW/m^2	123	69	29	NSI[3]	143	121
THR	MJ/m^2	88.0	54.4	29.7	16.2	123.9	123.4
AEHC	MJ/kg	12.1	8.2	4.8	2.8	13.2	11.7
Initial mass	g	83.6	86.0	86.0	89.7	107.6	126.4
MSI	g	82.8	85.3	85.4	NSI[3]	107.0	124.4
RMF	kg/kg	0.23	0.32	0.36	0.42	0.23	0.26
AMLR	g/m^2s	11.6	9.2	8.9	7.8	12.2	10.4
ASEA	m^2/kg	62	40	73	128	30	50

[1]Means for four replicates. MDF fibers FR treated to four levels of percentage weight gain.
[2]These were two commercial MDF products, Untreated (UT) and FR treat (FRT). Means fortworeplicates.
3There was no sustained ignition in three of the four replicates.

The HRR curves were the typical curves for thicker wood specimens with an initial peak HRR followed by a dwell in the HRR and a second peak HRR at the end of hte test (Figure 1). Kim and others [8] examined the use of a cone calrimeter to evaluate wood flooring and PVC flooring and considered two methods of sample preparation including the standard ceramic fiber substrate and a method using the cement mortar used in actual field applications as the substrate. In their tests of 8-10-mm thick wood floorings, the heat release rate curves in tests with the standard sample substrate exhibited the dual peaks that are typical for cone calorimeter tests of wood products. In their tests with a cement mortar substrate, only one peak was observed in the heat release rate curves. Hagge and others [6] also observed single peaks in the heat release rate curves for cone calorimeter tests with the cement board substrate used in the U.S. 25-foot tunnel test. The choice of substrate affects the heat transfer out the back of the specimen, particularly in the later part of the test.

The results (Table 1) indicated shorter TSI; lower PHRR, AHRR, and THR; lower AEHC; and higher RMF with increasing levels of APP treatment of the MDF. The effect of the treatment level on ASEA was inconsistent (Table 1). With some APP-treated specimens, the heating element was raised during later part of tests to prevent specimens from touching the heating elements. In one 20% specimen and three 30% specimens, there was no observation of sustained ignition. It is widely recognized that one of the flame retardancy mechanisms for phosphorus compounds is increased char formation [12]. The results for APP indicated increased smoke (ASEA) with the higher treatment levels which is consistent with monoammonium phosphate causing increased smoke emission [9].

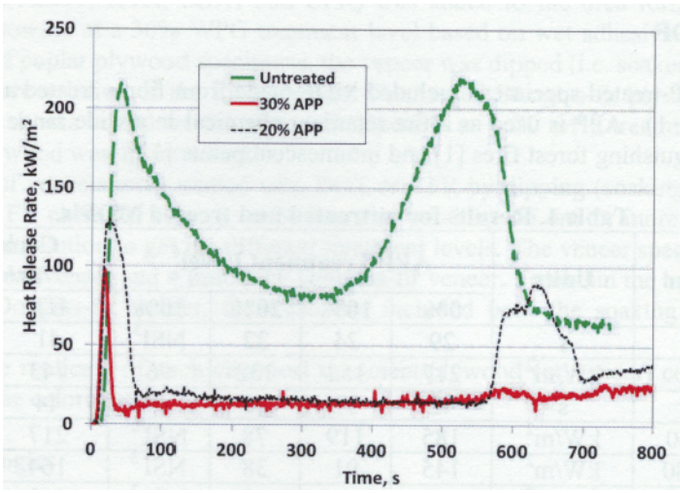

Figure 1. HRR curves for APP treated MDF

Tests included an untreated commercial MDF and a commercial FR treated MDF (Table 1). It was not clear what was responsible for the high initial PHRR. The appearance of the commercial products suggested there was also a non-FR surface coating. It was noted that the AHRR values for the untreated commercial MDF are not much higher than those for the untreated laboratory MDF specimens (Table 1). Compared with the comparable untreated specimen, the commercial FR treatment also reduced the PHRR, AHRR, AEHC, and AMLR. In similar cone calorimeter tests using the 50 kW/m^2 exposure, Östman and Tsantaridis [13] reported AHRR-60 results of 125 and 139 kW/m^2 for two untreated commercially abailable MDF's and 22 and 60 kW/m2 for two commercially available FR treated MDF's. These commercial products were 9 or 12 mm thick. These results are lower than the AHRR-60 results reported in Table 1. The ignition times were 22 and 31 s for the untreated MDF's and 37 and 515 s for the FR treated MDF's. These ignition times are similar to those reported in Table 1.

FR-treated poplar plywood

Results for the 3-ply poplar plywood includes specimens with the FR chemicals (APP, DOT, MDH, and ATH) added to the adhesive and specimens with veneers soaked with the FR chemicals (Table 2). Results for these thin 5 mm thick plywood samples include the initial PHRR and the final PHRR of the HRR curves (Table 2). The results for AHRR-180 and AHRR-300 were not reported due to the short duration of these tests.

Compared with the untreated plywood, the chemical additive to the adhesive had mixed effects on the test results. The small differences in the results and the single replicates make it difficult to make definite conclusions but ht4e addition of the fire retardant to the adhesive generally had little impact on the fire performance of the plywood in these tests. Su and others [14] conducted a more thorough study of adding boron and phosphate compounds to the adhesive used to make the plywood specimens. In their study x-ray photoelectron spectroscopy indicated migration of boron and phosphorus from the adhesive to the wood by about 0.6 mm. They noted that other research had indicated that thickness of the veneer is a factor in improved performance when FR chemical is added to the adhesive. Grexa and others [5] found that polyphosphate added to adhesive of hte plywood had more of an impact than adding MDH. Their most efficient system was applicaiton of diammonium hydrogen phosphate into the wood mass and magnesium hydroxide into glue mixture.

Table 2. Results for the 5 mm-thick, 3-ply, poplar plywood.

Parameter	Units	Adhesive treated (30% WPG)					Veneer treated[1]			
		UT	ATH	APP	DOT	MDH	UT	APP	DOT	CFR
TSI	s	71	73	93	68	74	79	33	81	121
PHRR	kW/m^2	63	49	73	75	59	144	152	82	81
tPHRR	s	35	34	43	48	34	57	36	35	9
Finl PHRR	kW/m^2	214	235	188	228	219	210	199	259	225
tFPHRR	s	136	126	141	124	126	137	150	124	123
AHRR-60	kW/m^2	117	135	141	120	140	164	107	179	114
THR	MJ/m^2	21.7	18.5	20	19.7	19.3	22.7	25.4	22.9	16.0
AEHC	MJ/kg	9.4	8.7	9.2	9.2	8.8	10.4	10.5	10.6	9.0
Initial mass	g	29.5	28.4	28.3	28.5	28.4	27.6	31.7	27.4	27.3
MSI	g	24.5	23.6	22.0	24.0	23.2	22.1	31.2	21.3	17.7
RMF	kg/kg	0.31	0.34	0.32	0.33	0.32	0.30	0.33	0.30	0.36
AMLR	g/m^{2}s	12.7	12.0	11.1	11.7	12.3	12.7	12.8	13.0	10.5
ASEA	m^2/kg	23	27	15	17	37	50	35	36	26

[1]Retentions of the FR chemicals in the treated veneers are not known.

DOT and other boron compounds are one of the most widely investigated FR chemicals for wood. One of the reasons for this popularity is that boron compounds are also wood preservatives. The flame retardancy mechanisms for borates include formation of a

retardancy mechanisms for the ATH and MDH is endothermic fuel-diluting water release [12]. ATH is a widely used inorganic flame retardant and smoke suppressant for plastics. In our tests of the 5 mm poplar plywood, the ATH and MDH did not reduce smoke production (Table 2). MDH is used as an alternative to ATH when a higher processing temperature is required in the manufacture of the plastic product. In her review of chemistry of fire retardancy of wood, LeVan [11] discusses these FR chemicals and reports of synergistic effects when these chemicals are used in combinations.

In our tests of poplar plywood with FR soaked veneer (TABLE 2 and Figure 2), the commercial CFR was most consistent in improving the test results with lower initial PHRR, AHRR-60, THR, AEHC, AAMLR and higher RMF compared with results for the untreated specimen. In similar tests of 5 mm thick untreated beech plywood, Östman and Tsantaridis [13] reported AHRR-60 results of 123 kW/m^2 and ignition time of 31 s.

FR-treated Douglas-fir plywood

Improvements in the results with the additional of the FR to the adhesive were more obvious in the results for the thicker 11 mm Douglas-fir plywood specimens (Table 3). For most of the tabulated resusts in Table 3, the APP and MDH produced more improvements than the ATH and DOT treatments. For example, the AHRR-60 results were 70 kW/m^2 for APP treatment and 71 kW/m^2 for MDH compared with 105 kW/m^2 for ATH, 106 kW/m^2 for DOT and 120 kW/m^2 for the untreated specimen.

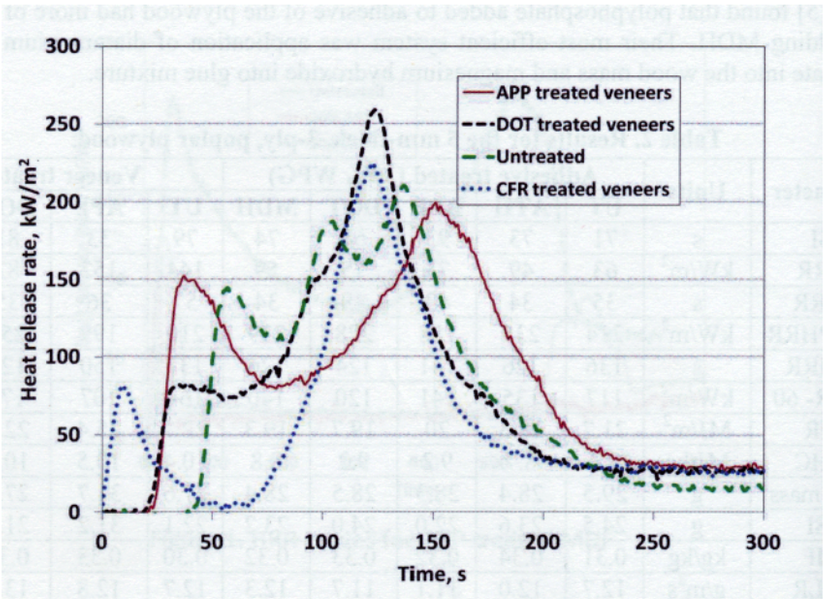

Figure 2. HRR curves for poplar plywood with treated veneers.

In similar tests of four 9 to 13 mm thick FR treated plywood products, Östman and Tsantaridis [13] reported AHRR-60 results of 29 to 58 kW/m^2 and ignition time of 30 to 629 s and one no ignition. In tests of 18 mm thick blockboards with 2 mm thick ekaba face veneers that had been dip-treated with DOT (7% WPG) and ATH (12% WPG), the PHRR were 191 kW/m^2 for the DOT, 180 kW/m2 for the ATH, and 204 kW/m^2 for the untreated face veneer blockboards [10]. Grexa [4] reported reductiona in the PHRR and the AEHC with commercial FR treated plywood compared with untreated plywood. The untreated Douglas-fir plywood had a PHRR ~220 kW/m2 while hte two FR treated plywood products had PHRR of ~120 and ~70 kW/m^2.

FR-treated veneers

Pieces of veneers with brushed or dip applications of the FR chemicals were also evaluated (Tables 4-6). DOT was brushed onto the 2 mm thick poplar veneer or the veneer was soaked in the DOT solution. The WPG of the treatment level (Tables 4-6) were calculated from the weights before treatment and after post-treatment drying of the specimens. The DOT treatments improved the results and better results obtained wiith higher treatment levels (Table 4). For example, the initial PHRR was 361 for the untreated

specimen and reduced to 315 and 268 kW/m² for the 9.2% and 19.4% brushed applied specimens, respectively, and 337 kW/m², 238 kW/m², 166 kW/m², and 175 kW/m² for the 5.2%, 14.9%, 27.7%, and 42.2% dip applied specimens, respectively.

In tests of 6, 12, and 18 mm thick untreated plywood, Au Yeung and Chow [3] reported the ignition times for the 50 kW/m² exposure increased from less than 20 s for the 6 mm thick plywood to about 60 s for the 18 mm thick plywood. In our 50 kW/m² tests, the ignition times were (1) 15 s for the untreated 2 mm poplar veneer (Table 4) and 71/79 s for the 5 mm thick poplar plywood and (2) 14 s for 4 mm thick Douglas-fir veneer (Table 6) and 60 s for the 11 mm thick Douglas-fir plywood (Table 3).

Table 3. Results for the 11 mm thick Douglas-fir plywood.

Parameter	Units	UT	Adhesive treated			
			ATH	APP	DOT	MDH
TSI	s	60	27	100	51	45
PHRR	kW/m^2	135	126	97	121	90
tPHRR	s	104	36	45	66	48
AHRR- 60	kW/m^2	120	105	70	106	71
AHRR-180	kW/m^2	88	74	65	68	63
AHRR-300	kW/m^2	84	66	72	60	62
THR	MJ/m^2	48	46	46	43	45
AEHC	MJ/kg	10.7	9.7	9.4	10.0	9.8
Initial mass	g	57.7	60.2	65.9	56.4	62.2
MSI	g	55.7	59.5	59.2	54.5	60.1
RMF	kg/kg	0.31	0.30	0.34	0.33	0.34
AMLR	g/m^{2}s	9.2	8.7	9.2	8.0	8.5
ASEA	m^2/kg	33	21	17	28	28

In the tests of the 2-mm thick poplar veneer brushed or soaked with the CFR chemical (Table 5), improvements in the results greater than the DOT treatment (Table 4) were observed. For example, the initial PHRR was 361 for the untreated specimen and reduced to 197 and 194 kW/m² for the 11.8% and 15.6% brushed applied specimens, respectively, and 299 kW/m², 153 kW/m², and 100 kW/m² for the 4.9%, 18.2%, and 26.2% dip applied specimens, respectively.

In the tests of the 4 mm thick Douglas-fir veneer treated with DOT and with CFR, the results were mixed (Table 6). The PHRR for the DOT treated specimen were much higher than the low PHRR for the untreated specimen and increased with treatment level. Yet, the AEHC for the DOT specimens were lower than for the untreated specimen and the RMF were higher for the DOT treated specimens (Table 6). As with the poplar veneer specimens (Tables 4 and 5), the Douglas-fir veneer specimens treated with the commercial CFR treatment performed better than the specimens treated with DOT (Table 6). These are results for only a single replicate of each treatment type, which can make comparison of results difficult.

Table 4. Results for the 2 mm-thick poplar veneer treated with DOT.

Parameter	Units	UT	DOT Brushed		DOT Soaked			
Treat. Level	WPG	0	9.2	19.4	5.2	14.9	27.7	42.2
TSI	s	15	17	19	16	22	NSI	30
PHRR	kW/m^2	361	315	268	337	238	166	175
tPHRR	s	28	26	27	23	26	31	33
AHRR- 60	kW/m^2	156	106	90	122	75	NSI	52
THR	MJ/m^2	12.7	10.2	9.9	11.5	8.8	7	7.6
AEHC	MJ/kg	15.8	12.7	15.0	15.1	11.7	10.4	11.4
Initial mass	g	7.1	7.2	7.9	6.7	7.9	9.1	9.7
MSI	g	6.6	6.6	7.5	6.2	7.1	NSI	8.2
RMF	kg/kg	0.00	0.01	0.27	0.00	0.17	0.35	0.40
AMLR	g/m^2s	8.3	4.4	4.9	5.6	4.5	3.7	3.9
ASEA	m^2/kg	91.7	49	42	53	47	7	25

Table 5. Results for the 2 mm thick poplar veneer treated with CFR formulation.

Parameter	Units	UT	CFR Brushed		CFR Soaked		
Treat. Level	WPG	0	11.8	15.6	4.9	18.2	26.2
TSI	s	15	9	9	10	NSI[1]	NSI[1]
PHRR	kW/m^2	361	197	194	299	153	100
tPHRR	s	28	21	21	19	20	21
AHRR- 60	kW/m^2	156	84	48	115	NSI[1]	NSI[1]
THR	MJ/m^2	12.7	10	10	10.6	9.5	8.4
AEHC	MJ/kg	15.8	15.2	14.6	15.6	13.4	14.3
Initial mass	g	7.1	7.8	7.2	6.4	7.6	8.2
MSI	g	6.6	7.5	6.8	6.1	NSI[1]	NSI[1]
RMF	kg/kg	0.00	0.25	0.16	0.06	0.17	0.37
AMLR	g/m^2s	8.3	4.9	4.1	5.1	3.4	-
MSI	g	6.6	7.5	6.8	6.1	NSI[1]	NSI[1]
ASEA	m^2/kg	91.7	28.1	42.7	58.4	41.9	-

[1] There was no sustained ignition of specimens.

CONCLUDING REMARKS

In this paper, we presented a range of cone calorimeter results for MDF, plywood, and veneer treated with several known inorganic FR chemicals and a commercial FR formulation. Results depended on the methods of application of the FR chemical and the wood medium being treated. The results from the cone calorimeter tests indicated the extent to which the fire retardant treatments reduced the heat release rates, reduced the effective heat of combustion and increased the residual mass fraction. The results for the commercial fire retardant treatment were generally better than the other treatments included in this study.

Table 6. Results for the 4 mm thick Douglas-fir veneer.

Parameter	Units	UT	DOT					CFR			
			Brushed			Soaked		Brus.	Soaked		
Treat. Level	WPG	0	3.8	7.8	16.0	12.8	25.9[1]	5.6	9.9	13.7	16.6[1]
TSI	s	14	38	29	52	74	112	11	10	48	79
PHRR	kW/m^2	126	206	297	279	213	66	98	127	127	159
tPHRR	s	18	113	120	117	115	48	13	78	100	91
AHRR- 60	kW/m^2	116	152	95	137	166	54	107	85	102	85
THR	MJ/m^2	30.8	24.1	23.6	23.9	19.8	10.6	18.2	16.8	17.4	9.9
AEHC	MJ/kg	16.2	12.8	11.8	11.0	10.0	6.6	11.5	10.6	9.1	6.5
Initial mass	g	19.4	21.8	24.5	25.4	24.8	24.2	19.1	18.2	24.9	21.5
MSI	g	19.2	20.4	23.6	22.4	19.9	14.7	18.8	18.0	21.2	15.4
RMF	kg/kg	0.14	0.24	0.28	0.24	0.29	0.42	0.27	0.24	0.32	0.37
AMLR	g/m^2s	8.9	11.7	13.1	10.5	12	10.9	11.1	8.1	11.2	9.7
ASEA	m^2/kg	102	73	79	61	27	5	42.0	3.1	7.7	43.1

[1] Treatment included FR chemical being brushed on the surface after the specimens were soaked in the FR chemical.

Acknowledgment

Thanks to State Forestry Administration, P.R.China for supporting the project "Manufacturing Technology of Fire-retardant and Smoke Suppressed Wood-based Panels". Acknowledge the work of Anne Fuller of FPL in conducting all the cone calorimeter tests.

Literature

[1] Àgueda A, Liodakis S, Pastor E, Planas E. 2009. Characterization of the thermal degradation and heat of combustion of *Pinus halepenis* needles treated with ammonium-polyphosphate-based retardants. J Therm Anal Calorim 98:235-243. DOI 10.1007/s10973-009-0134-0.

[2] ASTM International. 2008c. Standard test method for heat and visible smoke release rates for materials and products using an oxygen consumption calorimeter. ASTM E 1354-08a. West Conshohocken, PA.

[3] Au Yeung HW, Chow, WK. 2002. Cone calorimeter studies: effect of radiative heat flux and sample thickness on burning of plywood samples. International Journal on Engineering Performance-based Fure Codes, 4(4):106-109.

[4] Grexa O. 2000. Flame retardant treated wood products. In: Proc. 4th Wood & Fire Safety Conference, May 14-19, 2000, Štrbské Pleso, Slovak Republic, Technical University of Zvolen, pp. 101-110.

[5] Grexa O, Horváthová E, Bešinová O, Lehocký P. 1999. Flame retardant treated plywood. Polymer Degradation and Stability 64: 529-533.

[6] Hagge MJ, Bryden KM, Dietenberger MA. 2004. Effects of backing board materials on wood combustion performance. In: Proc. 5th Wood & Fire Safety Conference, April 18-22, 2004, Štrbské Pleso, Slovak Republic, Technical University of Zvolen, pp. 51-58.

[7] ISO (2002) 5660–1 Reaction to fire tests- heat release, smoke production, and mass loss rate - Part 1: heat release rate (cone calorimeter method). International Organization for Standardization, Geneva, Switzerland.

[8] Kim J, Lee J-H, Kim Sumin. 2011. Estimating the fire behavior of wood flooring using a cone calorimeter. J Therm Anal Calorim, Published on-line. DOI 10.1007/s10973-0011-1902-1.
[9] Kozlowski R, Wladyka-Przybylak M. 2001. Natural polymers, wood and lignocellulosic materials. In: *Fire Retardant Materials*, ed. Horrocks AR, Price D, Woodhead Publishing Limited, Cambridge, England, pp 293-317.
[10] Laufenberg T, Ayrilmis N, White R. 2006. Fire and bending properties of blockboard with fire retardant treated veneers. Holz als Roh-und Werkstoff, 64:137-143. DOI 10.1007/s00107-005-0041-4.
[11] LeVan SL. 1984. Chemistry of fire retardancy. In: Rowell RM ed. The chemistry of solid wood. Advances in chemistry series 207. Amercian Chemical Society, Washington, DC, Chapter 14, pp 531-574.
[12] Lewin M, Weil ED. 2001. Mechanisms and modes of action in flame retardancy of polymers. In: *Fire Retardant Materials*, ed. Horrocks AR, Price D, Woodhead Publishing Limited, Cambridge, England, pp 31-68.
[13] Östman B A-L, Tsantaridis LD. 1995. Heat release and classification of fire retardant wood products. Fire and Materials 19:253-258.
[14] Su W-Y, Subyakto, Hata T, Nishimiya K, Imamura Y, Ishihara S. 1998. Improvements of fire retardancy of plywood by incorporating boron or phosphate compounds in the glue. J Wood Sci 44:131-136.

Address for correspondence

1. Dr. Chen Zhilin: Reaearch Insititue of Wood Industry (CRIWI)
Chinese Academy of Forestry (CAF), Beijing 100091, China
Tel: +86-10-6288.9440, Fax: +86-10-6288.9440
chenzhilin@caf.ac.cn

2. Dr. Robert H. White: USDA, Forest Service, Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726-2398 USA
Tel: 01-608-231-9265, Fax: 01-608-231-9592
rhwhite@fs.fed.us

3. Dr. Zhiyong Cai, USDA, Forest Service, Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726-2398 USA
Tel: 01-608-231-9446, Fax: 01-608-231-9592
zcai@fs.fed.us

4. Dr. Fu Feng: Research Institute of Wood Industry (CRIWI)
Chinese Academy of Forestry(CAF), Beijing 100091, China
Tel: +86-10-6288.9973, Fax: +86-10-6288.9973
feng@caf.ac.cn

The use of trade or firm names in this publication is for reader information and does not imply endorsement by the USDA of any product or service. The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin. This publication was written and prepared in part by one or more U.S. government employees as part of their official duties, and therefore their contributions to the paper are in the public domain and not subject to copyright within the United States.

Wood & Fire Safety

7th International Scientific Conference

May, 13th - 16th 2012

The High Tatras Štrbské Pleso, The Patria Hotel, Slovakia

Proceedings

Edited by
Anton Osvald

Papers and posters presented at 7th International scientific Conference Wood and Fire Safety organised by University of Žilina, Faculty of Special Engineering, Department of Fire Engineering

Vydavatel: ŠMÍRA-PRINT, s.r.o., Česká Republika
Rok vydani: 2012
Náklad: 200ks
Tisk: Tiskárna Grafico, Opava
Grafická uprava a obálka: Roman Chvíla

ISBN 978-80-87427-23-1