

THERMAL DEGRADATION AND THERMAL CONDUCTIVITY OF GYPSUM–CEMENT PARTICLEBOARD

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Abstract. Thermal degradation of boards made from wood particles mixed with gypsum and gypsum–cement was determined in air and nitrogen by thermogravimetric analysis. The pure constituents of the boards (wood particles, gypsum, and Portland cement) were characterized separately. The thermal conductivity of the boards was determined using a heat flowmeter apparatus. Commercial gypsum board was used as a control for all the tests performed. Commercial gypsum board, pure gypsum, pure Portland cement, and gypsum–cement mixture showed mass losses between 18 and 22% at 800°C. Conversely, the wood particles were very sensitive to heat in the presence of air. In general, gypsum–cement particleboard exhibited better resistance to thermal degradation than gypsum particleboard, but it has the highest thermal conductivity as a result of its higher density. Thermal conductivity was shown to be strongly dependent on board density.

Keywords: Gypsum particleboard, Portland cement, thermal conductivity, thermogravimetric analysis (TGA).

INTRODUCTION

Gypsum board is widely used in building construction for interior wall coverings. It provides protection against fire and some lateral support. Gypsum board basically consists of calcium sulphate in the form of dihydrate crystals with overlay paper on both sides. The overlay paper plays an important role in the mechanical resistance of gypsum board (Cramer et al 2003). The board core has a low mechanical resistance, which is a disadvantage for some applications in building construction. Several studies have been carried out to improve its mechanical properties. The incorporation of mineral fiber, wood fiber, and wood particles has been suggested as potential means to improve these properties (Falk 1994). Although the addition of wood fiber and particles could partially improve

the mechanical properties of gypsum board, they are considered combustibles as a result of the organic nature of wood. This characteristic could also cause a decrease in thermal resistance of gypsum board.

Another disadvantage of gypsum boards is their poor resistance to moisture. The incorporation of Portland cement in the boards could partially solve this problem. Portland cement is mainly composed of tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A), and tetracalcium aluminoferrite (C_4AF) (Sha et al 1999) and is considered as moisture-resistant. Cement mixed with wood has been used for board manufacturing, but the use of cement in high proportions is a disadvantage as a result of the higher cost of the boards. At this time, the use of cement mixed with gypsum and wood particles has not yet been proposed as an alternative. On the basis of the characteristics of each constituent (gypsum, cement, and wood), the development of

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gypsum–cement particleboards should result in a product with better mechanical properties, greater moisture resistance, and acceptable thermal resistance. Additionally, the use of gypsum mixed with Portland cement could reduce the overall product cost because gypsum is available at a lower cost than Portland cement.

One of the most important applications of gypsum–cement particleboards could be as fire-resistant interior walls and thermal insulators in buildings. In this regard, the thermal stability of gypsum–cement particleboard must be assessed, which can be done by thermogravimetric analysis (TGA). This technique is used in thermal analysis in which changes in sample mass are monitored continuously while the sample is exposed to temperatures varying at a reproducible rate in a controlled atmosphere. TGA permits partial simulation of the thermal degradation occurring in fire events because it measures the mass losses of materials under the influence of elevated temperatures. It has been commonly used to evaluate the efficiency of different fire-retardant substances and to characterize wood thermal degradation (Ramiah 1970; Alarcon-Ruiz et al 2005; Gao et al 2006). TGA has not been used to characterize thermal degradation of gypsum and cement particleboard. Also, the suitability of boards as thermal insulators can be evaluated by performing thermal conductivity tests. The thermal conductivity of a material is defined as the heat conductivity capacity from one surface to another when subjected to a temperature gradient. This property is mainly affected by density, MC, and temperature of the material (Forest Products Laboratory 1999).

Although TGA and thermal conductivity do not consider the direct exposure of materials to flame, they are representative of some of the processes that occur in fire events. In the case of fire, board degradation is affected by elevated temperatures, the oxidative conditions of the atmosphere, and production of volatiles. This could be partially simulated by the use of TGA. Thermal conductivity is a good estimator of the characteristics of materials as thermal insulators. At elevated temperature, it is a main

factor as a fire barrier, especially when boards are attached to framing members.

The main purpose of this study was to characterize the thermal degradation and thermal conductivity of gypsum particleboard reinforced with Portland cement to compare its thermal behavior with that of gypsum particleboard and commercial, regular gypsum boards. In addition, the thermal resistance of gypsum–cement particleboard constituents (wood, gypsum, and Portland cement) was determined.

MATERIALS AND METHODS

Material

The gypsum used for this study was obtained from BPB Canada Inc, Montreal, Canada. It contained at least 80% of calcium sulphate hemihydrate ($\text{CaSO}_4 \cdot 0.5 \text{H}_2\text{O}$). Commercial type 10 Portland cement was used. It was obtained from the “Centre de Recherche Interuniversitaire sur le Béton (CRIB)” of Université Laval. Its composition is displayed in Table 1. The wood used was jack pine (*Pinus banksiana*) because previous work has shown its high compatibility with Portland cement (Defo et al 2004) with gypsum and with gypsum–cement mixture (Espinoza-Herrera and Cloutier 2008) by using isothermal calorimetry.

Board Manufacturing

The boards were made from 53% inorganic material, 22% jack pine particles (0.5 – 2.6 mm) at 10% MC (oven-dry basis), and 25% liquid water (based on the total humid mass of the wet components mixture). The mats were formed from the wet furnish and pressed at 60°C at 5 – 7 MPa for 30 min to a thickness of 11 mm. Two types of boards were made. The first contained only gypsum as an inorganic material. The second was a mixture of gypsum and Portland cement in a proportion of 70:30 by mass to increase the mechanical properties and moisture resistance of the boards. The proportions were based on the results of preliminary density and hydration tests. The boards were stored for at

Table 1. Chemical composition of type 10 Portland cement used in the current study.

Chemical name	Chemical	Main compound	Mass (%)
Tricalcium silicate	$3\text{CaO} \cdot \text{SiO}_2$	C_3S	50
Dicalcium silicate	$2\text{CaO} \cdot \text{SiO}_2$	C_2S	25
Tricalcium aluminate	$3\text{CaO} \cdot \text{Al}_2\text{O}_3$	C_3A	12
Tetrecalcium aluminoferrite	$4\text{Ca} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$	C_4AF	8
Calcium sulfate	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	CSH_2	3.5

least 28 d in a climate chamber at 20°C and 60% RH before testing.

The humid mass used for gypsum particleboard and gypsum–cement particleboard was the same. However, the gypsum–cement particleboard final density was higher as a result of its different hydration products. Gypsum, in the form of calcium sulphate hemihydrate ($\text{CaSO}_4 \cdot 0.5 \text{H}_2\text{O}$), hardens when it reacts with water, generating calcium sulphate dihydrate ($\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$). Portland cement also hardens when it reacts with water, but its most important hydration products are calcium silicate hydrate ($3 \text{CaO} \cdot 2 \text{SiO}_2 \cdot 4 \text{H}_2\text{O}$) and calcium hydroxide ($\text{Ca}[\text{OH}]_2$) (Sha et al 1999).

Thermal Degradation by Thermogravimetric Analysis

Thermal degradation tests were carried out with a Mettler Toledo thermobalance (Mettler Toledo GmbH Analytical, Schwerzenbac, Switzerland, TGA/SDTA851). All experiments were performed from 25 – 800°C at a scanning rate of 10°C/min⁻¹ in a nitrogen or air at 50 mL/min⁻¹. The samples analyzed in nitrogen were burned off without oxidizing the wood particles. The air atmosphere was used to essentially burn off the wood particles.

The samples studied were gypsum particleboard (GPB), gypsum–cement particleboard (GCPB), the core of commercial gypsum board (GB), jack pine wood particles (WPP), pure gypsum (G), gypsum–cement (GC), and pure Portland cement (C). Pure gypsum, C, and GC were analyzed in nitrogen only. The results were generated by the STAR software from METTLER. Three replications were performed for each test.

Jack pine wood was fragmented and sieved. The particles used were those that passed through a number 20 sieve and were retained on a number 40 sieve. They were air-dried at room conditions to a MC of about 10% at the time of testing. The inorganic material to water mass ratio was 2:1 (w/w). The GBP and GCPB samples were made from wood particles covered with gypsum and gypsum–cement mixture, respectively, and removed from the boards with a knife. The volume of the TGA crucible was 0.1 mL. The sample mass varied from 10 – 30 mg depending on material density. The commercial gypsum board used as a reference was of type ProRocTM regular of 12.7 mm thickness obtained from BPB Canada Inc, Montreal, Canada.

Thermal Conductivity Determination

The thermal conductivity of the boards was determined according to the ASTM C518-98 test method (ASTM 2000) for steady-state thermal transmission properties by means of the heat flowmeter apparatus. In fact, this apparatus establishes a steady-state unidirectional heat flux through a test sample between two parallel plates at constant but different temperatures. In conducting these tests, an HFS-4 heat flux sensor (Omega Engineering, Stamford, CT) was used. The test specimens were 153 × 153 mm and 11 – 12.5 mm thick covering the entire plate surface. The hot plate was at 117°C and the cold plate 77°C with a temperature difference of 40°C or a temperature gradient of about 3.5°C mm⁻¹. Once thermal equilibrium was reached, five successive observations were made at 5-min intervals.

The average thermal conductivity of each specimen was calculated as follows:

$$\lambda = \frac{QL}{A\Delta T} \quad (1)$$

where: λ = thermal conductivity ($\text{W} \cdot \text{m}^{-1} \cdot ^\circ\text{C}^{-1}$); Q = heat flow (W); L = specimen thickness, measured along a path normal to isothermal surfaces (m); A = area measured on a selected isothermal surface (m^2); ΔT = temperature difference ($^\circ\text{C}$).

The specific thermal conductivity of each specimen was calculated by dividing its measured thermal conductivity by its density to reduce the impact of density on the results. An analysis of variance was performed on the test results. When a significant difference was found between means, a Duncan's multiple range test was performed.

RESULTS AND DISCUSSION

Thermal Degradation by Thermogravimetric Analysis

The thermal behavior of the samples determined by TGA was reproducible for all materials analyzed. Hence, to facilitate the analysis of the results, a single curve per material is shown in Figs 1–3.

Pure gypsum. Figure 1 shows the results obtained for pure gypsum. The most important mass loss of this substance (18%) began around 100°C and stopped at 180°C , corresponding to water evaporation. From $180 - 650^\circ\text{C}$, the gypsum mass is stable. At about 680°C , a small mass loss of 2% was observed with stabilization

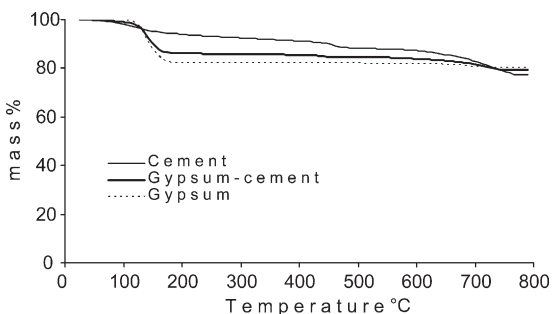
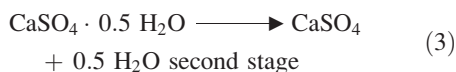
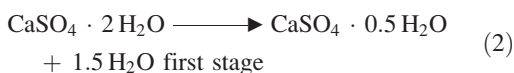


Figure 1. Thermal degradation of Portland cement, gypsum, and gypsum-cement mixture in nitrogen. Each curve represents the results obtained for one sample.

at 730°C . These results are similar to those reported in the literature for gypsum. Guerrero et al (2000) reported a characteristic mass loss of the gypsum samples between 100 and 200°C , which corresponded to the release of chemically bound water from gypsum decomposition. Chang et al (1999) studied the dehydration of $\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$ by TGA and thermo-Raman spectroscopy from $25 - 300^\circ\text{C}$. In fact, the changes in Raman spectra during a thermal process should correspond to the peaks in TGA. The results obtained confirmed that in the temperature range from $118 - 142^\circ\text{C}$, $\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$ is transformed into $\text{CaSO}_4 \cdot 0.5 \text{H}_2\text{O}$ and finally to CaSO_4 . These results correspond to the peaks observed from $103 - 136^\circ\text{C}$ in the TGA analysis. The transformation of gypsum into a hemihydrate structure and then into soluble anhydrite is completed sequentially after the two endothermic reactions given subsequently:



Pure Portland cement. Portland cement thermal degradation is shown in Fig 1. At 800°C , this material shows a mass loss of 22 – 25%. Even if the mass loss were more important than for gypsum at this elevated temperature, Portland cement showed a better behavior until 600°C . From this temperature on, quick mass loss was observed. The Portland cement thermal degradation curve shows three important mass losses. Alarcon-Ruiz et al (2005) described a similar behavior for a cement paste. In fact, the first mass loss, located between 100 and 200°C , is the result of dehydration reactions of several hydrates such as calcium silicate hydrate, carboaluminates, and ettringite. The second major mass loss occurring between 420 and 490°C corresponds to dehydroxylation of portlandite, another hydration product. The third, which appears at 600°C , is associated with the decarbonation of calcium carbonate.

Gypsum–cement. As can be observed in Fig 1, the gypsum–cement mixture had an intermediate thermal degradation behavior between that of the gypsum and cement components. The gypsum–cement curve of Fig 1 shows a fast mass loss between 100 and 180°C that can be related to gypsum. Afterward, the mass losses occurring between 420 and 480°C and the thermal behavior to 600°C can be associated with that of cement.

Jack pine wood particles. Figures 2 and 3 show the thermal degradation of jack pine wood particles in nitrogen and air, respectively. At 100°C, the WPP samples in air and nitrogen lost their free water. This step was followed by a mass stabilization period to 230–260°C. From 270°C, the WPP samples showed a fast decrease of mass in both atmospheres. Nevertheless, differences were observed at higher temperatures between air and nitrogen atmospheres. In air,

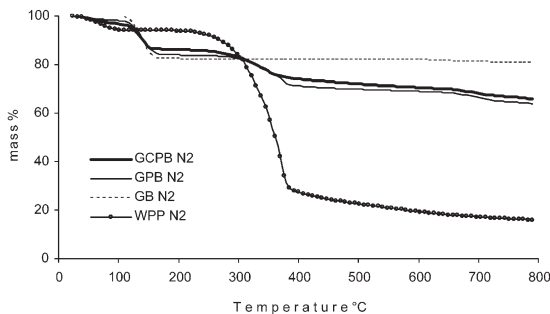


Figure 2. Thermal degradation of board samples and wood particles in nitrogen. Each curve represents the results obtained for one sample.

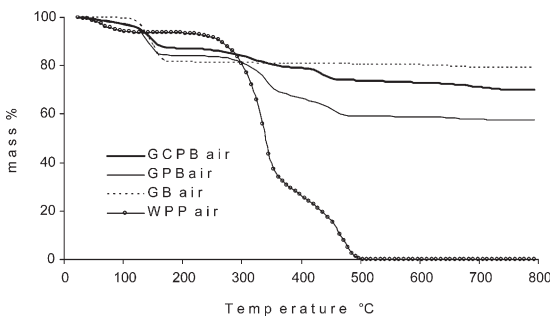


Figure 3. Thermal degradation of board samples and wood particles in air. Each curve represents the results obtained for one sample.

the WPP samples showed higher mass losses. At 350°C in air, WPP had lost 64% of its initial mass and all at 500°C (Fig 3). On the other hand, the WPP samples had a lower rate of degradation in nitrogen at 390°C (Fig 2). Unlike the samples exposed to air, they retained 15% of their initial mass at 800°C.

The literature shows that wood decomposes into volatiles and char when exposed to heat. Char is a dominant product at internal temperatures of less than 300°C, whereas volatiles are more present above 300°C. The volatiles, some of which are flammable, can be ignited if the volatile–air mixture has the appropriate composition in a temperature range of about 400–500°C. This gas-phase combustion appears as flames (Forest Products Laboratory 1999). Differences observed between mass losses of wood in nitrogen and air could be explained on that basis. The most important difference between nitrogen and air is the availability of oxygen. When oxygen reacts with the volatile compounds of wood, flame generation contributes to char oxidation thereby generating a faster and complete degradation of the sample.

Gao et al (2006) studied the thermal degradation of larch wood treated with guanil urea phosphate and boric acid as fire retardants by TGA, and by using a cone calorimeter. The thermal degradation of virgin larch wood analyzed by Gao et al (2006) and jack pine wood in the current study showed similar behavior. It is clear that wood thermal behavior is strongly dependent on the degradation rate of its main constituents. Our results show a characteristic mass loss at 240–280°C in air corresponding to 240–300°C in nitrogen, mainly caused by hemicellulose thermal degradation, which usually occurs first. The mass loss observed in air over 280–350°C (corresponding to 300–390°C in nitrogen) is associated with the thermal degradation of cellulose. As a result of the production of a large quantity of volatile and flammable products, the thermal degradation of cellulose plays a key role in the thermal degradation of wood (Gao et al 2006). This is usually characterized by a pronounced drop in the TGA

curve, indicating a fast degradation rate. The mass losses observed at 350–450°C in air and 390°C in nitrogen were associated with char formation from lignin. From 450–500°C in air, the combustion of char and other residues is observed until the total degradation of the samples. At this stage, charring and char oxidation can occur simultaneously (Gao et al 2006). Our results are in agreement with those of Ramiah (1970) who also analyzed the thermal degradation of the main constituents of wood by TGA. The author found that lignin was the most thermally resistant compound, whereas cellulose was classified as intermediate and hemicellulose was the less stable and more sensitive compound to thermal degradation.

Gypsum board core. The thermal behavior of samples obtained from GB core is shown in Figs 2 and 3. Although TGA in air generated a higher mass loss, the shape of the curves was similar in air and nitrogen. Overall, GB core is thermally stable, maintaining its mass until 110–120°C. However, its most important mass loss (18%) was observed between 120 and 170°C. From this temperature to 800°C, only a small mass loss (1–2%) occurred. The total mass losses (18–21%) can be the result of water present in the board. Mehaffey et al (1994) determined that calcium sulphate dihydrate, a primary component of the core of gypsum board, contains about 21% of the chemically combined water (by mass). As gypsum is heated to temperatures in excess of 80°C, it undergoes a thermal degradation process known as calcination. This process is usually completed at 125°C (Mehaffey et al 1994).

Gypsum particleboard. The thermal degradation of GPB in nitrogen and air is presented in Figs 2 and 3, respectively. The behavior of samples in both environments was very similar up to 280°C. The total water evaporation, between 100 and 160°C, was considered to be the main factor causing mass losses. A stable period without important mass loss occurred from 160–280°C. However, from this temperature on, differences were observed between both environments. Significant mass losses occurred from 280–470°C in air. From 470–800°C

in air, GPB experienced a slight mass loss. At the end of the tests, GPB conserved 58% of its initial mass in air. In contrast, GPB in nitrogen showed a lower mass loss. The most important mass losses stopped at about 390°C. From this temperature up to 800°C, the mass loss rate decreased. At the end of the test, the samples had lost about 35% of their initial mass.

Gypsum–cement particleboard. As shown in Figs 2 and 3, the total water evaporation in GCPB appears between 160 and 170°C. At about 260°C in nitrogen and air, GCPB increases its degradation rate until about 360°C where it decreases again. The thermal behavior of GCPB in air and nitrogen is similar until 300°C (Table 2). However, from 350°C, differences can be observed in relation to the atmosphere used. From this temperature up, the mass losses of GCPB are higher in nitrogen than in air. At the end of the tests, the GCPB sample in nitrogen remains within 61% of its initial mass, whereas it retains 69% of its initial mass in air.

Global Comparison of Sample Thermal Behavior in Nitrogen and Air

Figure 2 shows that GB was the most resistant material to thermal degradation. This behavior is the result of the sole presence of inorganic material in the core of the board. GCPB has shown a slightly better thermal resistance than GPB in nitrogen. This shows that cement provides better protection to wood particles than gypsum. The mass loss between 290 and 400°C in the GCPB and GPB curves corresponds to wood degradation. As can be observed, wood particles without gypsum and gypsum–cement protection are very sensitive to heat. Indeed, WPP had lost 85% of its initial mass at 800°C in nitrogen.

Figure 3 demonstrates that thermal degradation in air is more drastic. The results show that WPP sustained complete degradation at about 500°C. The results demonstrate that the incorporation of gypsum and of a mixture of gypsum–cement provided efficient protection to the wood particles against thermal degradation. Thus, the use of inorganic materials delayed

Table 2. Average mass loss of boards and its constituents at different temperatures in nitrogen and air.

Temp.	Average mass loss (%)										
	GB N ₂	GB air	GPB N ₂	GPB air	GCPB N ₂	GCPB air	WPP N ₂	WPP air	G N ₂	GC N ₂	C N ₂
25°C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100°C	0.0	0.0	1.5	2.0	3.0	2.0	5.0	5.0	0.0	1.0	1.5
150°C	12.0	13.0	11.0	12.0	12.0	9.0	6.0	6.0	8.5	6.5	4.0
200°C	18.0	18.0	16.0	15.0	13.5	13.0	6.0	7.0	18.0	13.5	6.0
250°C	18.0	18.5	16.0	15.0	14.0	14.0	8.0	8.0	18.0	14.0	7.0
300°C	18.0	18.5	17.0	18.0	17.0	17.0	16.0	17.0	18.0	14.0	7.0
350°C	18.0	19.0	21.0	29.0	25.0	21.0	42.0	64.0	18.0	14.5	8.0
400°C	18.0	19.0	27.0	32.0	27.0	22.0	72.0	72.0	18.0	14.5	9.0
450°C	18.0	19.0	28.0	37.0	28.0	26.0	75.0	84.0	18.0	15.5	10.0
500°C	18.0	19.0	29.0	39.0	30.0	27.0	76.0	100.0	18.0	15.5	12.0
550°C	18.0	19.0	30.0	39.0	31.0	28.0	80.0	100.0	18.0	15.5	12.0
600°C	18.0	19.0	30.0	39.0	32.0	28.0	81.0	100.0	18.0	16.0	13.0
650°C	18.5	19.5	30.0	40.0	34.0	29.0	82.0	100.0	18.0	16.5	14.0
700°C	18.5	20.5	32.0	40.0	36.0	30.0	83.0	100.0	19.5	17.5	17.0
750°C	18.5	20.5	34.0	40.0	38.0	31.0	84.0	100.0	20.0	20.5	21.0
800°C	18.5	20.5	35.0	40.0	39.0	31.0	85.0	100.0	20.0	20.5	22.0

GB, gypsum-board core; GPB, gypsum particleboard; GCPB, gypsum-cement particleboard; WPP, jack pine wood particles; G, pure gypsum; C, pure Portland cement; GC, gypsum-cement.

thermal degradation of the hemicelluloses and cellulose from 240°C for wood particles to 300°C for boards with gypsum and gypsum-cement mixture. In air, the positive effect of the incorporation of Portland cement to the boards is clear, mainly in the step related to the degradation of cellulose. Table 2 presents the average mass loss at different temperatures for the boards and their constituents in nitrogen and air. The mass loss corresponding to cellulose degradation at 350°C was lower for GCPB (21%) than for wood (64%) and GPB (29%). Moreover, at the end of the TGA tests in air, GCPB showed a lower mass loss than GPB.

It is also shown in Table 2 that the final mass losses in air occurred in the following order: WPP > GPB > GCPB > GB. In nitrogen, the final mass losses were: WPP > GCPB > GPB > C > GC ≈ G > GB. In general, the materials of inorganic nature (GB, G, GC, and C) presented similar final mass losses between 18 and 22%. Jack pine wood particles had the most important mass losses in both atmospheres.

In general, the addition of Portland cement improved the thermal resistance of wood compared with the sole addition of gypsum. However, the best thermal resistance was observed in the core

of commercial GB resulting from the presence of pure inorganic compounds.

Thermal Conductivity

Table 3 shows the results of thermal conductivity obtained for GB, GPB, and GCPB. Analysis shows significant differences between the thermal conductivity of each type of board. As shown in Table 3, GCPB exhibited the highest thermal conductivity ($0.596 \text{ W} \cdot \text{m}^{-1} \cdot ^\circ\text{C}^{-1}$). It can be related to the higher density of this board ($987 \text{ kg} \cdot \text{m}^{-3}$). Gypsum particleboard had lower density values ($834 \text{ kg} \cdot \text{m}^{-3}$) and thermal conductivity ($0.484 \text{ W} \cdot \text{m}^{-1} \cdot ^\circ\text{C}^{-1}$). The thermal conductivity of GB ($0.353 \text{ W} \cdot \text{m}^{-1} \cdot ^\circ\text{C}^{-1}$) was lower than that of GPB and GCPB. This result can be attributed to its lower density ($615 \text{ kg} \cdot \text{m}^{-3}$) and higher porosity. It is known that air is not a good heat conductor (Grigoriev 1985) and the thermal conductivity of a porous material decreases as porosity increases (Suleiman et al 1999). The same statements have been made by Kollmann and Côté (1968) who reported that the thermal conductivity of particleboard and wood are strongly dependent on density. Nevertheless, as shown in Table 3, the specific thermal conductivity of GB, GPB, and

Table 3. Values of average thermal conductivity, heat flux per unit area, density, and MC of boards at the moment of the tests.

	GB	GPB	GCPB
Thermal conductivity ($W \cdot m^{-1} \cdot ^\circ C^{-1}$)	0.353 C	0.484 B	0.596 A
Heat flux ($W \cdot m^{-2}$)	1164	1746	1977
Density ($kg \cdot m^{-3}$)	615	834	987
MC (%)	20.4	19.5	16.0
Specific thermal conductivity ($W \cdot m^2 \cdot kg^{-1} \cdot ^\circ C^{-1}$)	5.75×10^{-2} A	5.81×10^{-2} A	6.10×10^{-2} A

Means with different letters are significantly different ($p \leq 0.05$).

GB, gypsum-board; GPB, gypsum particleboard; GCPB, gypsum-cement particleboard.

GCPB did not present significant differences because the impact of the material density on thermal conductivity is reduced or eliminated.

The thermal conductivity values obtained in this study match those reported by Bekhta and Dobrowolska (2006). They found a thermal conductivity of $0.189 - 0.753 W \cdot m^{-1} \cdot ^\circ C^{-1}$ for wood-gypsum boards with a density of $850 - 1300 kg \cdot m^{-3}$. They also demonstrated that board density has a considerable impact on heat conduction. On the other hand, Lee (1984) reported lower thermal conductivity ($0.0822 W \cdot m^{-1} \cdot ^\circ C^{-1}$) at an average density of $512 kg \cdot m^{-3}$ for cement-bonded cypress excelsior board. However, the plate temperatures used by this author ($37^\circ C$ for the hot plate and $10^\circ C$ for the cold plate) were lower than those used in the current work. Other studies (Avramidis and Lau 1992; Suleiman et al 1999) have also demonstrated that thermal conductivity increases with increasing temperature.

CONCLUSIONS

The results of this study showed that commercial gypsum board, pure gypsum, Portland cement, and gypsum-cement mixture had low mass losses during TGA. However, the thermal behavior of those composites was different according to the characteristics of their chemical components. Wood particles were drastically degraded when heated in nitrogen or air. Oxygen present in air significantly accelerated the degradation of wood particles. In contrast, wood particles as part of gypsum particleboard and gypsum-cement particleboard had good protection against thermal degradation as a

result of the presence of the inorganic material. The gypsum-cement mixture offered better protection to the wood particles than pure gypsum when tested in air.

Gypsum-cement particleboard had the highest thermal conductivity ($0.596 W \cdot m^{-1} \cdot ^\circ C^{-1}$). Gypsum particleboard had an intermediate thermal conductivity ($0.484 W \cdot m^{-1} \cdot ^\circ C^{-1}$), whereas gypsum board had the lowest ($0.353 W \cdot m^{-1} \cdot ^\circ C^{-1}$). Thermal conductivity was proportional to panel density. According to the thermal conductivity results, gypsum-cement particleboard was shown to be a poorer thermal insulator than gypsum particleboard and gypsum board. However, the specific thermal conductivities of gypsum board, gypsum particleboard, and gypsum-cement particleboard did not have significant differences.

Overall, the results of this work show that the combination between wood particles, gypsum, and cement provides a good alternative to improve the global thermal characteristic of the boards. Because Portland cement is considered moisture-resistant, it could also contribute to the board's protection against moisture.

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