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Burning Characteristics of Wood-based Materials using Cone Calorimeter and Inclined Panel Tests*[1]

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ABSTRACT

Research to discuss the fire performance of materials requires tools for measuring their burning characteristics and validated fire growth models to predict fire behavior of the materials under specific fire scenarios using the measured properties as input for the models. In this study, burning characteristics such as time to ignition, weight loss rate, flame spread, heat release rate, total heat evolved, and effective heat of combustion for four types of wood-based materials were evaluated using the cone calorimeter and inclined panel tests. Time to ignition was affected by not only surface condition and specific gravity of the tested materials but also the type and magnitude of heat source. Results of weight loss rate, measured by inclined panel tests, indicated that heat transfer from the contacted flame used as the heat source into the inner part of the specimen was inversely proportional to specific gravity of material. Flame spread was closely related with ignition time at the near part of burning zone. Under constant and severe external heat flux, there was little difference in weight loss rate and total heat evolved between four types of wood-based panels. More applied heat flux caused by longer ignition time induced a higher first peak value of heat release rate. Burning characteristics data measured in this study can be used effectively as input for fire growth models to predict the fire behavior of materials under specific fire scenarios.

Keywords: burning characteristic, ignition, weight loss rate, flame spread, heat release rate, cone calorimeter, inclined panel test

1. INTRODUCTION

Fire is a special design consideration addressed to minimize the risk of failure modes including structural collapse. Fire is not a loading condition in the traditional structural sense of applied forces, but instead it is an environmental condition that can have a dramatic impact on load carrying capacity and structural safety. The primary objective of fire resistant structural design is to maintain structural integrity during a fire for a sufficient period so that occupants may safely evacuate, fire fighters may safely extinguish the fire, and property loss

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may be minimized.

The primary areas of fire research related to structural engineering are fire growth, thermal degradation, and fire endurance. Especially, fire growth research offers the opportunity to measure and simulate the thermal conditions associated with actual fires, and has the objective to improve predictions of heat and smoke release rate, temperature development, and products of combustion.

Research to discuss the fire performance of materials requires the tools for measuring their burning characteristics and validated fire growth models to predict the fire behavior of the materials under specific fire scenarios using the measured properties as input for the models. Burning characteristics are ignition time, weight loss rate, flame spread, heat release rate, effective heat of combustion, and so on. Among them, heat release rate is widely considered one of the most dominant material properties influencing the growth of fire. Its measurement under a simulated fire environment was made possible by the introduction of an oxygen consumption method. Also, the cone calorimeter is becoming the most standard tool used to evaluate heat release rate of building materials.

Moghtaderi *et al.* (1997) reported the results of a combined experimental and theoretical study of piloted ignition using cellulosic materials. He concluded that the ignition temperature was significantly affected by both moisture content and incident heat flux. Silcock and Shields (1995) employed dimensional analysis to determine which dimensionless groups are relevant to the piloted ignition process and proposed a protocol for the analysis of ignition data for combustible materials based on the flux-time product. Fangrat *et al.* (1996) measured surface temperature at ignition during cone calorimeter tests for several plywoods and particleboard in horizontal and vertical configurations. It was found that the surface temperature at ignition depends not only on the material properties but also strongly on the experimental conditions. Hill and Quintiere (2000) utilized the oven test method to predict the propensity of bulk materials to ignite spontaneously. The results of small-scale laboratory oven tests were analyzed and compared with large-scale fire incidents involving several materials in question. Bock and Klement (1999) evaluated fire behavior of building material subjected to an impingement by a small flame, e.g. the flame of a match using the single flame source test. Under modified test conditions, certain timber materials previously assigned to Euroclass F would be designated Euroclass E.

Lattimer and Beitel (1998) conducted a thorough review to verify the correctness of equations used to calculate heat release rate in standard test methods and found 22 incorrect equations. Lyon (2000) examined the role of solid-state thermal degradation kinetics in steady-flaming combustion. Expressions for the burning surface temperature, pyrolysis zone depth and fractional weight loss rate were derived from heat transfer in limited, nonisothermal pyrolysis kinetics.

Rhodes and Quintiere (1996) developed ignition and burning rate data for thick (25 mm) black Polycast PMMA in a cone calorimeter heating assembly and established a testing protocol that lead to the prediction of ignition and burning rate from cone data. Gallina *et al.* (1998) addressed the fire behavior of polypropylene compounded with six classes of flame retardants. The application of the cone calorimeter for the assessment of thermal characteristics of tested materials and their comparison with thermogravimeter were studied.

Since the available amount of burning characteristic data for wood-based materials is generally quite limited, four types of wood-based

Table 1. Specific gravity, moisture content and thickness of tested materials.

	Specific gravity (g/cm^3)	Moisture content (%)	Thickness (mm)
Medium-density fiberboard	0.72	6.2	12.3
Particleboard	0.65	7.2	12.3
Oriented strandboard	0.59	6.8	11.9
Plywood	0.54	10.3	8.7

materials (plywood, Oriented Strandboard, Medium-density Fiberboard, and particleboard) for interior finishing materials were evaluated using the cone calorimeter and inclined panel tests.

2. MATERIALS and METHODS

2.1. Materials

Four types of wood-based materials were tested; MDF (Medium-density Fiberboard), PB (particleboard), OSB (Oriented Strandboard), and plywood. The specimens were cut into 300 mm square for inclined panel tests and 100 mm square for cone calorimeter tests. Prior to both tests, all specimens were conditioned in a humidity chamber at 50% relative humidity and 20°C for 14 days or more, and specific gravity, moisture contents, and thickness of each specimen were measured (Table 1).

2.2. Methods

2.2.1. Inclined panel tests

Inclined panel tests were carried out to evaluate the ignition time, wdight loss rate and flame spread properties of four types of wood-based materials by a flame type heat source. Testing equipment and methods were conformed to the intentionally modified standard of KS F 2819 (Testing method for incombustibility of thin materials for buildings). As shown in Fig. 1, 300 mm square specimen was placed on the frame at a 45° incline, and 10 thermocouples were attached to the front and back surfaces of the specimen. A flame source was applied to the bottom of the specimen while simultaneously the temperature data acquisition system (Fig. 2) was initiated.

Fig. 1. Experimental set-up for inclined panel tests.

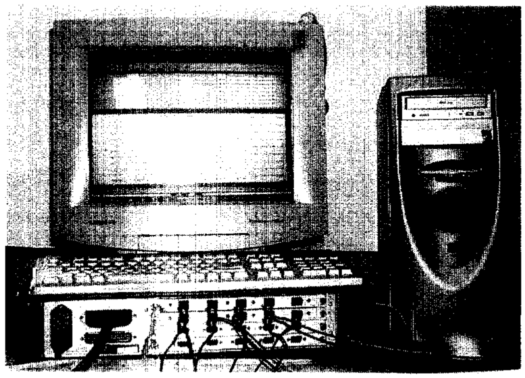

Fig. 2. Surface temperature aquisition system (SYS 5000).

Two types of flame length (50 mm and 100 mm) were applied to evaluate the effect of the magnitude of the heat source. Heating was continued for 5 minutes. From the tested specimen, weight loss was obtained by dividing weight change by total heated time and the flame spread area was measured using transparent graph paper.

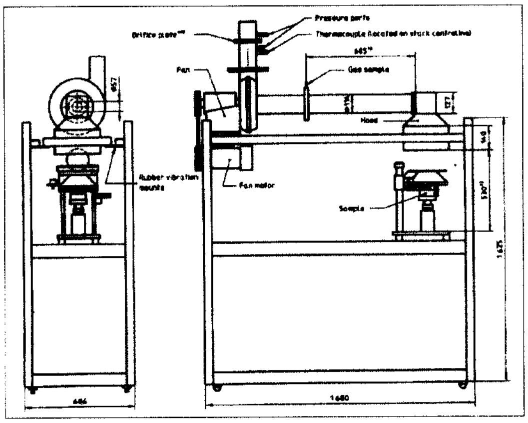

Fig. 3. Schematic diagram of cone calorimeter.

2.2.2. Cone calorimeter tests

The cone calorimeter test is a bench-scale test used to determine the reaction to fire of surface lining materials used in buildings. The test apparatus consist basically of an electric heater, an ignition source, and a gas collection system (Fig. 3).

All specimens tested in the cone calorimeter were in a horizontal orientation. Specimens were wrapped in a single layer of aluminum foil and placed into a 50 mm high specimen holder. After mounting and placing them in the right position, specimens were exposed to a radiant heat flux of 50 kW/m^2 from an electric heater. All procedures for testing were conformed to ISO 5660(Fire tests -Reaction to fire-, part 1: Rate of heat release from building products - cone calorimeter method).

3. RESULTS and DISCUSSION

3.1. Ignition

The ignition of cellulosic materials, such as wood and wood-based materials, has been of interest for a long time due to its direct relation to fire hazard and fire safety issues. Generally, ignition refers to the appearance of flame at the surface of a material which has been exposed to some type of external heating. Typically, in building fires, the thermal radiation from the flame, the ceiling layer, and hot walls is the primary source of external heating. The initiation of flaming may be spontaneous or piloted. The latter occurs in the presence of an ignition source, such as a flame or an electrical spark. The phenomenon of piloted ignition is of great importance in fire safety research since it occurs at low critical surface temperatures and is associated with the initiation and subsequent growth and development of fire from a small ignition source.

In this study, ignitions by a flame type heat source and radiant heat flux were evaluated using inclined panel tests and cone calorimeter tests, respectively.

While the onset of ignition in the cone calorimeter tests could be easily detected, that in the inclined panel tests was very difficult to detect visually. So, time to ignition in inclined panel test was determined by rapid temperature change on the front and back side of specimen.

Table 2. Time to ignition measured by cone calorimeter and inclined panel tests (sec.).

	Cone calorimeter test	Inclined panel test		
	(50 kW/m^2)	5 cm flame	10 cm flame	T_{ig} (°C)
Medium-density Fiberboard	41	68	64	705
Particleboard	40	56	42	693
Oriented Strandboard	22	52	48	669
Plywood	28	34	30	643

In Table 2, ignition time of each material, measured by both test methods (inclined panel and cone calorimeter test), was shown. It was considered that the surface condition and specific gravity of the specimen were major factors affecting the ignition time in both tests.

Differences in ignition times between testing methods was caused by differences of heating sources. Differently from a constant radiant heating source applied in the cone calorimeter test, the flame type heating source applied in inclined panel test was not constant during the test because of heat loss. In inclined panel test, surface temperature at ignition time was higher than the recorded temperature of the previously published literature. This fact was thought to be caused by the differences of heating sources between testing methods and by heat loss in inclined panel test.

3.2. Weight loss rate

Weight loss rate of material exposed to a flame type heat source and radiant heat flux was closely related to flame severity, flame spread, and burning rate. Weight loss data measured by both test methods were shown in Table 3.

Results from cone calorimeter test indicated that weight loss rate after ignition was nearly constant, about 0.1 g/sec., regardless of material types. This fact was thought to be caused by a severe heating condition of 50 kW/m^2 heat flux. So, additional tests under various heat fluxes are needed in the future. In the case of inclined panel test, however, weight loss rate was affected by material types. As specific gravity of material decreased, weight loss rate increased. It was considered that heat transfer from the contacted flame used as the heat source into the inner part of the specimen was inversely proportional to specific gravity.

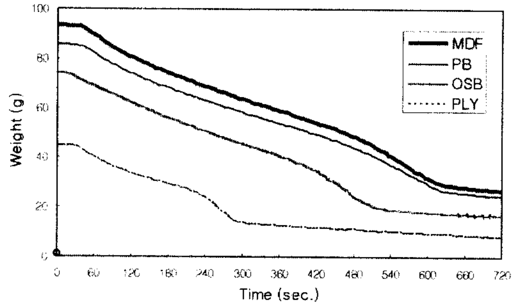

Fig. 4. Time-dependent weight change measured by cone calorimeter.

time-dependent weight change and weight loss rate in cone calorimeter test was shown in Fig. 4 and 5, respectively

3.3. Flame spread

Flame spread along the surface lining materials was an important factor affecting fire growth in building fires. Charred area measured by using transparent graph paper in the inclinded panel test was considered as area over which flame had spread. Also, lateral and vertical flame spread rate was calculated by lateral and vertical flame spread length divided by total heated

Table 3. Weight loss rate measured by cone calorimeter and inclined panel tests (g/s).

	Cone calorimeter test		Inclined panel test	
	Before ignition	After ignition	5 cm flame	10 cm flame
Medium-density fiberboard	0.066	0.103	0.029	0.090
Particleboard	0.058	0.095	0.028	0.137
Oriented strandboard	0.067	0.097	0.048	0.147
Plywood	0.055	0.105	0.051	0.150

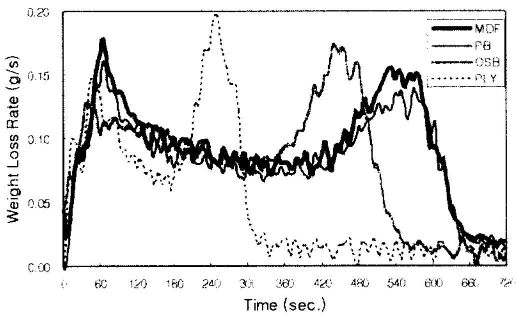

Fig. 5. Time-dependent weight loss rate measured by cone calorimeter.

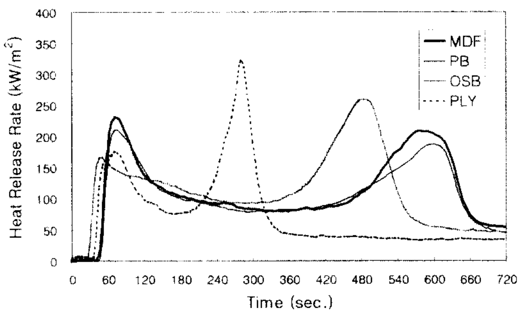

Fig. 6. Heat release rate measured by cone calorimeter.

time. Charred area and flame spread rates in both direction were given in Table 4. Similar to the results of weight loss rate, as specific gravity of material decreased, flame spread rate increased. It was taken into account that flame spread was closely related with ignition time at the near part of the burning zone.

3.4. Heat release rate

One of the key burning characteristics is heat release rate during burning. Heat release rate is generally considered one of the most dominant material properties affecting the growth of fire. Its measurement in a simulated fire environment was made possible by the introduction of the oxygen consumption method. Likewise, the cone calorimeter is becoming the most useful standard tool used to evaluate heat release rate of building materials. The cone calorimeter is capable of measuring not only time-dependent heat release rate but also many other burning characteristics. Using such a device, trends of heat release rate, total heat evolved, and effective heat of combustion for wood-based panels were evaluated.

Figs. 6, 7, and 8 compare the time histories of heat release rate, total heat evolved, and effective heat of combustion between different types of wood-based panels.

As shown in Fig. 6, there were two peaks in heat release rate for all specimens. One appeared shortly after ignition, then the heat release rate decreased rapidly with time due to the formation of a heat insulating char layer near the sample surface. Since the back side of the sample was insulated, after heat reached there, the sample was heated more and subsequently the thermal degradation was accelerated and the heat release rate started to

Table 4. Flame spread properties measured by inclined panel tests.

	Charred area (cm^2)		Flame spread (cm/sec.)			
	5 cm flame	10 cm flame	5 cm flame		10 cm flame	
			Lateral	Vertical	Lateral	Vertical
Medium-density Fiberboard	113	336	0.027	0.060	0.047	0.096
Particleboard	108	376	0.026	0.063	0.051	0.097
Oriented Strandboard	180	406	0.033	0.067	0.052	0.097
Plywood	197	412	0.044	0.070	0.060	0.113

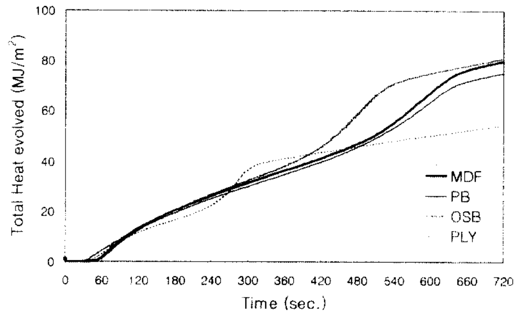

Fig. 7. Total heat evolved in cone calorimeter tests.

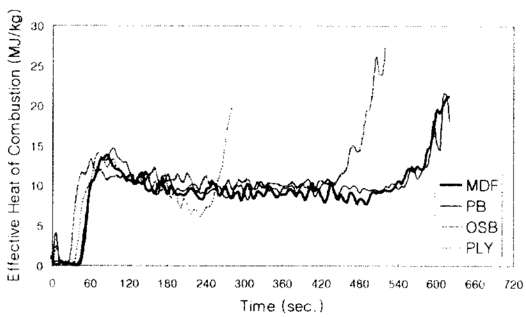

Fig. 8. Effective heat of combustion calculated by heat release rate and weight loss rate.

increase again until the sample was significantly consumed. From Fig. 6, time to ignition was easily determined as time to rapid increase of heat release rate. First peak values of heat release rate for plywood and OSB were somewhat smaller than those for PB and MDF. Since the time to ignition of MDF and PB was lognger than that of plywood and OSB, more heat flux was transferred to the surface of MDF and PB.

Fig. 7 indicated that there was little difference between the total heat evolved in all specimens except thinner plywoods. This fact was caused by severe heating condition of 50 kW/m^2. Effective heat of combustion calculated by dividing heat release rate by weight loss rate were nearly constant at a value of 10 MJ/kg, independent of material types after ignition. This value will be useful as input for fire growth models.

4. CONCLUSIONS

In this study, burning characteristics such as time to ignition, weight loss rate, flame spread, heat release rate, total heat evolved, and effective heat of combustion for four types of wood-based materials were evaluated using the cone calorimeter and inclined panel tests. From the results of this study, conclusions were summarized as follows :

1) Time to ignition was affected by not only surface condition and specific gravity of tested materials, but also type and magnitude of heat source.

2) Results of weight loss rate, measured by inclined panel tests, indicated that heat transfer from the contacted flame used as the heat source into the inner part of the specimen was inversely proportional to specific gravity of material.

3) Flame spread was closely related with ignition time at the near part of the burning zone.

4) Under constant and severe external heat flux, there was little difference in weight loss rate and total heat evolved between four types of wood-based panels.

5) More applied heat flux caused by longer ignition time resulted in a higher initial peak value of heat release rate.

6) Burning characteristics data measured in this study will be useful as input for fire growth models for predicting fire behavior of the materials in specific fire scenarios.

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