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Evaluating the flammability of wood-based panels and gypsum particleboard using a cone calorimeter

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ABSTRACT

This study examined the combustion characteristics of wood-based panels and gypsum particle board (GPB) made from wood particles using a cone calorimeter according to the ISO 5660-1 specifications. The combustion characteristics of the wood-based panels and GPB were measured in terms of the time to ignition (TTI), heat release rate (HRR), smoke production rate (SPR) and CO yield under a fire condition. The results demonstrated variations in the burning characteristics between the wood-based panels and a significant influence of the surface materials and construction elements on the HRR and SPR. The HRR, SPR and the CO yield of GPB were significantly lower than those of the wood-based panels.

1. Introduction

In recent years, the increasing demands on forestry resources for different applications have led to shortages of wood supply. Therefore, there is growing need to find alternative raw materials and increase the utilization rates of wood resources including wood-based panels, such as particle board (PB), medium density fiberboard (MDF), plywood, hardboards and wood flooring [1,2]. In particular, gypsum PB (GPB), which has superior properties, such as a lack of formaldehyde emission, fire-resistance and sound insulation compared to wood-based panels, has been used [3,4]. GPB consists mainly of natural gypsum with residual or recycled wood particles. In the manufacturing process for GPB, gypsum is added to water citric acid, pressed into stable and odorless panels, dried, and cut to the customary sizes. Moreover, the wood particles are not dried, and GPB is pressed under cold conditions, which reduces the thermal energy consumption. In addition, GPB employs industrially disposed gypsum, which is a by-product of many chemical processes [3,5]. GPB has attracted considerable research attention due to its widespread availability in nature, its ecological and technological properties, low energy consumption in manufacturing and many other positive properties [6]. Owing to these advantages, the largest use of gypsum is in the manufacture of GPB for use in partition walls, attachment shuttering, wall and ceiling paneling, and suspended ceilings.

The increasing demand for wood-based panels and GPB in building and interior materials has prompted concerns regarding their combustibility [7]. Wood-based panels ignite when exposed to fire, releasing heat, which can further promote the fire in some circumstances. For these reasons, stringent fire regulations govern the use of building and interior materials and other applications. These regulations require that the fire reaction properties meet specified levels. The reaction properties that are often used to define the fire hazard include the heat release rate (HRR), time to ignition (TTI) and flame spread rate, which are important because they affect the temperature and spread of a fire [8].

This study evaluated the fire safety performance of wood-based panels and GPB using a cone calorimeter. The cone calorimeter is a newly developed instrument for measuring the heat release and smoke emission behavior from a burning surface and analyzing the combustion products when a constant flow of air is provided to a confined space [9,10]. Of the many fire reaction properties, it is generally recognized that the HRR is the single most important factor in controlling fire hazards.

The aim of this study was to determine the combustion characteristics of wood-based panels and GPB according to the ISO 5660-1 using a cone calorimeter.

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2. Experimental

2.1. Materials

Wood-based panels, including 9 mm-thick PB, 12 mm-thick MDF, 8 mm-thick high density fiberboard (HDF), 8 mm-thick plywood and 8 mm-thick laminate flooring were obtained from Dongwha Enterprise Co. Ltd., South Korea. Laminate flooring consists of HDF as the core material with a deco paper bonded onto the face of the HDF using melamine–urea–formaldehyde resin [2]. Building gypsum was obtained from a gypsum manufacturer (Shan Xi Province, PR China). *Eucalyptus sp.* and *Pinus massoniana* wood particles were provided by Cang Song GPB manufacturer (Shan Dong Province, PR China) and Nanjing New Human Board Industry Co., Ltd. (Jiang Su Province, PR China), respectively. Screen analysis involves passing wood particles through screen meshes of various sizes. This was performed to determine

(a) *Eucalyptus sp.* (b) *Pinus massoniana*

Fig. 1. GPBs made with *Pinus massoniana* and *Eucalyptus sp.* wood particles [3].

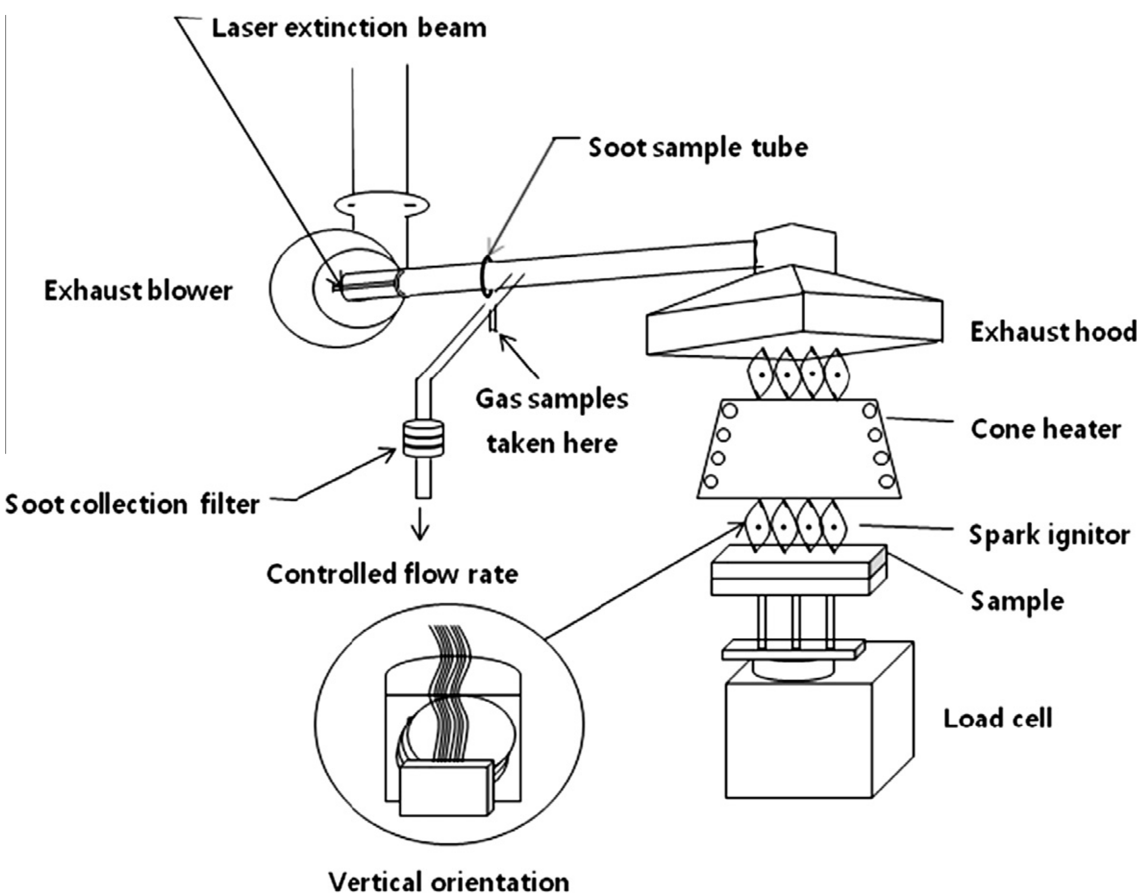


Fig. 2. Experimental set-up of the cone calorimeter.

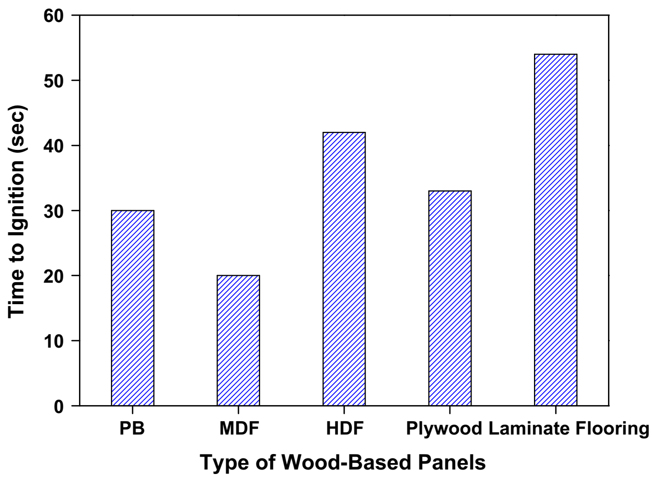


Fig. 3. TTI of the wood-based panels.

the wood particle size distribution. The proportions of screen analysis (S) of the particles (opening) were 10.1% for $S < 0.71$ mm, 10.9% for $0.71 \text{ mm} < S < 1.00$ mm, 15.2% for $1.00 \text{ mm} < S < 1.40$ mm, 35.7% for $1.40 \text{ mm} < S < 2.00$ mm, and 28.1% for $2.00 \text{ mm} < S$. Citric acid ($C_6H_8O_7$) was added at a 0.05% concentration, based on the gypsum weight, as a retarder.

2.2. GPB manufacture method and condition

Each material was weighed at a wood/gypsum ratio of 0.3 and a water/gypsum ratio of 0.4. The particles were placed in a blender after which citric acid in water and the weighed gypsums were added. Boards, 10 mm × 300 mm × 300 mm in size, were formed. The sample boards had a target density of 1.20 g/cm^3. The mats were pressed at 3 MPa at room temperature, 40 °C and 60 °C for 2.0 h. The moisture content of the GPB mats was reduced to approximately 2%–3% in a dryer at 45 °C. After removing from the dryer, the mats were stored at room temperature for one week. Fig. 1 shows the GPBs made with *P. massoniana* and *Eucalyptus sp.* wood particles [11].

2.3. Flammability testing

Cone calorimeter tests were carried out according to the procedures indicated in the ISO 5660-1 standard using a Fire Testing Technology cone calorimeter (Fire Testing Technology LTD., UK). The wood-based panels and GPB were conditioned

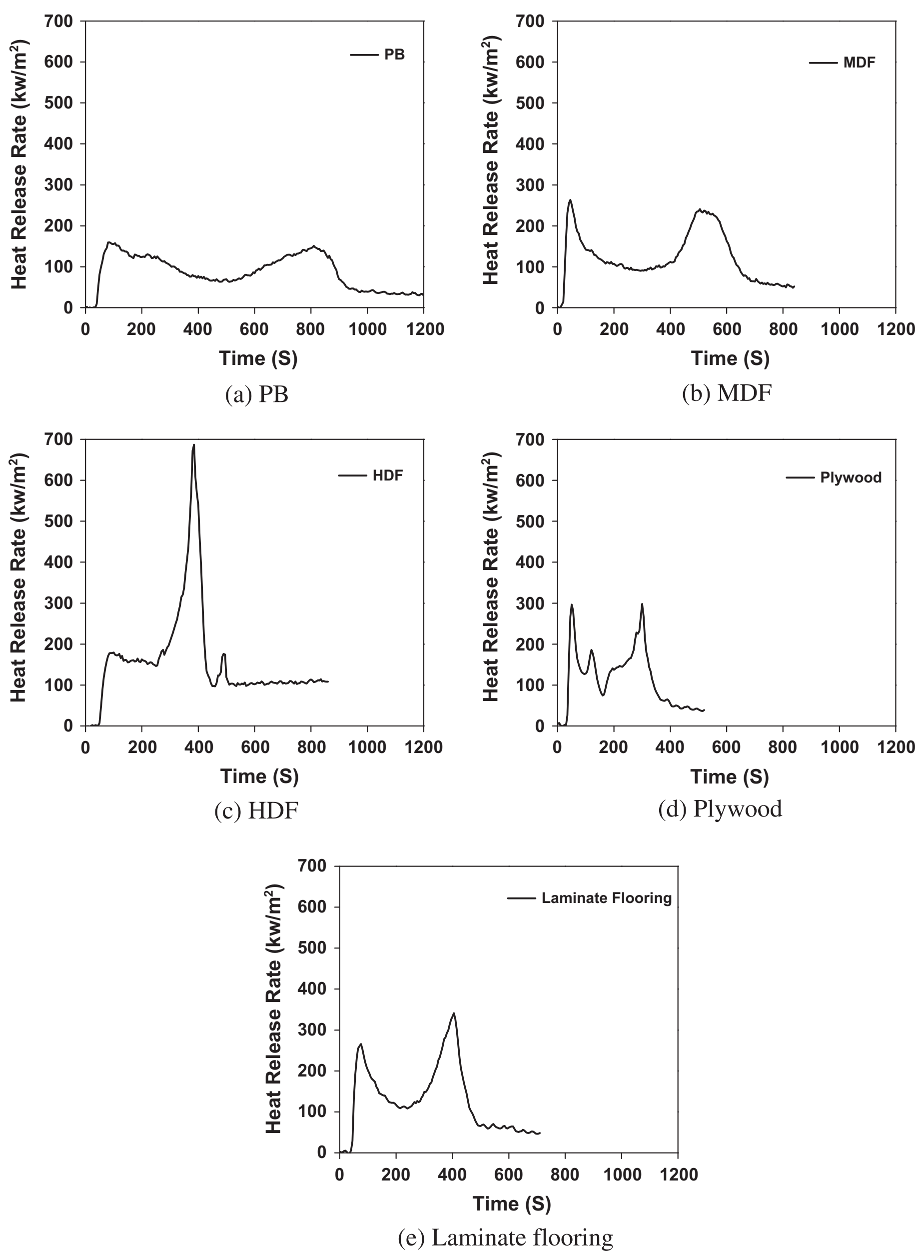


Fig. 4. Heat release rate (HRR) of the wood-based panels as a function of time.

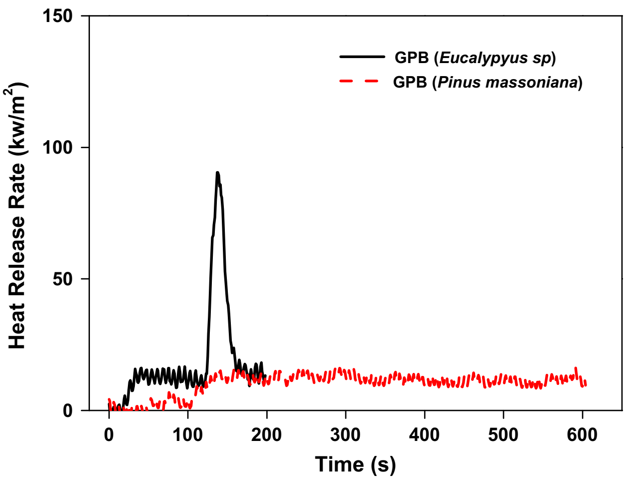
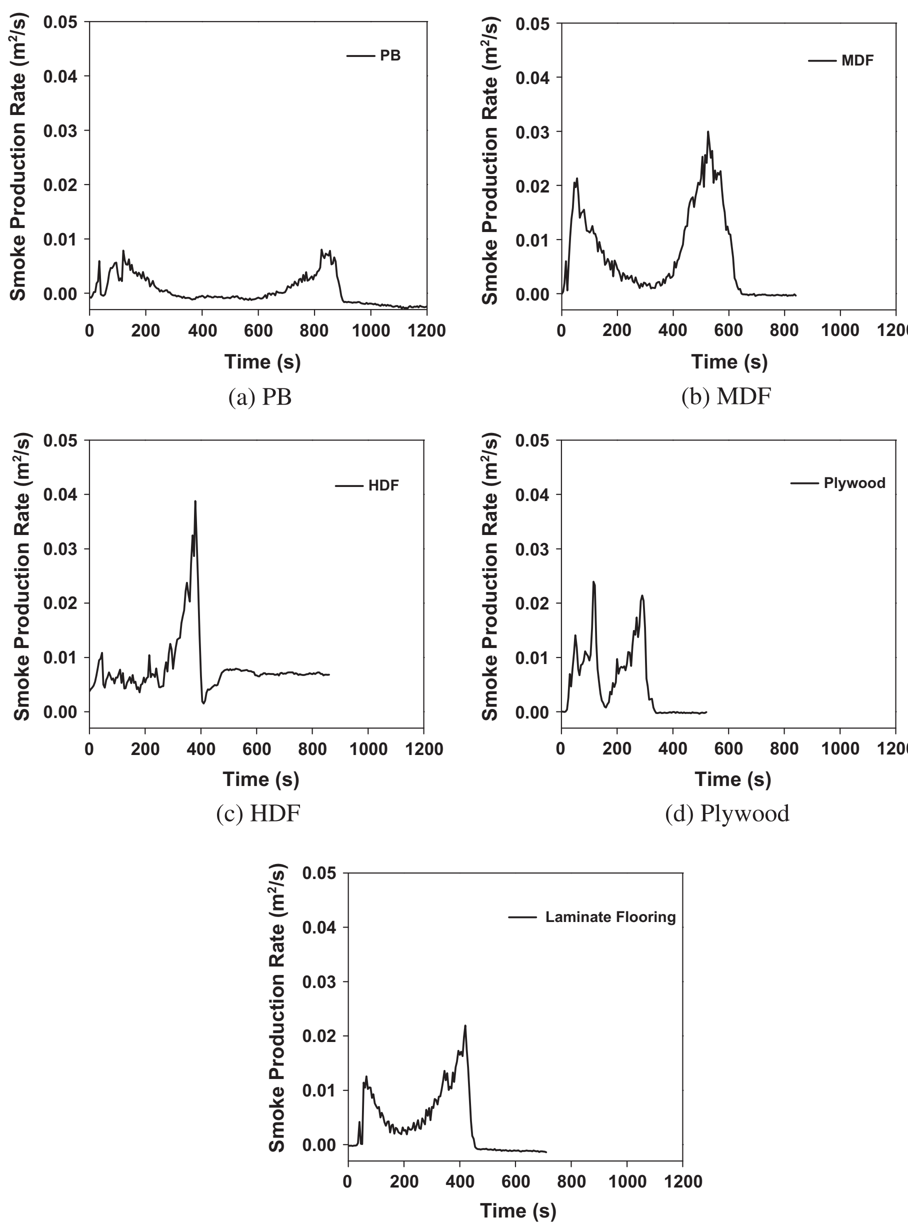


Fig. 5. Heat release rate (HRR) of GPB as a function of time.

Table 1
Screening values of *Pinus massoniana* and *Eucalyptus sp.* particles [3].

Wood species	Screening value of particle	
	Mesh	%
Pinus massoniana	~20	52.9
	20 ~ 40	20.1
	40 ~ 60	9.2
	60 ~ 80	6.5
	80 ~ 100	4.7
	100 ~ 120	1.4
	120~	5.2
Eucalyptus sp.	~20	9.9
	20 ~ 40	47.9
	40 ~ 60	21.6
	60 ~ 80	11.2
	80 ~ 100	4.6
	100 ~ 120	1.1
	120~	3.5



(a) PB (b) MDF (c) HDF (d) Plywood (e) Laminate flooring

Fig. 6. Smoke production rate (SPR) of the wood-based panels as a function of time.

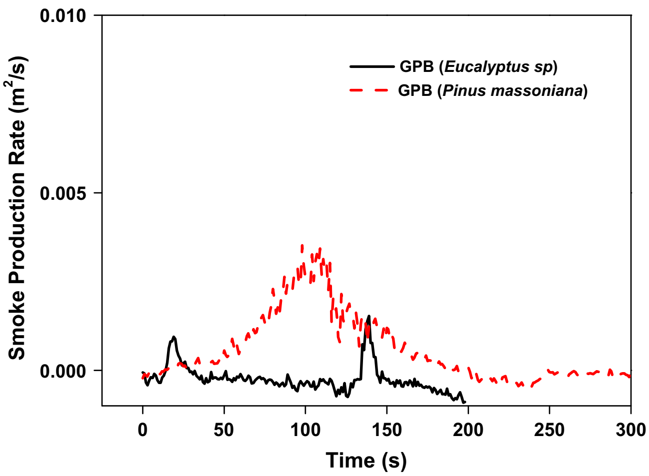


Fig. 7. Smoke production rate (SPR) of GPB as a function of time.

to equilibrium at 55% RH and 23 °C prior to testing. The dimensions of the *GPB manufacture* were 10 × 100 × 100 (mm) and the thickness of the wood-based panels showed the material section. All samples were measured in the horizontal position. The square specimens were irradiated with a heat flux of 50 kw/m^2. Fig. 2 shows the experimental set-up of the cone calorimeter. During the test, the following parameters were determined: TTI, HRR, peak HRR (PHRR), smoke production rate (SPR) and carbon monoxide yield. The TTI index is the time to flame initiation on the samples surface due to heat radiation. HRR can be calculated using the following equation:

$$\dot{q}''(t) = \frac{\dot{q}(t)}{A_s}$$

$$\dot{q}(t) = \left(\frac{\Delta h_c}{r_o}\right)(1.10)C\sqrt{\frac{\Delta P}{T_e}}\frac{(X^{\circ}_{O_2} - X_{O_2}(t))}{1.105 - 1.5X_{O_2}(t)}$$

$\dot{q}''$ is the heat released rate per unit area (kW/m^2), $\dot{q}$ is the heat release rate (kW), A_s is the initially exposed area (m^2), Δh_c is net heat of combustion (kJ/kg), 1.10 is the ratio of the oxygen to air molecular weights and r_o is the stoichiometric oxygen/fuel mass ratio (–). The PHRR is considered to be the parameter that best expresses the maximum intensity of a HRR curve.

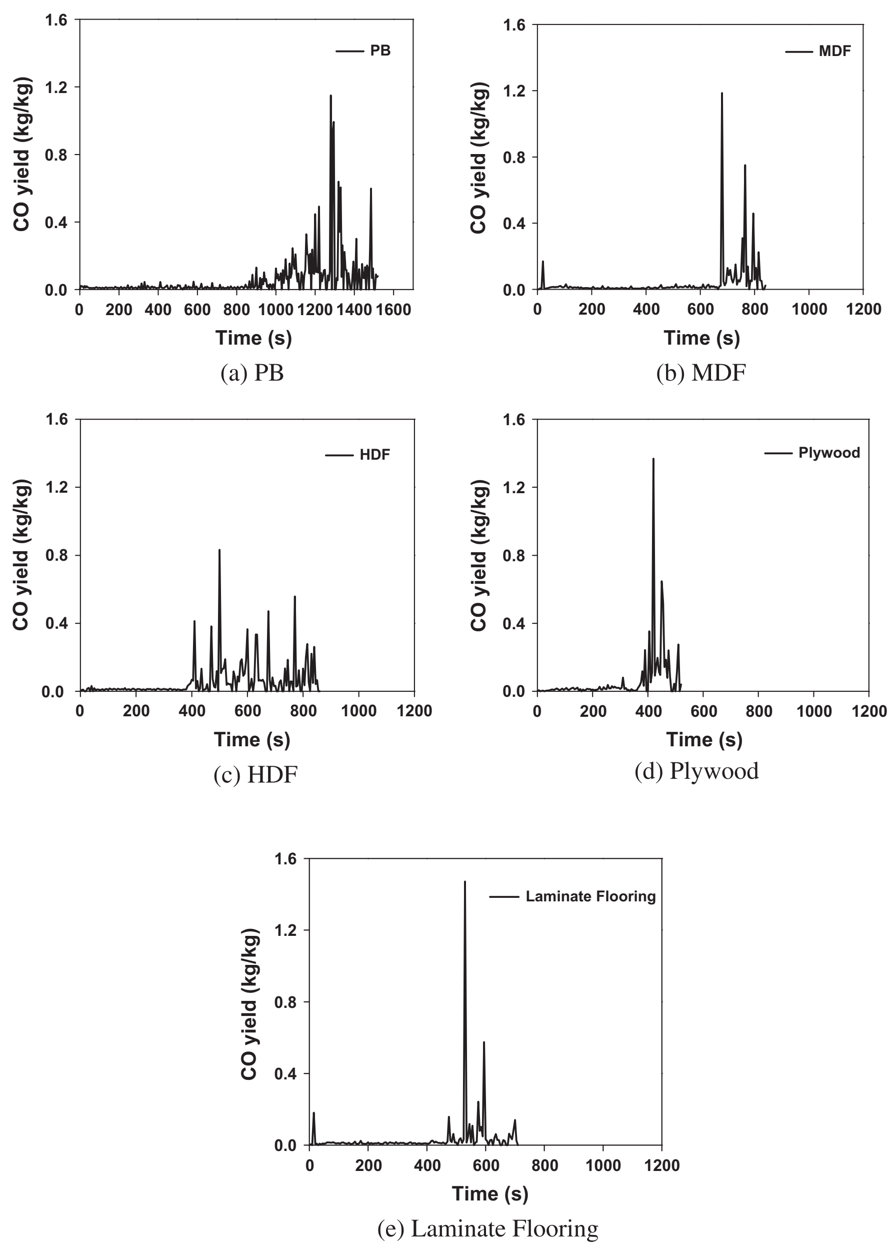


Fig. 8. CO release from the wood-based panels as a function of time.

3. Results and discussion

3.1. TTI and heat release of wood-based panels and GPB

The TTI, HRR and SPR are important parameters for evaluating the flame retardancy and flammability of interior materials [9]. Fig. 3 shows the TTI of wood-based panels. The TTI of laminate flooring was the longest of the wood-based panels. This indicates that the laminate flooring was bonded to the face of the HDF as a core material with melamine–urea–formaldehyde, resin-treated, deco paper, which acted as a flame retardant in the laminate flooring. TTI of HDF was longer than that of MDF, indicating that MDF burns more easily owing to its lower density than HDF. MDF and HDF are composed mainly of wood fibers bonded together with a synthetic resin under heat and pressure. The specific gravity of MDF ranges from 0.50 to 0.88 and that of HDF is more than 0.9 [12]. The TTI of plywood was slightly longer than that of PB, which was attributed to the difference in the structure materials of PB and plywood. PB is composed of wood particles as anisotropic materials, whereas plywood is a composite fabrication with a grain direction change of 90° between each layer [13]. The TTI of GPB made from *P. massoniana* and *Eucalyptus sp*. could not be measured because gypsum is a nonflammable material when exposed to high heat flux.

Figs. 4 and 5 show the HRR curves of the wood-based panels and GPB. The HRR of wood-based panels increased rapidly after ignition. In general, the thermal degradation of wood and wood materials is studied for two reasons: wood can be used as a source of energy and chemicals, and can contribute to fire growth [14]. The PHRR of GPB made from *Eucalyptus sp*. was slightly higher than that of GPB made from *P. massoniana* by 120 s–150 s. This may be due to the larger particle size of *P. massoniana* than *Eucalyptus sp*. Table 1 lists the size of the GPB wood particles [11]. The HRR and PHRR of GPB were significantly lower than those of the wood-based panels, confirming the markedly higher fire-resistance and thermal stability of GPB than those of wood-based panels. These results confirmed the greater safety of GPB as an interior material when exposed to fire, compared to wood-based panels. With increasing burning time, a char layer formed on the surface of the wood-based panels, and the HRR decreased [8,14]. The PHRR of HDF was the highest of the wood-based panels, possibly because HDF is composed of high density wood fibers, which allows easy flame propagation in the depth direction when ignition occurs. The PHRR of PB was the lowest among the wood-based panels examined and exhibited a wide range. It was difficult for the flame to propagate deeply into the board owing to its construction with larger wood particles.

3.2. Smoke emission of wood-based panels and GPB

Many types of interior materials release dense smoke that limits the visibility and can cause disorientation for people attempting to escape from a fire. The production of smoke and toxic gas along with the HRR play an important role in understanding the fire hazard related to interior materials [8,9]. Figs. 6 and 7 show the SPR curves of the wood-based panels and GPB. The SPR of HDF and PB was the highest and lowest among the wood-based panels, respectively. This was attributed to their highest and lowest HRR, respectively. The SPR of plywood and laminate flooring was lower than that of MDF, indicating that the melamine–urea–formaldehyde, resin-treated, deco paper of the laminate flooring and wood veneer of the plywood reduced the SPR. The SPR of GPB was much lower than that of the wood-based panels because gypsum is a noncombustible material. Wood-based panels are used widely as construction materials in the building industry. However, one of the limitations of wood as a building material is its flammability [15]. Therefore, the high HRR and SPR of HDF necessitate treatment with a fire retardant and chemical treatment to improve the fire safety and behavior.

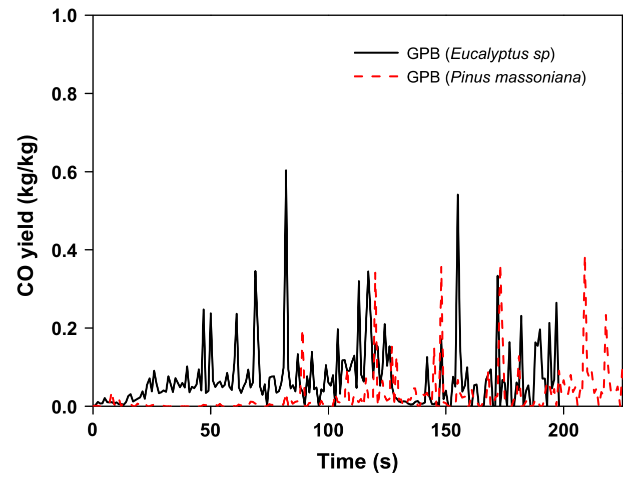


Fig. 9. CO release from GPB as a function of time.

Figs. 8 and 9 show the CO yield of the wood-based panels and GPB. The gas products released by decomposing wood-based panels and GPB depend on the chemical nature of the organic constituents, oxygen availability and fire temperature [8]. After an ignition time of 400 s, the CO emitted from the wood-based panels was increased significantly because the CO and smoke release is increased as these materials put out the flames. The CO yield of the wood-based panels was higher than that of GPB. Wood-based panels are composed mainly of combustible organic constituents, such as cellulose, hemicelluloses and lignin. The CO yield of the laminate flooring was the lowest of the wood-based panels due to the fire retardant property of the melamine–urea–formaldehyde, resin-treated, deco paper. The importance of reducing smoke to increase human survival in a fire has prompted the characterization of the smoke properties for a wide range of interior and construction materials. From these results, it was concluded that the HRR and SPR are important factors for evaluating a fire hazard and that the application of gypsum to interior materials as a frame retardant is an effective method for enhancing the fire safety and resistance.

4. Conclusions

The combustion characteristics of wood-based panels and GPB were investigated according to the ISO 5660-1 using a cone calorimeter. The TTI of laminate flooring and MDF was the longest and shortest, respectively, among the wood-based panels. However, the TTI of GPB made from *P. massoniana* and *Eucalyptus sp*. could not be measured because gypsum is a nonflammable material. PHRR and SPR of HDF were the highest owing to their construction with easily combustible materials, whereas those of PB were the lowest because it was difficult for the flame to propagate deeply into PB owing to its construction with larger wood particles. The CO yield of the laminate flooring was the lowest among the wood-based panels due to the fire retardant property of the melamine–urea–formaldehyde, resin-treated, deco paper. The HRR, SPR and CO yield of GBP were significantly lower than those of the wood-based panels, confirming the greater safety of GPB from a fire hazard than wood-based panels. Overall, GPB with a higher wood-particle content should be considered as a replacement for wood-based panels due to the superior fire retardant properties of gypsum.

References

[1] Akgül M, Çamlibel O. Manufacture of medium density fiberboard (MDF) panels from rhododendron (*R. ponticum L.*) biomass. Build Environ 2008;43(4):438–43.

[2] Kim S, Kim J-A, Kim H-J, Hyoung Lee H, Yoon D-W. The effects of edge sealing treatment applied to wood-based composites on formaldehyde emission by desiccator test method. Polym Test 2006;25(7):904–11.

[3] Feng Q, Deng Y, Kim H, Lei W, Sun Z, Jia Y, et al. Observation and analysis of gypsum particleboard using SEM. J Wuhan Univ Technol–Mater Sci Ed 2007;22(1):44–7.

[4] Kojima Y, Yasue T. Synthesis of large plate-like gypsum dihydrate from waste gypsum board. J Eur Cer Soc 2006;26(4–5):777–83.

[5] Deng Y, Furuno T. Study on gypsum-bonded particleboard reinforced with jute fibres. Holzforschung 2005;56(4):440–5.

[6] Skujans J, Vulans A, Iljins U, Aboltins A. Measurements of heat transfer of multi-layered wall construction with foam gypsum. Appl Therm Eng 2007;27(7):1219–24.

[7] Yang HS, Kim DJ, Kim HJ. Combustion and mechanical properties of fire retardant treated waste paper board for interior finishing material. J Fire Sci 2002;20(6):505–17.

[8] Mouritz AP, Mathys Z, Gibson AG. Heat release of polymer composites in fire. Compos Part A: Appl Sci Manuf 2006;37(7):1040–54.

[9] Li B. Influence of polymer additives on thermal decomposition and smoke emission of poly(vinyl chloride). Polym Degrad Stabil 2003;82(3):467–76.

[10] Yimin L, Yao B, Qin J. Preliminary burning tests on PVC fires with water mist. Polym Test 2005;24(5):583–7.

[11] Kim S, Kim JA, An JY, Kim HS, Kim HJ, Deng YH, et al. Physico-mechanical properties and the TVOC emission factor of gypsum particleboards manufactured with *Pinus Massoniana* and *Eucalyptus sp*. Macromol Mater Eng 2007;292(12):1256–62.

[12] Kartal SN, Green Iii F. Decay and termite resistance of medium density fiberboard (MDF) made from different wood species. Int Biodeterior Biodegrad 2003;51(1):29–35.

[13] Gratkowski MT, Dembsey NA, Beyler CL. Radiant smoldering ignition of plywood. Fire Safety J 2006;41(6):427–43.

[14] Grexa O, Lübke H. Flammability parameters of wood tested on a cone calorimeter. Polym Degrad Stabil 2001;74(3):427–32.

[15] Grexa O, Horváthová E, Besinová Og, Lehocký P. Flame retardant treated plywood. Polym Degrad Stabil 1999;64(3):529–33.