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Cone Calorimeter Tests for Fire Retardant Treated (FRT) Plywood

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Copy no. 3 of 5

Table of Contents

List of Figures

List of Tables

1 Background

FPInnovations contracted the National Research Council Canada (NRC) to test the performance of a new fire retardant coating that is applied to plywood to reduce surface flammability and improve fire resistance. The fire retardant treated (FRT) plywood samples have been provided by FPInnovations. The NRC evaluated the performance of the FRT plywood samples using the cone calorimeter apparatus at the fire safety. The samples were subjected to different incident heat fluxes to evaluate their performance. Test conditions and results are provided in this report.

2 Experimental setup

Shown in Figure 1a) is the cone calorimeter at the fire safety unit that was used to conduct the experiments. Shown in Figure 1b) is a photo of a FRT plywood sample. Summary of experimental conditions is shown in Table 1; the samples have been subjected to three levels of incident heat fluxes (20, 35 and 50 kW/m^2). Initial sample mass ranged from 60 to 67 grams. Sample thicknesses ranged from 7.2 to 7.7 mm. Three duplicates of each incident heat flux were conducted to insure repeatability.

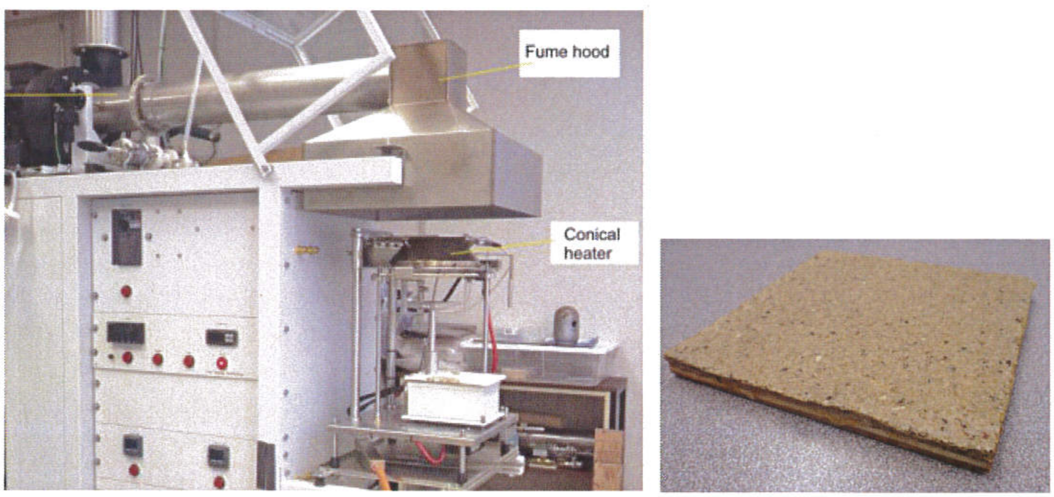

Figure 1. a) The Cone calorimeter at the NRC b) Fire retardant treated plywood sample

Table 1. Summary of experimental conditions

Incident heat flux (kW/m^2)	run #	Initial mass (g)	Initial thickness (mm)
20	1	64.18	7.4
20	2	67.14	7.7
20	3	63.72	7.5
35	1	66.77	7.5
35	2	63.31	7.6
35	3	64.53	7.2
35	4	61.25	7.4
50	1	62.14	7.3

50	2	60.11	7.5
50	3	64.21	7.3
50	4	62.93	7.3

3 Results and discussion

Shown in Table 2 is a summary of experimental results for all runs: Time to ignition, peak HRR, time to peak HRR (**t_{peak}**), Total Heat Release (THR) and Mass lost. Here are some general observations of the experimental results:

- Peak HRR increased with the increase in incident heat flux
- Time to peak HRR decreased
- THR increased with the increase in incident heat release
- Mass lost increased with the increase in incident heat flux

Table 2. Summary of experimental results

Incident heat flux (kW/m^2)	Run #	Time to ignition (s)	Peak HRR (kW/m^2) @ t_{peak} (s)	THR (MJ/m^2)	Mass lost (g)
20	1	243	187 @ 521	60.3	44.4
20	2	242	177 @ 547	64.3	45.8
20	3	235	182 @ 565	63.1	44.9
35	1	84	263 @ 418	74.1	52
35	2	69	217 @ 377	72.2	50.2
35 (run stopped @ 600 seconds)	3	78	230 @ 413	-	-
35	4	57	248 @ 395	72.3	49.6
50	1	28	310 @ 344	76.1	52.2
50	2	19	305 @ 322	75	51.6
50	3	45	271 @ 337	76.6	52.8
50	4	50	272 @ 315	76.7	52

Figure 2 shows the results of HRR versus time for all runs:

- Figure 2a) HRR vs time for incident heat flux 20 kW/m^2,
- Figure 2b) HRR vs time for incident heat flux 35 kW/m^2,
- Figure 2c) HRR vs time for incident heat flux 50 kW/m^2.

The figures indicate good repeatability of duplicated runs for each incident heat flux level. Results from duplicated runs were averaged for comparison. Results of the averaged HRR curves are shown in Figure 3. As expected, higher incident heat flux resulted in higher peak HRR occurring at an earlier time, earlier ignition and shorter burning duration.

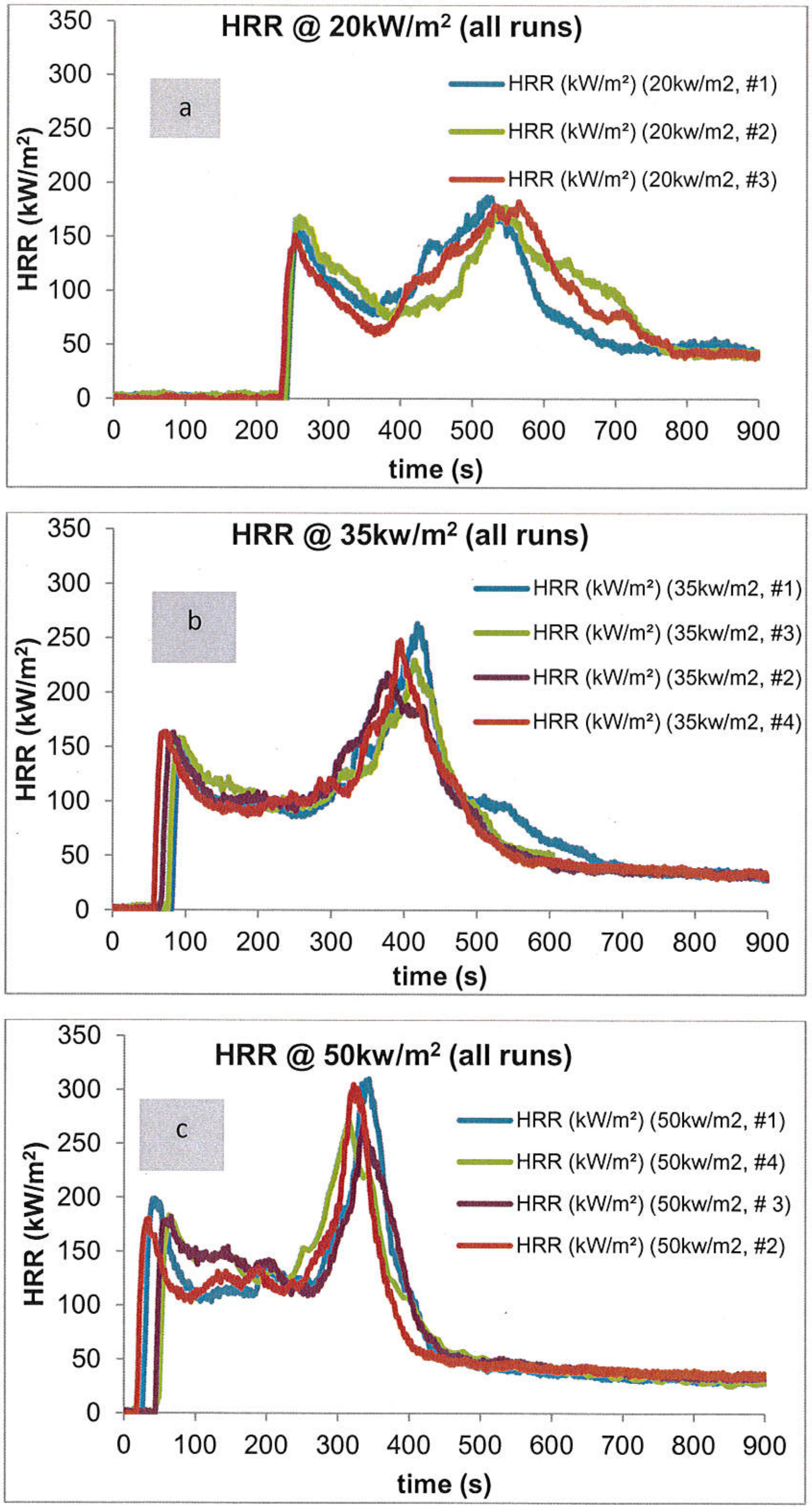

Figure 2. a) HRR @ 20kw/m^2 Incident heat flux for all runs b) HRR @ 35kw/m^2 Incident heat flux for all runs c) HRR @ 50kw/m^2 Incident heat flux for all runs

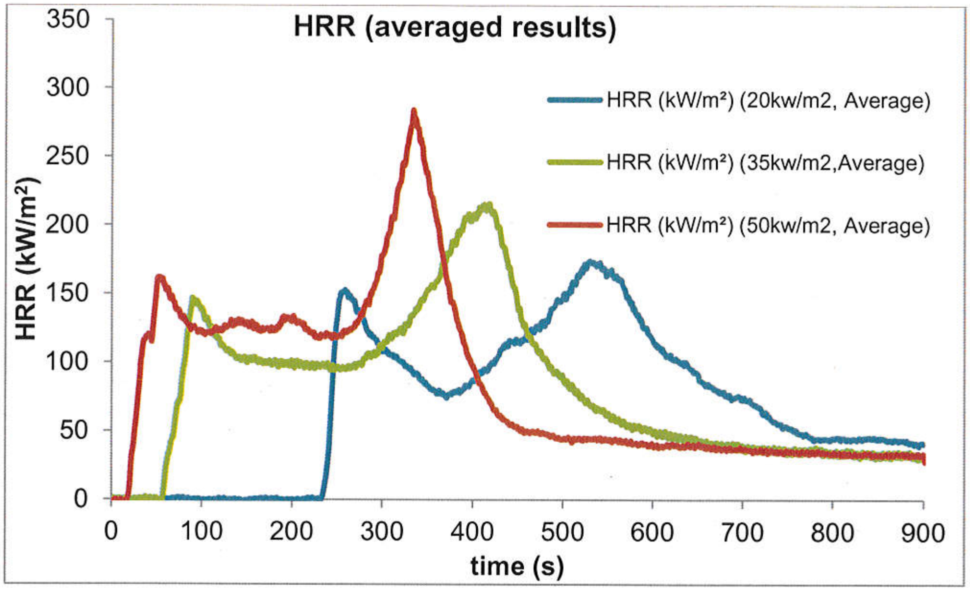

Figure 3. Averaged HRR results of all three incident heat fluxes

3.1 Comparison with data from the literature

Shown in Figure 4, Figure 5 and Figure 6 are comparisons with fire retardant treated (FRT) plywood from the USDA database as well as untreated samples from the same database. The two samples used for comparison are Douglas fir (DF) FRT plywood and south pine (SP) FRT plywood. The Douglas fir (DF) sample was 11.5 mm, and the south pine (SP) sample was 11mm. Cone calorimeter results from both samples were cited in a conference paper presented in the 12th annual business communication conference on flame retardancy (1). The samples were treated using a salt flame retardant that reduced mass loss, effective heat of combustion, peak HRR and THR (1). It also increased the time to ignition. The authors explained the mechanism by which the salt retardant works as following: it increases the char content while decreases the combustible tar portion of the wood volatiles (1). Looking at the figures (Figure 4, Figure 5 and Figure 6), the following remarks are observed:

- The HRR curves from the tested samples looks qualitatively similar to the data from the literature
- The HRR curve from the tested samples is higher than the data from the literature at most points
- In comparison with the untreated sample from the database, the tested treatment did not show improvement in terms of ignition or heat release rate. However, it is important to note that the untreated sample was thicker (11.5 mm) which means it had a higher thermal inertia. So this is not a direct comparison.
- The tested FRT seems to work better in the higher incident heat flux range, since its performance is relatively closer to the samples from the USDA data base (2) and (3) at the 50 kw/m^2 incident heat flux case (Figure 6).

It is important to note that the differences between the tested samples and the samples form the USDA data base:

- The tested samples in this study were thinner (i.e., ~7 mm versus ~11 mm)
- The method of protection in the sample tested in this study is different: A layer of glued husk was added to the plywood for protection. Although the full composition of the protection layer is not known, the possible mechanism of protection is that the husk layer acts as a thermal barrier.
- The samples from the USDA database were treated with a salt retardant which protects the plywood by increasing the char content and decreases the combustible tar content.

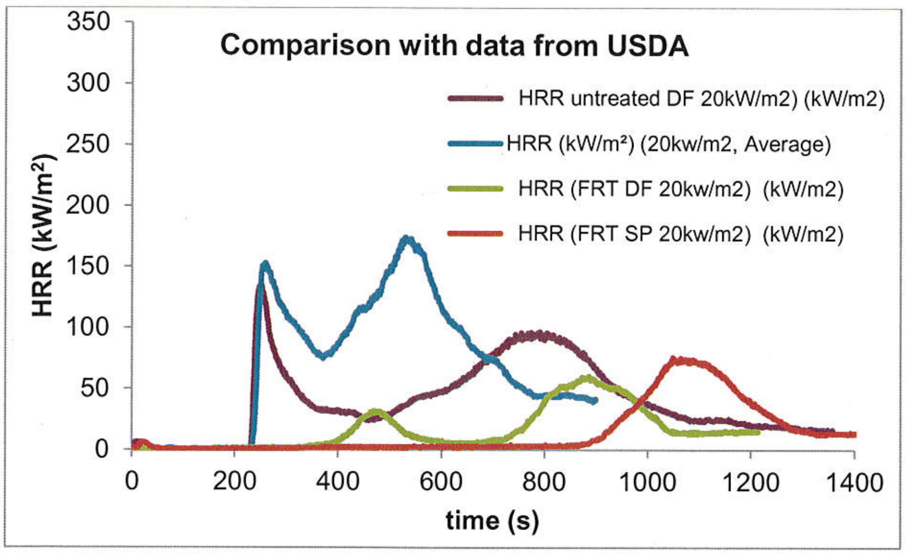

Figure 4. Comparison of HRR curve with data from the literature (2) (3)(20 kw/m^2 incident heat flux)

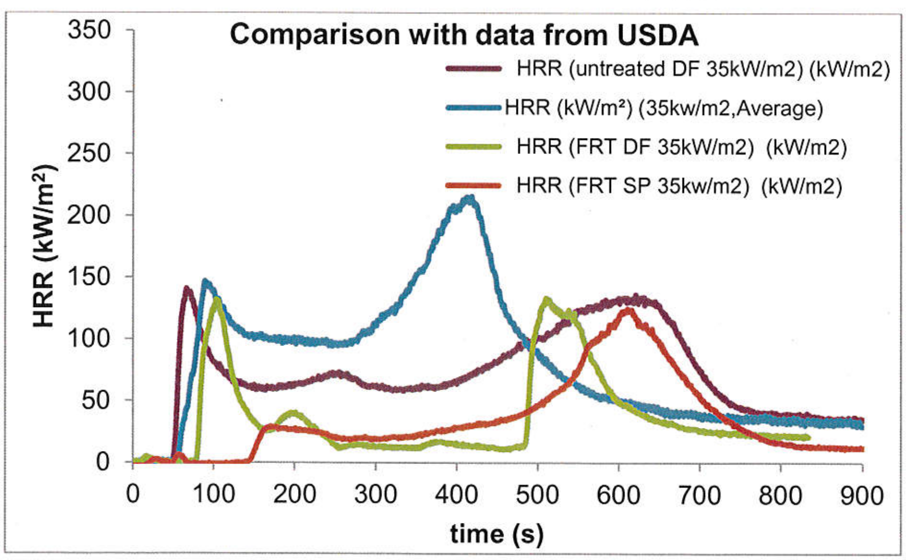

Figure 5. Comparison of HRR curve with data from the literature (2) (3)(35 kw/m^2 incident heat flux)

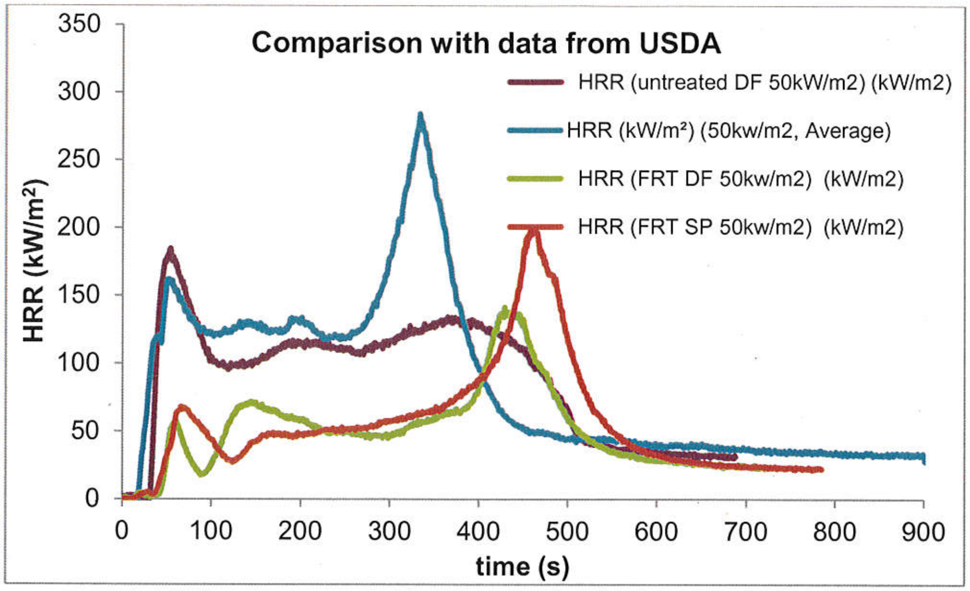

Figure 6. Comparison of HRR curve with data from the literature (2) (3)(50 kw/m^2 incident heat flux)

3.2 Critical heat flux

Figure 7 shows different plots for incident heat flux versus the reciprocal of time to ignition with different exponent based on the method used to determine the critical heat flux. All methods rely on different assumptions; for example the method suggested by Janssens (4) is based on the assumption that the sample is thermally thick (5) (i.e., Fourier number $[k/\rho c)t_{ig}/\delta^2]$ is less than 0.1) and the incident heat flux during the experiments is larger than $q''_{critical}/0.9$ (5).

Where K = thermal conductivity, ρ = sample density, C = specific heat and δ = sample thickness and $q''_{critical}$ = the critical heat flux.

Janssens approximation (4) states that the critical heat flux is the X-axis intercept from the linear regression of $1/t_{ig}^{0.547}$ versus incident heat flux. Where "t_{ig}" is the time to ignition in seconds (s). The method also relies on the assumption of negligible radiation loss from the sample compared to the convective losses, which is valid for vertically oriented samples.

Another method developed by Delichatsios et al. (6) suggests that the intercept of "$1/t_{ig}^{0.5}$" versus incident heat flux is equal to 0.64 the critical heat flux ($0.64q''_{critical}$). In this method the sample also has to be thermally thick. Contrary to Janssens approximation, the convective heat loss is assumed negligible compared to the radiation heat loss from the sample, which is valid for samples tested in horizontal orientation.

Results of both methods are shown in Table 3. Both values of $q''_{critical}$ are questionable since they are very low. This might be attributed to the fact that the tested samples are not thermally thick and the assumptions used in each method are not quite applicable to the tested samples. Also, there was some variability in the time to ignition at the high incident heat flux runs (50 kW/m^2). This variability might be attributed to variation in the fire retardant thickness.

Shown in the third row of Table 3 is the result of critical heat flux if the sample is assumed to be thermally thin (7). The sample is usually assumed thermally thin if its thickness is less than 1mm, in which case the temperature gradient within the sample is negligible. The results of this method are also questionable since the tested sample cannot be considered "thermal thin". Results of this method are included here for comparison.

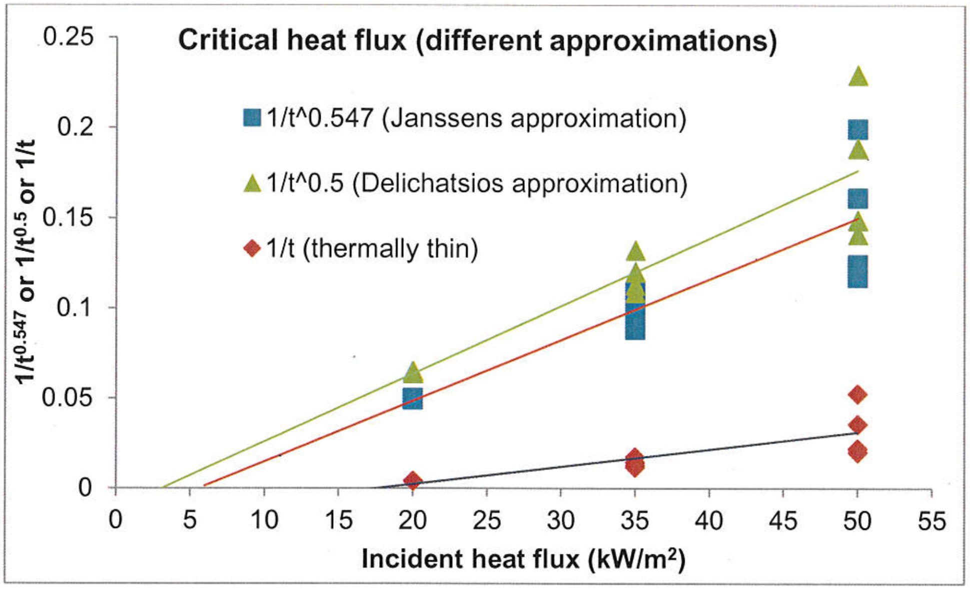

Figure 7. Critical heat flux based on different approximations

Table 3. Critical heat flux based on different approximations

Method reference	Method description	Linear fit equation	R^2 value	Critical heat flux (kW/m^2)
Janssens (4)	X axis intercept of q" vs $1/t^{0.547}$ is $q''_{critical}$	Y=0.00338X-0.01899	0.8	4.8
Delichatsios et al (6)	X axis intercept of q" vs $1/t^{0.5}$ is ~ $0.64*q''_{critical}$	Y=0.00376-0.0116	0.8	5.6
Thermally thin (7)	X axis intercept of q" vs 1/t is ~ $0.3*q''_{critical}$	Y=0.000964-0.01689	0.66	58

According to Scudamore et al (8), the tested samples, most probably, lie within a transitional category (3 mm to 10 mm) where samples are not considered thermally thick nor thermally thin. Hence the deviation and variability in the calculated critical heat flux values. For this kind of material, Scudamore et al (8) suggested conducting extensive testing at flux levels where time to ignition (t_{ig}) is very long.

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