Effects of Some Mineral Wools and Adhesives on Burning Characteristics of Particleboard

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In this study, effects of adhesive and additive's type and ratio on burning characteristics of particleboard (PB) added glass wool (GW) and rock wool (RW) were researched. PB's furnish was derived from 50% Crimean pine, 30% Eastern Black Sea oak, 15% quaking aspen, and 5% residues of wood machining, and moisture content of furnish was 1.5 to 3%. Seventy PBs with 0.64 g/cm^3 density, urea formaldehyde (UF)/melamine formaldehyde (MF) fixed amount, 14 mm thickness, 45x45 cm^2 dimensions and 10%, 15%, 20% SW/GW additives were produced. The 150 ºC pressing temperature with 25 kg/cm^2 compression pressure was constant. Burning tests for determination of ignition time, flaming combustion temperature, flaming combustion duration, smoldering combustion duration, and mass loss during burning were made according to DIN4102 standards. According to the results of the tests, adhesive type did not affect ignition time and mass loss. While flaming combustion temperature of PB with UF was 19% higher, flaming combustion duration and smoldering combustion duration was 32% and 29% lower than those of PB with MF, respectively. While ignition time of PB with GW was 50% higher than that of PB with RW, changes in burning properties were similar for both PBs. An increase in the content of GW and RW affected burning properties of PB positively and an increase of ignition time up to 196% were obtained.

Keywords: Particleboard; Rock wool; Glass wool; Wood composite; Fire resistance

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INTRODUCTION

Particleboards (PBs) are one of the wood-based composite board types preferred the most in the production of interior space equipment elements due to being inexpensive and having sufficient resistance characteristics despite their low cost. A further advantage is that they can be combined easily with other decorative veneer materials. Such a widespread use of PBs has made them the most important material that contributes to fire resistance in interior spaces. The fact that PBs are materials that can ignite and burn easily within interior spaces has been the cause of an increase in the threat of fires starting, developing, and spreading more rapidly. These characteristics limit the use of PBs in the design of spaces in accordance with fire laws. Hence, the fire resistance properties should be improved to use PB confidently in spaces. It is necessary to make

special applications on PBs during production in order to acquire "fire-retardant" characteristics envisaged in the fire safety standards.

Some reactive chemicals, such as chlorendic acid ($C_9H_4Cl_6O_4$), tetraphthalic acid ($C_8H_6O_4$), and polyhydric alcohols ($HOCH_2(CHOH)_nCH_2OH$), decrease the total burning temperature. This effect can be attributed to decreasing the temperature of degradation, reducing the ratio of flames spread to the surface, decreasing the formation of flammable gases, and by increasing the ratio of coalification and by changing the composition of volatile substances. Chemicals such as monoammonium phosphate ($NH_4H_2PO_4$), diammonium phosphate ($(NH_4)_2HPO_4$), ammonium compounds, boron compounds, and zinc chloride ($ZnCl_2$) with a physical effect provide for the spreading of non-volatile gases during burning, slows down burning and extends the period required for wood to ignite with absorption of heat, and increases the fire resistance of PBs (Leao 1993). Addition of phosphine (PH_3) in different ratios (0 to 15%) to cotton stalk particles increases the fire resistance of PBs and as the ratio of additive increases, the fire resistance also increases (Pandey and Gurjar 1986). Addition of aluminum, iron, and magnesium silicate ($Mg_3Si_4O_{10}(OH)_2$) to cotton stalk particles can provide an increase up to 25-fold in the fire resistance of PBs (Kozlowski *et al.* 1999). The addition of a mixture of diammonium phosphate ($(NH_4)_2HPO_4$), monoammonium phosphate ($NH_4H_2PO_4$) and phosphoric acid (H_3O_4P), and boric acid (H_3BO_3) to hemp particles provides an increase of up to 120% in the fire resistance of PBs (Izran *et al* 2010). While PBs produced from walnut shell with additions of 15% ash to urea formaldehyde and phenol formaldehyde adhesives have a fire-ignition temperature of 535 °C, this value is 299 °C in PBs without ash. Increase in the ratio of ash decreases the fire-ignition temperature (Gürü *et al.* 2008). In PBs produced from kenaf (*Hibiscus cannabinus*), the impregnation process with diammonium phosphate and monoammonium phosphate produces a higher fire retardant compared to the impregnation process with boric acid (H_3BO_3) (Izran *et al* 2009). In the case of potassium carbonate (K_2CO_3), borax ($Na_2B_4O_7{\cdot}10H_2O$) and Wolmanit-CB substances are applied to Oriented Strand Board (OSB) with the brush spreading and dipping methods; the highest fire retardant was in the boards to which Womanit-CB was applied with the dipping method (Ozkaya *et al.* 2007). A difference was not observed in the fire resistances of PBs produced from radiata pine particles with polymeric methylene diphenyl diisocyanate (PMDI) ($C_{15}H_{10}N_2O_2$) resin and PBs with wood veneers and with melamine foil glued on their surfaces (Garay 2012). In PBs produced from white birch (*Betula papyrifera*) with additions of boric acid in the ratios of 8%, 12%, and 16%, an increase was provided in fire resistance with an increase in the ratio of boric acid and led by a decrease in loss of mass. Furthermore, the use of inner bark particles in the mixture also decreases loss of mass (Pedieu *et al.* 2012). In PBs produced from rubberwood particles (*Hevea brasiliensis*) with the addition of BP fire retardant in concentration ratios of 15%, 20%, 25%, and 30%, the loss of mass in burning of PBs decreases up until the level of 25% concentration and after this point no change was observed. Furthermore, as the level of concentration increases, the area of burning decreases (Izran *et al.* 2011). Maminski *et al.* (2011) studied thermal capacity, thermal conductivity, and MOR of PBs produced by mixing mineral wool in the ratios of 10%, 20%, and 30%, without specifying the type of mineral wool. They stated that while there was no effect on the thermal conductivity and thermal capacity at the mixture ratio of 10%, a difference was

created of up to 7% in thermal conductivity and 19% in thermal capacity at the mixture ratios of 20% and 30%.

As can be seen from the previous studies, various materials as an additive or a filler can be used in PB manufacturing to develop its some chemical and physical properties. We used GW and RW as additives to improve some burning properties of PB.

GW and RW are the most preferred construction materials with the objective of heat insulation beneath the sidings of indoor and outdoor spaces, roofs, dividing walls with sandwich construction, and doors. Factors that are effective in this preference are the fact that their ignition temperatures are high compared to other materials and that their heat conductivity coefficients are low (Stec and Hull 2011). Due to these characteristics, it was thought that the mixture of these materials in certain ratios in the PBs would increase the fire resistance values of PBs. Accordingly, in this study it was aimed to determine the effect of using GW and RW in the ratios of 10%, 15%, or 20% as an additive and UF and MF as a binder on some burning properties of PB such as ignition time, flaming combustion temperature, flaming combustion duration, smoldering combustion duration, and loss of mass.

MATERIALS AND METHODS

Materials

Particles

The particles used in the production of boards that would be used in the tests were taken from the PB factory that had been dried to a moisture content of 1.5 to 3.0%. The particles were composed of 50% Crimean pine (*Pinus nigra*), 30% Eastern Black Sea oak (*Quercus pontica*), 15% quaking aspen (*Populus tremula*), and 5% industrial wood shavings. There was no bark in the mixture. The thicknesses of the particles were between 0.3 mm and 0.5 mm, widths between 2.10 mm and 3.85 mm, and lengths between 2.10 mm and 10.45 mm.

Binders of urea formaldehyde (UF) and melamine formaldehyde (MF)

The density of urea formaldehyde was 1.24 g/cm^3 at 20 °C, pH value 8.1, viscosity 170 centipoises and amount of solid material was 55%. The density of melamine formaldehyde was 1.22 g/cm^3 at 20 °C, pH value 9.0, viscosity 150 cPs, and amount of solid material was 54%.

Glass wool (GW) and rock wool (RW)

The heat conductivity resistance of glass wool used as an additive material in the production of PBs was 0.045 W/mK, heat conduction coefficient was 0.028 kcal/mh °C at 0 °C, heat conduction coefficient was 0.065 kcal/mh °C at 450 °C, fiber diameter interval was 3 to 40 microns, and the specific heat was 0.19 kcal/kg °C. The heat conductivity resistance of rock wool used as an additive material in the production of PBs was 0.039 W/mK, heat conduction coefficient was 0.039 kcal/mh °C at 10 °C, and the density was 150 kg/m^3.

Automatic Laboratory Press

The HURSAN T100 brand automatic laboratory press was used for compressing PB draft specimens under the influence of heat and pressure. The dimensions of the flat surface of the press were 60 by 60 cm^2, temperature interval was 0 to 250 °C, and the pressure capacity was 250 bars.

Testing Cabinet

A testing cabinet (Fig. 1) with a volume of 800 x 800 x 1450 mm^3 was used in the determination of some burning values of the specimens in accordance with the DIN 4102 standards and that could measure the flame height values with the help of heat and scales with thermo elements.

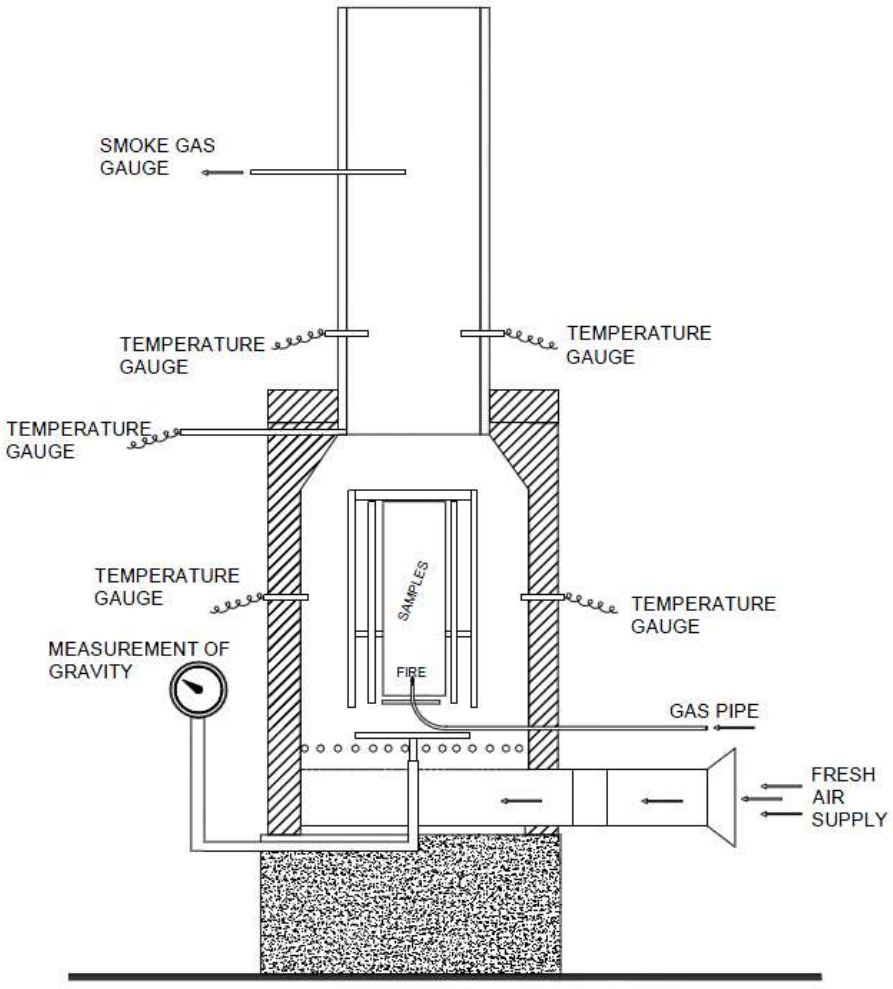

Fig. 1. Testing Cabinet

Preparation of the Specimens

The target density of PBs were projected as 0.64 g/cm^3 by taking into account PBs on the market. By accepting pressing area as 50x50 cm^2 and thickness of PB as 16 mm, it was found that total particles, additive material, and amount of adhesive that would be used as the mixture was 2,560 g. The adhesive amount of the mixture was determined to be 10% (256 g) by taking into consideration the proposals and application values in the literature. Whereas, the amount of particles used were decreased in accordance with the ratio of use of the additive material.

The pressing process was applied at a temperature of 150 ºC under a pressure of 30 kg/cm^2 and for a period of 10 min to the rock wool and glass wool in the form of a sheet in order to transform it into fiber. Subsequently, the fiber process was made with a mixer for duration of 15 min. The particle and additive materials in varying amounts according to the ratios of 10%, 15%, and 20% additive materials were weighed with a scale having a sensitivity of 0.01 g and were mixed manually until the mixture was homogenized. Urea or melamine formaldehyde adhesives were added to the mixture with a spray gun. The mats were spread on a steel plate that was brushed with Vaseline to prevent surface bonding with the help of a template in a manner that would form a 50 by 50 cm^2 surface area and the draft specimens were formed by smoothing the surface. After this process, the template surrounding the draft specimens was removed, Vaseline was spread on a single side of the upper surface, and the draft specimen was made ready for pressing by placing on the steel plate.

The mat between two steel plates was placed in a hot press heated up to a temperature of 150±5 °C and compression was made until the moving upper surface came in contact with the stop piece that provided for adjustment of the 16 mm PB thickness. At this point, compression pressure was determined to be 25 kg/cm^2. The compression period for all the PBs was applied for 18 min. At the end of this period, the PBs were removed from the press and were adapted to the surrounding climate by being kept in a closed environment separately without being stacked on top of each other. The production of the PBs was completed, with the material transformed into boards with a final dimension of 45 by 45 cm, with the cutting of a 25 mm part from each corner. The PBs were sanded in a calibrating machine with a 180-grit sander to bring into a net thickness of 14 mm. The PBs were produced in accordance with different variables and were transformed into burning test specimens with the dimensions of 1000 mm x 190 mm x 14 mm for complying with the DIN 4102-1 standards (DIN 1998).

Methods

The mass of each specimen was measured with a digital precision scale having a sensitivity of 0.01 g for determining the loss of mass after burning. The specimens were fixed with connecting elements within a cage made of stainless steel and this cage was hung on hangers within the burning cabinet.

After placement of the cage, the mechanism of door was closed and the burning process was started with gas flames. Pressured air was given from below with a fan to provide for flames rising directly to the top. The burning process with gas flames continued for 10 min. In case the temperature within the cabinet reached a temperature of

200 °C or the height of flames exceeded 80 cm at the moment of burning, then the experiment was ended. The ignition, flaming combustion and smoldering combustion duration within the burning process were measured with a chronometer having a sensitivity of 0.01 s. The flaming combustion temperature was measured with 5 each thermo elements within the cabinet that was computer-aided to measure once every minute and at a sensitivity of 0.01 ºC. After completion of the burning process and after cooling, the masses of specimens were once again measured with a scale having a sensitivity of 0.01 g and the losses of mass were calculated with the Eq. 1 (DIN 4102),

$$ML = \frac{k_i - k_s}{k_i} x100(\%) \quad (1)$$

where *ML* is the loss of mass (%), k_i is the mass of a specimen before burning, and k_s is the mass of a specimen after burning.

RESULTS AND DATA ANALYSIS

The analysis of variance was made for determining whether or not the type of adhesive used in production, the type of additive material, and the ratios of additive of PBs affected the ignition time, flaming combustion duration, smoldering combustion duration, flaming combustion temperature, and loss of mass at end of burning (Tables 1 and 2). According to the ANOVA results, with the exception of type of adhesive x ratio of additive for flaming combustion duration, dual interactions of type of additive material x ratio of additive and dual interactions of type of adhesive x ratio of additive for smoldering combustion duration (all of the other single, dual, and triple interactions had a level of error smaller than ($p<0.05$)), it was found that type of adhesive, type of additive material, and ratio of additive had a positive effect on burning characteristics of PBs. The homogeneity test determined whether the differences among the values for burning characteristics of the effective variables were significant and the results are shown in Tables 1 and 2.

Table 1. Statistical Values for Burning Characteristics of PBs for UF Adhesive According to Type and Ratio of Additive Material (v: variation coefficient)

Particleboard type		$X_{min.}$	$X_{max.}$	$X_{average}$	v (%)
UF adhesive (control)	Ignition time (s)	45.00	66.00	59.25	0.16
	Flaming combustion duration	639.00	785.00	712.50	0.75
	Smoldering combustion duration	1,950.0	2,230.0	2,062.50	0.07
	Flaming combustion temperatures	240.00	260.00	248.75	3.43
	Loss of mass (%)	32.10	32.80	32.55	0.96
UF adhesive and 10% glass wool additive	Ignition time (s)	72.00	80.00	76.25	0.05
	Flaming combustion duration	328.00	415.00	371.75	2.08
	Smoldering combustion duration	950.00	1,120.0	1,040.00	0.08
	Flaming combustion temperatures	169.90	212.30	190.06	9.28
	Loss of mass (%)	25.40	25.90	25.65	0.81
UF adhesive and 15% glass wool additive	Ignition time (s)	80.00	87.00	83.50	0.03
	Flaming combustion duration	336.00	358.00	347.50	1.17
	Smoldering combustion duration	940.00	982.00	968.00	0.02
	Flaming combustion temperatures	157.01	197.44	181.30	9.61
	Loss of mass (%)	23.40	23.80	23.58	0.72
UF adhesive and 20% glass wool additive	Ignition time (s)	94.00	97.00	95.50	0.01
	Flaming combustion duration	327.00	342.00	335.25	1.21
	Smoldering combustion duration	920.00	950.00	930.00	0.02
	Flaming combustion temperatures	147.30	172.45	163.73	6.87
	Loss of mass (%)	18.40	18.90	18.65	1.12
UF adhesive and 10% rock wool additive	Ignition time (s)	60.00	66.00	63.00	0.05
	Flaming combustion duration	315.00	340.00	327.75	2.04
	Smoldering combustion duration	880.00	930.00	908.75	0.03
	Flaming combustion temperatures	144.76	176.66	166.11	8.73
	Loss of mass (%)	26.90	27.90	27.55	1.64
UF adhesive and 15% rock wool additive	Ignition time (s)	80.00	88.00	83.75	0.05
	Flaming burning duration (s)	296.00	310.00	303.25	1.64
	Smoldering combustion duration	820.00	850.00	835.00	0.02
	Flaming combustion temperatures	143.41	168.15	159.41	7.18
	Loss of mass (%)	27.10	27.90	27.43	1.24
UF adhesive and 20% rock wool additive	Ignition time (s)	88.00	125.00	98.75	0.18
	Flaming combustion duration	245.00	297.00	271.50	2.00
	Smoldering combustion duration	730.00	780.00	755.00	0.03
	Flaming combustion temperatures	112.64	151.96	137.19	12.4
	Loss of mass (%)	26.40	26.90	26.65	0.89

Table 2. Statistical Values for Burning Characteristics of Particleboards for MF Adhesive According to Type and Ratio of Additive (v: variation coefficient)

Particleboard type		$X_{min.}$	$X_{max.}$	$X_{average}$	v (%)
MF adhesive (control)	Ignition time (s)	55.00	58.00	56.75	0.02
	Flaming burning duration (s)	474.00	501.00	488.00	0.37
	Smoldering combustion duration (s)	1,430.00	1,490.00	1,457.50	0.02
	Flaming combustion temperatures (°C)	184.55	223.93	208.70	9.93
	Loss of mass (%)	32.60	34.60	33.38	2.71
MF adhesive and 10% glass wool additive	Ignition time (s)	123.00	130.00	126.75	0.03
	Flaming combustion duration (s)	259.00	269.00	264.50	1.09
	Smoldering combustion duration (s)	780.00	800.00	787.50	0.01
	Flaming combustion temperatures (°C)	180.20	200.21	188.31	5.01
	Loss of mass (%)	24.00	24.70	24.45	1.27
MF adhesive and 15% glass wool additive	Ignition time (s)	133.00	140.00	136.75	0.02
	Flaming combustion duration (s)	213.00	242.00	228.00	1.26
	Smoldering combustion duration (s)	650.00	710.00	677.50	0.04
	Flaming combustion temperatures (°C)	158.24	176.09	169.24	4.74
	Loss of mass (%)	22.00	22.40	22.20	0.82
MF adhesive and 20% glass wool additive	Ignition time (s)	240.00	251.00	246.50	0.02
	Flaming combustion duration (s)	168.00	176.00	172.50	0.01
	Smoldering combustion duration (s)	500.00	520.00	511.25	0.02
	Flaming combustion temperatures (°C)	88.90	112.67	99.64	11.19
	Loss of mass (%)	21.40	21.90	21.60	1.00
MF adhesive and 10% rock wool additive	Ignition time (s)	77.00	81.00	79.50	0.02
	Flaming combustion duration (s)	260.00	278.00	269.50	3.12
	Smoldering combustion duration (s)	780.00	820.00	802.50	0.02
	Flaming combustion temperatures (°C)	166.69	202.40	186.46	7.97
	Loss of mass (%)	22.10	22.60	22.43	1.05
MF adhesive and 15% rock wool additive	Ignition time (s)	122.00	130.00	126.50	0.03
	Flaming combustion duration (s)	246.00	260.00	253.50	2.29
	Smoldering combustion duration (s)	740.00	770.00	753.75	0.02
	Flaming combustion temperatures (°C)	160.82	185.97	178.03	6.56
	Loss of mass (%)	21.80	22.50	22.08	1.40
MF adhesive and 20% rock wool additive	Ignition time (s)	145.00	152.00	148.75	0.02
	Flaming combustion duration (s)	229.00	267.00	248.50	1.56
	Smoldering combustion duration (s)	700.00	780.00	740.00	0.05
	Flaming combustion temperatures (°C)	151.90	174.85	162.18	6.46
	Loss of mass (%)	19.20	19.60	19.38	0.88

Ignition Time (IT)

Specifications for the homogeneity test for determining IT values connected to the triple interaction of type of adhesive, type of additive material, and ratio of additive and differences among them are given in Table 3.

Table 3. Homogeneity Groups According to Ignition Time Connected to Type of Adhesive, Type of Additive Material, and Ratio of Additive

Adhesive type	Additive	Additive ratio							
		0		10%		15%		20%	
		IT[a]	HG[b]	IT	HG	IT	HG	IT	HG
UF	Control	59.25	G	-	-	-	-	-	-
	Glass wool	-	-	76.25	F	83.50	F	95.50	E
	Rock wool	-	-	63.00	G	83.75	F	98.75	E
MF	Control	56.75	G	-	-	-	-	-	-
	Glass wool	-	-	126.80	D	136.80	C	172.50	A
	Rock wool	-	-	79.50	F	126.50	D	148.80	B

[a] Ignition time (s), [b] Homogeneity group

Comparative levels of ignition time of variables have been given in Fig. 2.

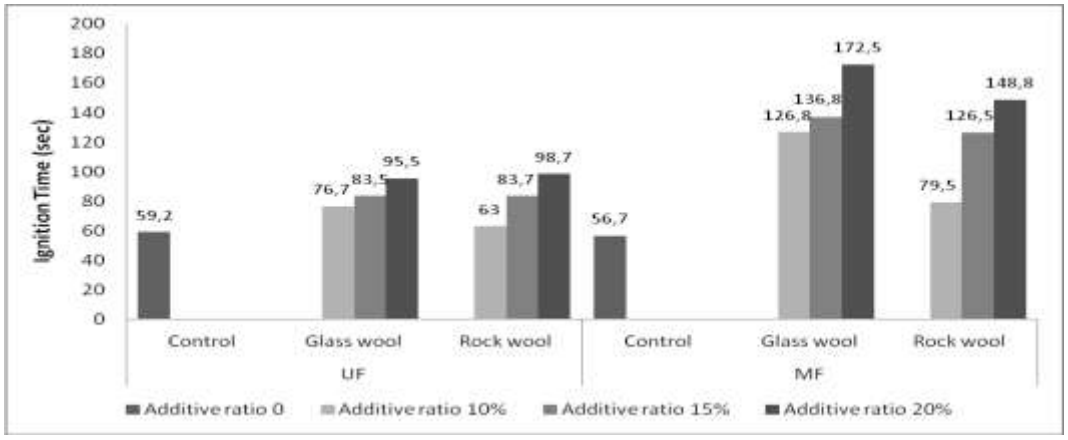

Fig. 2. Comparative levels of ignition time according to the variables

As it can be observed from Table 3 and Fig. 2, since ITs (59.24 s – 56.75 s) of PBs both with UF and MF adhesive were the least and the difference between them was statistically insignificant, RW and GW additives increased ITs of PBs. While increasing the ratio of additive from 10% to 15% in GW additive PBs with UF adhesive did not affect IT, as the ratio of additive was increased in all of the other PB types, IT also increased. While IT was increased from 59.29 s to 95.50 s in GW added PBs with UF adhesive, it was increased from 59.25 s to 98.75 s in RW added PBs. IT in GW added PBs with MF adhesives was increased from 56.75 s to 172.50 s and was increased from 56.75 s to 148.80 s in RW added PBs.

Flaming Combustion Temperature (FCT)

The homogeneity test for determining FCT and differences among them connected to the triple interaction of type of adhesive, type of additive material and ratio of additive have been given in Table 4.

Table 4. Homogeneity Groups According to Flaming Combustion Temperatures Connected to Type of Adhesive, Type of Additive Material, and Ratio of Additive

Adhesive type	Additive type	Additive ratio							
		0		10%		15%		20%	
		FCT[a]	HG[b]	FCT	HG	FCT	HG	FCT	HG
UF	Control	208.70	F	-	-	-	-	-	-
	Glass wool	-	-	190.0	E	181.	D	163.73	C
	Rock wool	-	-	166.1	D	159.	C	137.19	B
MF	Control	248.75	G	-	-	-	-	-	-
	Glass wool	-	-	188.3	E	178.	D	99.64	A
	Rock wool	-	-	186.4	E	164.	C	162.18	C

[a] Flaming combustion temperature .(°C),
[b] Homogeneity group

Since FCT of PBs both with UF and MF adhesives but no additive were the highest (208.70 °C to 248.75 °C), addition of GW and RW decreased FCT of PBs. The use of UF adhesive instead of MF adhesive as a binder in the production of PBs caused a decrease in FCT from 248.75 °C to 208.70 °C. While increasing the ratio of additive in PBs with MF adhesive and GW additive from 15% to 20% did not affect FCT, as the ratio of additive increased in all the other PB types, FCT decreased. While FCT decreased from 208.70 °C to 163.73 °C in PBs with UF adhesive and GW additives, it decreased from 208.70 °C to 137.19 °C in PBs with RW additives. FCTs decreased from 248.75 °C to 99.64 °C in PBs with MF adhesive and GW additives and decreased from 248.75 °C to 162.18 °C in PBs with RW additives.

Flaming Combustion Duration (FCD)

The homogeneity test for determining FCD of PBs connected to the triple interaction of type of adhesive, type of additive material and ratio of additive and differences among them have been given in Table 5. The FCD (712.50 s) of UF adhesive PBs without additives was higher than FCD (488.00 s) of MF adhesive PBs without additives.

Since FCD (712.50 s and 488.00 s) of both UF adhesive and MF adhesive PBs without additives was higher than all of the other PBs with additives, both the addition of GW and RW decreased FCD. While increasing the ratio of additive from 10% to 15% in PBs with MF adhesive and RW additives did not affect FCD, as the ratio of additive was increased in all of the other PB types, it decreased FCD. While FCD of PBs with UF adhesive and GW additives decreased from 712.50 s to 335.25 s, PBs with RW additives decreased from 712.50 s to 271.50 s The FCD in PBs with MF adhesive and GW additives decreased from 488.00 s to 172.50 s and PBs with RW additives decreased from 488.00 s to 248.50 s.

Table 5. Homogeneity Groups According to Flaming Combustion Duration Connected to Type of Adhesive, Type of Additive Material, and Ratio of Additive

Adhesive type	Additive type	Additive Ratio							
		0		10%		15%		20%	
		FCD[a]	HG[b]	FCD	HG	FCD	HG	FCD	HG
UF	Control	712.50	H	-	-	-	-	-	-
	Glass wool	-	-	371.75	F	347.50	E	335.25	E
	Rock wool	-	-	303.25	D	327.75	E	271.50	C
MF	Control	488.00	G	-	-	-	-	-	-
	Glass wool	-	-	264.50	C	228.00	B	172.50	A
	Rock wool	-	-	269.50	C	253.50	C	248.50	B

[a] Flaming combustion duration (s)
[b] Homogeneity group

Smoldering Combustion Duration (SCD)

The homogeneity test for determining SCD and differences among them connected to the triple interaction of type of adhesive, type of additive material and ratio of additive are given in Table 6.

Table 6. Homogeneity Groups According to Smoldering Combustion Duration Connected to Type of Adhesive, Type of Additive Material, and Ratio of Additive

Adhesive type	Additive type	Additive ratio							
		0		10%		15%		20%	
		SCD[a]	HG[b]	SCD	HG	SCD	HG	SCD	HG
UF	Control	2,063.00	H	-	-	-	-	-	-
	Glass wool	-	-	1,040.00	F	968.00	E	930.00	E
	Rock wool	-	-	908.00	E	835.00	D	755.00	C
MF	Control	1,458.00	G	-	-	-	-	-	-
	Glass wool	-	-	787.00	C	677.00	B	511.00	A
	Rock wool	-	-	802.00	C	753.00	C	740.00	B

[a] Smoldering combustion duration (s)
[b] Homogeneity group

The SCD (2,063.00 s) of PBs with UF adhesive without additives was higher than SCD (1,458.00 s) of PBs with MF adhesive without additives. Since SCD (2,063.00 s and 1,458.00 s) of PBs with both UF and MF without additives was higher than all of the other PBs with additives, both GW and RW additives decreased SCD.

While increasing the ratio of additive from 15% to 20% in PBs with GW additives and UF adhesive and from 10% to 15% in PBs with RW additives and MF adhesive did not have an effect on SCD, as the ratio of additives in all of the other PB types was increased, SCD was decreased. While SCD in PBs with GW additives and UF adhesive decreased from 2063.00 s to 930.00 s, PBs with RW additives decreased from 2063.00 s to 755.00 s.

Loss of Mass (LM)

The homogeneity test for determining loss of mass values after burning connected to triple interaction of type of adhesive, type of additive material, and ratio of additive, and the differences among them are given in Table 7.

Table 7. Homogeneity Groups According to the Loss of Mass Values After Burning Connected to Type of Adhesive, Type of Additive Material, and Ratio of Additive

Adhesive type	Additive type	Additive ratio							
		0		10%		15%		20%	
		LM[a]	HG[b]	LM	HG	LM	HG	LM	HG
UF	Control	32.60	G	-	-	-	-	-	-
	Glass wool	-	-	25.75	E	23.48	C	18.75	A
	Rock wool	-	-	27.60	F	27.35	F	26.77	F
MF	Control	33.25	G	-	-	-	-	-	-
	Glass wool	-	-	24.45	D	22.20	B	21.60	B
	Rock wool	-	-	22.42	B	22.07	B	19.37	A

[a] Loss of mass (%)
[b] Homogeneity group

Comparative levels of loss of mass of variables have been given in Fig. 3.

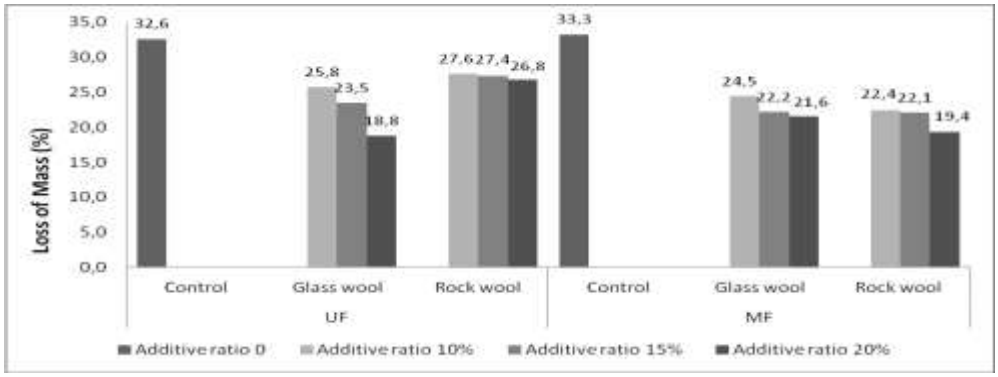

Fig. 3. Comparative levels of loss of mass according to the variables

Since LM values (32.60% and 33.5%) of PBs with both UF and MF adhesive and without additives were the highest with the difference between them insignificant, RW and GW additives decreased LM of PBs during burning. Since LM values (32.60% and 33.25%) of PBs both with UF and MF adhesive and without additives were higher than LM of all the other boards with additives, both GW and RW addition in production decreased LM. While increasing ratio of additive from 10% to 15% in PBs with RW additives and UF adhesive, increasing from 15% to 20% in the PBs with GW additives and MF adhesive and increasing from 10% to 15% in PBs with RW additives and MF adhesive did not affect LM, as the ratio of additive increased in all of the other PB types, LM decreased. While LM in PBs with GW additives and UF adhesive decreased from 32.60% to 18.70%, in PBs with RW additives it decreased from 32.60% to 26.77%. LM

decreased from 33.25% to 21.60% in PBs with GW additives and MF adhesive and decreased from 33.25% to 19.37% in PBs with RW additives.

DISCUSSION

According to the statistical analysis of data as a result of the tests made according to the related standards, the burning characteristics of PBs tested for type of adhesive, type of additive material and ratio of additive used in production had important effects with single, double and triple interactions.

The use of UF or MF adhesive as a binder in production did not affect ignition time or loss of mass of PBs. While flaming combustion temperatures of PBs with MF adhesives were 19% higher (248 ºC and 208 ºC) compared to UF adhesives, flaming combustion duration was 32% lower (712 s and 488 s) and smoldering combustion duration was 29% lower (2,063 s and 1,458 s). Fillers in UF may have been effective in the lowering of flaming combustion temperature and in the increasing of flaming and smoldering combustion durations of the PB with UF adhesive compared to those of the PB with MF adhesive (Marra 1992).

Without taking type of adhesive and ratios of additive into account, the average ignition times of PBs with GW additives, with a 100% increase, went from 58 s to 115 s; flaming combustion temperature, with a 27% decrease, went from 228 ºC to 167 ºC; flaming combustion duration, with a 52% decrease, went from 600 s to 286 s; smoldering combustion duration, with a 54% decrease, went from 1,760 s to 818 s; and loss of mass, with a 33% decrease, went from 33% to 22%. On the other hand, for PBs with RW additives, these ratios were as follows: 70% increase (from 58 s to 99 s), 29% decrease (from 228 ºC to 162 ºC), 54% decrease (from 600 s to 278 s), 55% decrease (from 1,760 s to 798 s) and 27% decrease (from 33% to 24%). The highest ratio of change in additives was in PBs with GW additives for ignition time up to 196%, for flaming combustion temperature up to 57%, for flaming combustion duration up to 71%, for smoldering combustion duration up to 71% and for loss of mass up to 45%. This order of change in the PBs with RW additives was as follows: 155%, 40%, 59%, 58%, and 42%.

Increasing ratios of GW or RW yield PBs fire retardant and also improve burning characteristics of PBs. For example, in PBs with UF adhesive and a 10% GW additive, while there was a 22% increase (from 59 s to 76 s) in ignition time, raising the ratio of additive to 15% increased ignition time 41% (from 59 s to 83 s) and raising the ratio of additive to 20% increased ignition time 61% (from 59 s to 95 s). These increases in PBs with MF adhesive were as follows: 125% (from 56 s to 126 s), 143% (from 56 s to 136 s) and 207% (from 56 s to 172 s).

Previous research studies have shown significant increases in fire resistance of PBs with different plants mixed with some chemical substances that delayed burning of boards. For example, as the result of mixing phosphine (PH_3) at the ratio of 15% to boards produced from cottonseed hulls, there was a 15-fold decrease in loss of mass after burning and a 101-fold decrease in flaming combustion duration (Pandey 1986). As the result of mixing coal dust with walnut shell boards, a 2-fold decrease in flaming combustion temperature was reported (Guru *et al.* 2008). Mixing aluminum, iron, and

magnesium silicate ($Mg_3Si_4O_{10}(OH)_2$) with cotton stalk boards increased ignition time 25-fold (Kozlowski 1999). Mixing diammonium phosphate ($(NH_4)_2HPO_4$), monoammonium phosphate ($NH_4H_2PO_4$) and boric acid (H_3BO_3) with kenaf boards increased ignition time 2.5-fold (Izran 2009).

The use of GW and RW in production, connected to type of binder and ratio of additive, increased ignition time and decreased flaming combustion temperature, durations of flaming and smoldering combustion, and loss of mass at ratios from 30% to 335%. The heat conductivity coefficient of GW and RW is 0.045 W/m.K and ignition temperature is around 1000 ^oC. The values of wooden materials are approximately at the level of 1/5 of these. The fact that the ignition temperature is high, provides for later ignition of materials with flames and that the heat conductivity coefficient is low, postpones expansion of fire by decreasing the transfer of environmental heat around the burning point during burning. Furthermore, the thin fibrous structure of glass wool and rock wool prevents spreading to depths of flames by accelerating surface qualification.

Both GW and RW are classified as non-combustible or limited combustibility depending on the binder content. While both loose small quantities of pyrolysable binders above the temperature of 250 ^oC, most of the mass will not burn and there is insufficient fuel for a flame to propagate through the bulk of material, so their contribution to the fuel load is negligible (Stec and Hull 2011). These technical properties of GW and RW may have been effective in the increase of ignition time and in the decreases of flaming combustion temperature, durations of flaming and smoldering combustion, and mass of loss.

CONCLUSIONS

1. The use of UF or MF as a binder did not affect ignition time. But, flaming combustion temperatures of PBs with MF were higher, and durations of flaming and smoldering combustion were lower than those of PBs with UF.
2. GW additive provided a 100% increase in the ignition time and decreases of 27%, 52%, 54%, and 33% for flaming combustion temperature, durations of flaming and smoldering combustion, and loss of mass, respectively. These ratios for PBs with RW were as follows: a 70% increase and decreases of 20%, 54%, 55%, and 27%, respectively.
3. As the ratio of GW or RW in the PB increased, changes in burning characteristics rose. For example, in PBs with UF adhesive and a 10% GW additive while there was a 22% increase in ignition time, raising the ratio of additive to 20% increased ignition time by 61%.

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