BASIC STUDIES ON WOOD PANEL FIRE TEST METHODS

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ABSTRACT

Choice of wood for making panel fires is fir or spruce as these natural fuels are available in North America. If panel fire extinguishment studies have to be performed in other locations (like India) it is desirable to identify equivalent wood species. This requires study of crib and panel combustion behaviour with objectives (a) weight loss v/s time for panel fires to set extinguishment start time for other species (b) determination of the effect of wood properties. The results of the preliminary study show that the density of the wood matters significantly. Details of the panel combustion behaviour as stand-alone elements as well as a part of crib-panel assembly are presented to enable understanding of the combustion behaviour. It is specifically brought out that wood of density of about 450 kg/m^3 would be an appropriate choice for the material.

INTRODUCTION

Cribs and panel fires form a part of compartment fires that are engineered fires aimed at rating and testing of fire extinguishers. UL 711 (the standard of Underwriters laboratories, USA) prescribes the standard for rating and fire testing of fire extinguishers. A part of this standard discusses Class A fires, which constitutes wood fires, both in crib and panel arrangement. For extinguishers to be eligible for a given class and rating, two out of three test fires must be extinguished, for wood cribs and two consecutive test fires, in case of panel fires [**1**]. One of the key aspects is the distinction in the approach between crib and panel fires to decide when the fire is to be attacked (for extinction). Crib fire has a mass loss criterion, namely, the fire is to be attacked when the weight loss during the test fire is at 45%. For panel fire weight loss criterion is not set but extinguishing is to be started at a certain time after the start of the fire (that is performed in a standard procedure). When the residual panel material after extinguishment is examined, a certain amount of green wood should be left behind; then alone the test is considered acceptable. Normally, the wood of choice is fir or spruce based on the availability of these natural fuels in North America. If such tests have to be performed in other locations (like India, for instance) it is desirable that alternate equivalent wood species are identified. This calls for a study of the crib and panel combustion behaviour from twin objectives. (a) determination of the relationship between weight loss and time in the case of panel fires so that the time at which extinguishing is started can be set for other species, and (b) determination of the properties of the wood used in making the panels that affect the combustion behaviour. Both of these can be used as inputs to possible modification to the standard for panel fire tests.

PANEL FIRE DESCRIPTION

Wood panels specified as per UL 711 vary primarily in the length of the individual wood member, in the number of wood members arranged in each layer and the number of layers itself. Typically, 19 *mm* square pieces are arranged one over the other with spacing of 19 *mm* for the entire length and width of 2.45 *m* x 2.45 *m*. The fire is initiated with fine wood curlings (called excelsior) of 4.5 *kg* in four batches, each batch fed 45 seconds after the earlier one (thus, the total time of the combustion of excelsior material is three minutes). The lump of the curlings is spread along the width at the bottom of the panel. The initiation of fire is performed by lighting a small sprinkling of n-heptane along the width. An examination of the videos of the tests [**2**] shows that the excelsior pile is irregular in its distribution along the width. It is understood that this distribution is not critical to the result as perceived by the designers of the test. After three minutes of the initiation of the fire, the panel is allowed to burn on its own for duration of one and a half minutes or a time at which the bottom elements of the panel are noticed to crack up. At this time, the extinguishing process is initiated. After successful extinction, the elements around a meter above the bottom are examined for the amount of green biomass in the cross section. The extinguishment is considered successful if the green biomass is about 6 mm in diameter [**1**]. This approach does not involve any mass measurement that is done for crib tests where 45% loss in weight becomes the criterion for the initiation of extinguishment. If we notice the variability in the procedure adopted for panel tests, it is not clear why the weight loss technique has been abandoned. Also, the correlation of the amount of core biomass remaining unburnt with the success of the test has not been defined clearly.

The aim of the present study is to relate the amount of core biomass remaining unburnt to the total mass of the crib-panel and to also understand the role of crucial properties of biomass. Density of the biomass is one crucial property that is not specified in the code that influences ignition and combustion times.

ANALYSIS OF ACTUAL FIRE TESTS

There is several panel fire videos posted in the cyberspace [**2**]. These show the actual process as well as fire behaviour. If we couple these with the requirements set out in the standard, we can estimate the power level and the fire behaviour. The combustion of 1.1 *kg* of excelsior material occurs in 45*s*. Of course some combusting char is left behind at this time. This is inferred because each time a new excelsior material is pushed, the ignition is caused by the remaining material. Considering the variability in the actual combustion rate it is appropriate to consider about 90% is burnt up in 45*s*. This implies a combustion rate of 1.3 *kg/min* (22 *g/s*, 0.36 MW_{th}). If we examine the video more carefully, the weight loss rate is the highest at the beginning because the surface area available for combustion is the highest to begin with. The width of the material is about 100 *mm* in front of the panel. The two dimensional conical flame (conical normal to the panel) that arises from the combusting material rises up to 2 *m* randomly across the width depending on the nature and amount of material at a specific location. A calculation (to be discussed later) shows that the gas stream speed is between 2 to 4 *m/s* next to the surface. Since each crib element (of 19 *mm* x 19 *mm* cross section) is separated from the other, classical approach of a free convective boundary layer next to the panel would not be appropriate to estimate the ignition and burn rate of the individual crib elements.

The flow properties of the hot gas next to the element at 1 *m* height from the bottom are hot gas density, ρ_g = 0.35 to 0.45 kg/m^3, velocity, V_g = 2 – 4 *m/s*, Characteristic length, L = 0.019 *m*, viscosity, $\mu_g = 4 \times 10^{-5}$ *kg/ms*, specific heat, c_{pg} = 1200 *J/kgK*, conductivity, k_g = 0.07 *W/mK*. The heat flux to the surface is obtained as $q'' = h_g (T_g - T_w)$ where q'' is the heat flux, h_g is the heat transfer coefficient, T_g and T_w are the gas and wall temperatures. The heat transfer coefficient is estimated from the Nusselt number (*Nu*) correlation. $Nu = h_g L / k_g = 0.33 Re^{0.5}$ for laminar flow and $0.03 Re^{0.8}$ for turbulent flow, where *Re* is the Reynolds number, $Re = \rho_g V_g L / \mu_g$. Reynolds number works out to 200 – 400. This may appear strange at the first sight since the flame has developed over 1 m and would demonstrate a flow behaviour consistent with *Re* ~ 10,000 to 20,000 (about fifty times the value obtained earlier). It is true that the turbulent characteristics will be governed by this *Re*. However, because of *interrupted positioning of the cribs*, each boundary layer will start-off at the bottom of the crib and end at the top. The Nusselt number then works out to 4.6 to 6.6. This leads to h_g of 17 – 25 W/m^2K. The temperature difference $(T_g - T_w)$ varies between 300 and 600 *K* with higher temperature values dominating in the early stages and lower values at the later stages. This then leads to heat flux values in the range of 5 – 15 kW/m^2. If we had chosen to assume that the Re that is appropriate is the larger of the values, the heat flux would have been 50 – 80 kW/m^2. The actual heat transfer behaviour will be between these two extremes. Quintiere [**3**] has presented values for turbulent heat transfer to wall in the range of 10 – 40 kW/m^2 consistent with the above estimates. Armed with the heat flux values we can attempt to estimate the ignition times and mass burn rates.

Ignition time is estimated from the classical equation for thick solids that is applicable in the present case [**3**] as $T_{ig} = (\pi/4)\, k_c \rho_c c_{pc} [(T_{ig} - T_0)/q'']^2$, Where k_c, ρ_c, and c_{pc} refer to condensed phase conductivity, density and specific heat, T_{ig} to the ignition temperature. The mass flux under the influence of a gaseous flux is obtained from the data presented [**3**] as $m'' = 11 + 5\ (q''/75)$ for Douglas fir material. Using values for Douglas fir [**3**], $k_c \rho_c c_{pc}$ = 0.25 (across grain) and 1.4 (along grain), T_{ig} as 384 °C (across the grain) and 258 °C (along the grain), we get the values of ignition time for several values of flux as shown in Table 1. The burn time is estimated by dividing the mass per unit length (say 1 m) by the mass burn rate. The mass is obtained from multiplying the volume for 1 *m* length by the density as 0.019 x 0.019 x 1 x 550 = 156.5 *g*. The mass burn rate *m''* obtained from the above equation further multiplied by the burning surface area given by 4 x 0.019 x 1 m^2. These are shown in Table 1.

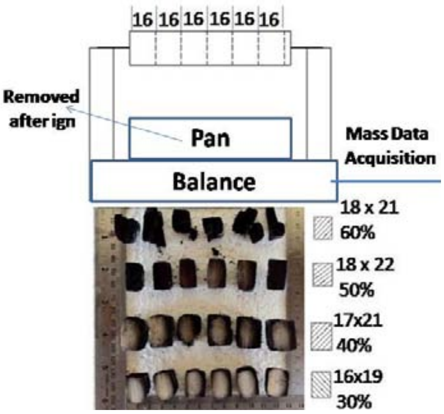
Table 1 Ignition and combustion times for several heat fluxes (Douglas fir)

q''* *kW/m²	**Grain direction**	**Ignition time, *s***	**Mean ign. time, *s***	**Combustion time, *s***	**Overall burn time, *s***
10	Across	240	288	176	464
	Along	336			
20	Across	61	86	166	252
	Along	131			
40	Across	16	25	150	175
	Along	35			

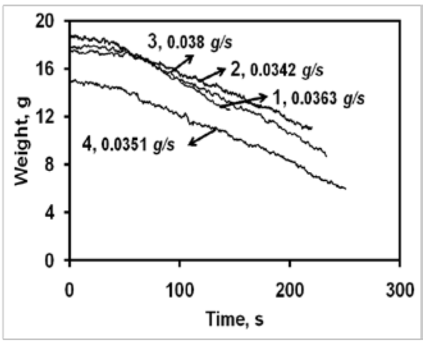
The actual duration of the panel fire test is about 240 *s*. Since it is expected that some material is left unburnt at a height of 1 *m* (about 12.5 % because 6 *mm* square is expected to be left behind for a 19 *mm* square), the flux levels are close to the lower end – 10 to 20 kW/m^2.

EXPERIMENTS

Experiments are planned in steps – (a) mass loss of individual elements of crib in smaller groups (b) study of the effect of density on a wood member and (c) combustion of representative crib-panel and the analysis of the material in the test zone (1*m* above the bottom zone). Cross section of panel selected corresponds to the size prescribed for 1A panel described in UL 711[**1**]. Experiments are carried out to understand the ignition behaviour of excelsior and impact of its properties on the ignition of panels. It is found that choice of the excelsior, its moisture content as described in the standard (drawn from base wood, fir or aspen) itself has a major impact on panel fire results. A comparable material must be identified for use. It is found that a mixture of locally available wood shavings moistened in kerosene mixed with 15% hexane had ignition behaviour comparable to prescribed material.



a. Setup and sample sections



b. Mass remaining (1–30%; 2-40%; 3-50%; 4-60%)

Fig. 1 Individual member study

(Images shown are equidistant sections of wood samples taken at mass lost fractions indicated by the side of each row. Dimensions of original green biomass dimensions in mm, are also shown.)

All experiments consisted of mass and/or temperature data acquisition through IOTech personal DAC (10 μV LC 80 *hz* acquisition rate). Balance of 3 *kg* range and 0.1 *g* Least Count (LC) is used for individual member experiments. A 100 *kg* range 5 *g* LC balance is used for panel fire studies. K type thermocouples of 1 *mm* bead size are used for temperature measurement.

Individual Members

Members of 19 *mm* x 19 *mm* cross section [**1**] (1A panel size), having densities between 450 – 470 kg/m^3 were cut into pieces of 100 *mm* each and the sample is placed horizontally on a horizontal stand as shown in Fig 1a. Experiment consisted of igniting the member using a pool fire beneath it, which is removed after ignition. Mass loss is monitored and the sample is quenched (using nitrogen) at a predetermined mass corresponding to a designated mass loss fraction. Mass loss rate at 30%, 40%, 50% and 60% were determined. All members were cut across their axes after extinction of the fire at the respective mass loss fractions. Higher the mass loss fraction, lower the fraction of unburnt wood was found in the core of the wood member. All members were examined across their cross sections, at 6 sections, (16 *mm* apart) of the member, as shown in Fig 1a. The sample, which lost 30% wood, shown in the bottom of the figure has a noticeably greater unburnt area than the sample that lost 60% of its mass. Fig 1b shows the mass remaining v/s time of each of the 4 samples. Unburnt core mass fraction correlated well with the mass of unburnt wood obtained from cross section analysis.

Density Effect

To study the effect of density on the burn rate, sample of heavier density wood, having density of 960 – 975 kg/m^3 is sandwiched between lighter density woods, (light $wood_1$ and light $wood_2$) each having a density of ~ 460 – 475 kg/m^3, using a thin layer of adhesive.

Each of these pieces measured 33 *mm* individually and three pieces put together, treated as a single individual member is burnt using excelsior soaked with an 85:15% of kerosene and hexane. The wood member is allowed to burn and the fire is extinguished at (a) 30% of the mass loss of the whole member and (b) 40% of mass loss of the whole member. Longitudinal sections of the members were taken, on completion of the experiment. The surface of the wood member exposed to the flame had turned into char, to a greater degree than the opposite surface. However, the core of the wood member remained unburnt, in comparison. On visual inspection, the denser wood in the middle of the assembly has a greater unburnt portion than the lighter wood on the sides. Wood of lighter density (450 – 475 kg/m^3) may be more appropriate for the panel fire experiments. Fig 2a shows the two wood members cut in longitudinal sections exposing the relatively unburnt parts for both 30% mass loss rate and 40% mass loss rate.

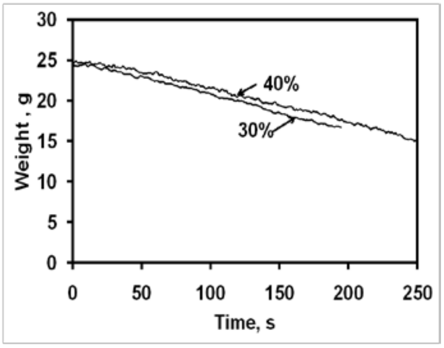


Fig. 2 a Coupled density wood samples *(numbers are in kg/m³)*

Fig. 2b Mass loss data

Table 2 shows the condition of wood members and actual mass loss percentage of each piece that make up the wood member. Fig 2b shows the mass loss rate of each of the member.

Table 2 Cross section details of hybrid wood tests

% Mass loss	Time taken, *s*	Denser wood 960 *kg/m³*	Lighter wood 460 *kg/m³*
30	195	21% lost Char depth 1-2 mm	42% lost Char depth 4 - 5 mm
40	260	30% lost Char depth 1-2 mm	51% lost Char depth 5 - 6 mm

Panel fire test

UL 711 - 1A panel of 2.45 x 2.45 *m* is the minimum size that is used for rating fire extinguishers. For the present study, a panel of 0.6 x 0.6 *m*, which represents 25% of the scale, is constructed using prescribed procedure. Top insets of Fig. 3 show two views of the panel. Arrangements made for obtaining panel weight history and temperatures in the region of 9-12 strips are also shown. The panel is ignited using excelsior, saturated with a fuel mixture of 85:15% (by volume) kerosene and hexane in a rectangular pan of 0.6 x 0.1 x 0.02 *m* height. This ignition strategy is found more attractive compared to the use of locally found excelsior alone. The panel weight loss history is recorded. The pan used for ignition is removed 60 seconds after ignition. At 120 seconds, (2 minutes), when the horizontal furring strips are on the verge of breaking, the panel is extinguished. All the 14 furring strips are sectioned at 165 mm form right end of the panel. Fig. 3 (bottom) shows these sectional images. The charred and green biomass regions can be clearly distinguished. Using the original c/s area of the panel and area of green biomass at this section, mass loss fraction at the instant of quenching and therefore overall mass loss rate can be obtained.

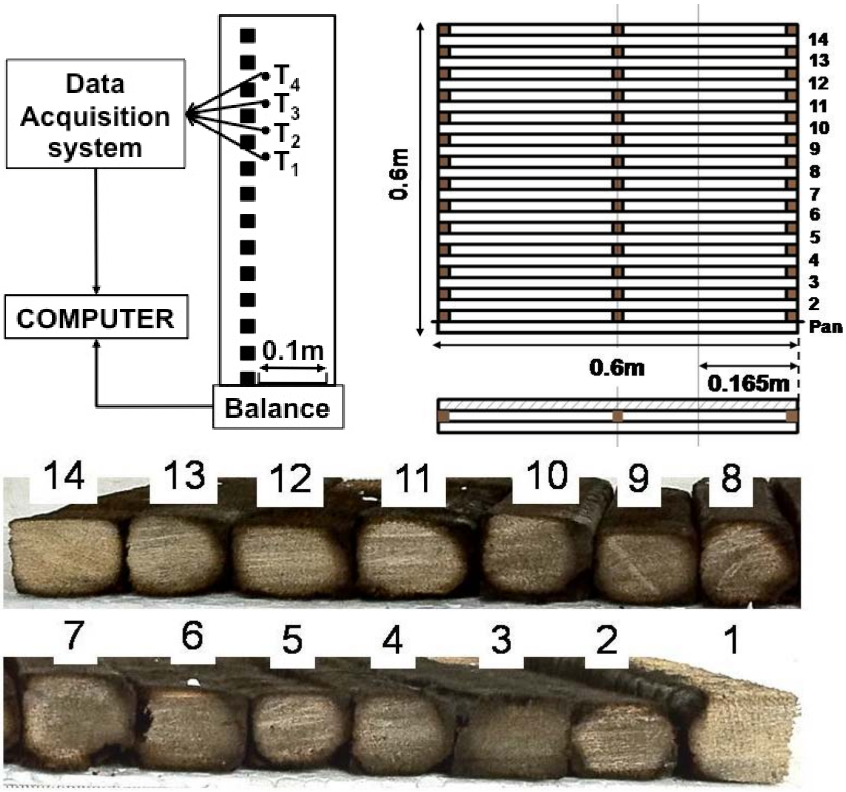
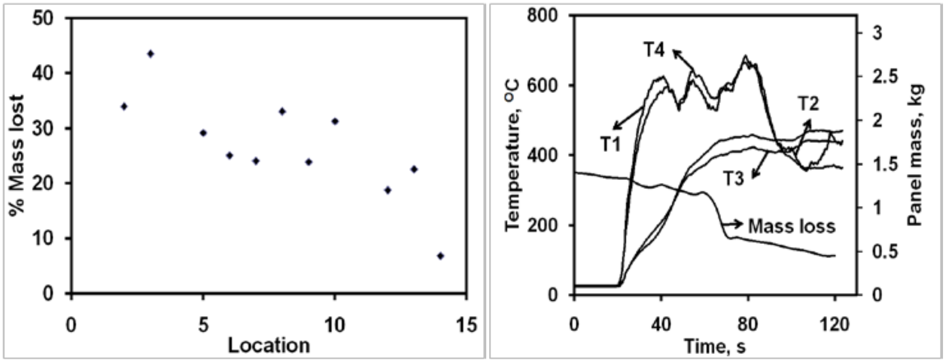


Fig. 3 Details of panel construction & section views of panel members after test *(**Top left**: end view of panel indicating thermocouples location & balance. **Top right**: front and top views **Bottom**: section view of panel members after quenching (25% mass loss) at 165 mm from right end)*

Examination of judiciously chosen combination longitudinal and cross sections of all panel members can lead to evaluation of mass loss rate at any chosen location. This useful data can be employed to carry out CFD studies on the panel to evaluate temperature and flow fields during panel fire test. Fig. 4a shows panel mass loss fraction as a function of height. It is found that mass lost fraction has varied from 40% to 25% at analyzed vertical section. Amount of green biomass remaining in the core is found to decrease towards the centre compared to ends by observation of longitudinal sections of the panel. Figure 4b gives temperature histories. The peak temperature recorded is 700 ^{O}C at 375 *mm* from the bottom of the panel. Mass loss in the central region is found to be greater than sides.



a. Mass loss with height **b. Mass and temperature history**

Fig. 4 Result plots from panel fire studies

CONCLUSION

The results of the preliminary study show that the density of the furring strips constituting panel matters significantly. It appears that wood of density 450 – 475 kg/m^3 is appropriate as panel material to enable extinguishment under the standard UL 711 requirements. Tests indicate criteria for qualification can be based on extinguishment start time decided by panel weight loss criteria that is far more certain compared to visual indicators or elapse of fixed time after ignition. Experiments will be conducted using a wider range of wood species to allow a wider choice of the wood species by providing specifications on density and perhaps other relevant parameters.

REFERENCES

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