Cement & Concrete Composites 34 (2012) 218–222

Contents lists available at SciVerse ScienceDirect

Cement & Concrete Composites

journal homepage: www.elsevier.com/locate/cemconcomp

Design of a low-density wood–cement particleboard for interior wall finish

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ARTICLE INFO

Article history:
Received 30 June 2010
Received in revised form 27 September 2011
Accepted 30 September 2011
Available online 13 October 2011

Keywords:
Wood–cement
Particleboard
Low-density
Gypsum panel
Welan Gum
Wood residues

ABSTRACT

Gypsum boards form a very large part of the building walls and ceilings finishing market. However, they have poor screw-withdrawal resistance, low hardness and are highly sensitive to moisture. The objective of this study was to determine whether it is possible to make wood–cement particleboards of the same density as gypsum boards while avoiding these drawbacks.

Wood–cement particleboards were made by pouring the wood–cement paste in a mould. This was made possible by adding a viscosity modifying mixture to the mixing water and a set accelerating mixture to improve wood/cement compatibility. The mechanical properties and surface quality of the wood–cement particleboards were improved by using, on the board surfaces, paper sheets that were the same as those used on gypsum boards.

The average specific gravity of the wood–cement particleboards was the same as gypsum boards, at 0.7. The average bending modulus of rupture obtained for the wood–cement particleboards was 10 MPa in the finishing paper principal direction and 5 MPa in the other direction compared to 5.5 MPa and 1.6 MPa respectively for gypsum boards. The average screw-withdrawal resistance of wood–cement particleboards was 570 N, that is, 1.7 times higher than for gypsum boards.

1. Introduction

Wood–cement particleboards have been on the market for a long time. At the beginning of the 20th century, wood wool and magnesite were used to make low-density panels. Later, magnesite was replaced by cement. These panels were used for thermal and acoustic insulation and are still produced. In the late 1960s, "high-density" (specific gravity of about 1.3) wood–cement panels, with smaller wood particles processed from industrial wood residues, were developed for structural applications [1]. Nowadays, these panels are used as exterior walls, roof shingles and tiles for exterior applications. The most significant advantages of wood–cement boards are their high resistance to decay, fungi, insects and fire.

Gypsum boards are commonly used in North America for finishing interior walls and ceilings. They present several advantages: good fire resistance, lightness, low cost and easy installation. They also have drawbacks: low resistance to screw withdrawal, rather low hardness and high sensitivity to moisture. Also, gypsum is not available at low cost everywhere in the world.

The main problem in wood–cement panel design is the compatibility of these two materials. Wood can in fact inhibit cement setting. The effect of wood on cement setting depends on many factors, of which wood species and harvesting season have the greatest impact [2]. In fact, wood contains extractive compounds that dissolve in the mixing water. It is known that polysaccharides contained in wood extractives are responsible for the inhibition of cement setting [3–7] because they prevent the forming of one of their main hydrates (C–S–H) [8].

Specific tests have been developed to quantify the compatibility of wood and cement. Calorimetry allows the classification of wood species as a function of their compatibility with cement [4,9–13]. It appears that most softwood species (e.g. pine, spruce and fir) are often more compatible than hardwood species (e.g. birch, maple and beech). A study of Canadian species [4] showed that jack pine (*Pinus banksiana* Lamb.) presents the highest compatibility of the species studied. It was observed that putting a set accelerating admixture in the mixing water significantly improves compatibility [14,15], compensating for the inhibitory effect of wood extractive compounds.

The overall objective of this study is to design low-density wood–cement panels with higher resistance to screw withdrawal,

Abbreviations: C, mass of cement in the mixture; C–S–H, Calcium Silicate Hydrate; MOE, modulus of elasticity (MPa); MOR, modulus of rupture (GPa); *n*, number of samples tested; *s*, standard deviation; SEM, Scanning Electron Microscopy; W, mass of water in the mixture; wd, mass of wood in the mixture.

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doi:10.1016/j.cemconcomp.2011.09.020

higher hardness and less sensitivity to moisture than conventional gypsum boards. Experiments were carried by pouring a wood–cement paste in a mould. The mechanical properties and surface quality of the wood–cement particleboards were improved by using, on the board surfaces, paper sheets that were the same as those used on gypsum boards.

2. Materials and methods

2.1. Design approach

The most important characteristic required was a target specific gravity of about 0.7, similar to that of gypsum boards. To attain this, the wood–cement–water mixture used had a very high W/C ratio – about 1.2. Therefore, water not used for cement hydration occupies a volume during cement setting and then it evaporates, leaving space to air. The porosity created reduces final panel density and confers better insulating properties.

In order to make a low-density panel which is easy to fabricate, the wood–cement panels were not pressed. The wood–cement–water mixture was cast in a mould of the desired shape ($560 \times 460 \times 14\ mm^3$) closed with a cover held in place by C-clamps. This fabrication process is closer to that of concrete than of wood particleboard.

As the wet mixture contained a lot of water (high W/C ratio), the segregation risk was high. The segregation observed here was different from that of conventional concrete because wood particles have a lower density than water. Therefore, wood particles tend to float in the mixture. The solution to this problem was to use an additive to increase the viscosity of the mixture, resulting in a more homogeneous consistency and easier moulding.

The bending modulus of rupture (MOR) of existing wood–cement particleboards with a specific gravity of 1.2–1.4 is higher than 10 MPa [16]. Our target specific gravity was 0.7 with the aim of obtaining a MOR equal or higher to that of raw gypsum board (about 1.5 MPa) or gypsum board finished with paper (about 8 MPa). If the finishing paper has a good adherence on the panel, it increases its bending properties, including the MOR. The finishing paper provides a good surface for painting.

2.2. Materials used

Jack pine (*Pinus banksiana*) wood chips (obtained from a sawmill located near Shawinigan, Quebec, Canada) were refined in a Pallmann PSKM6 300 ring refiner. The particles were screened and those between 2 and 6 mm were retained.

Two cement types were tested:

- Type 10 cement.
- Type 30 cement with 5% of aluminous cement in order to obtain a fast setting time without the use of set accelerating admixture.

A set accelerating admixture (“Polarset” from “Grace” – only for Type 10 cement) and a viscosity modifying admixture (“Euco Nivo L” produced by “Euclide”) containing Welan Gum and a superplasticizer were used.

Two types of paper are used in the manufacturing process of gypsum boards. On the top face, the paper is specially adapted for painting. On the back face, the paper has a lower quality. The same products were used in our study (commercialised by “Norampac” under trade names “Gypsum-Grey” and “Gypsum-Ivory”).

2.3. Characterisation tests

In order to characterise and compare wood–cement and gypsum boards, their mechanical properties were tested. Determination of mechanical performance of wood particleboards is usually done following the ASTM D 1037-96 standard [17]. It allows determining the modulus of rupture (MOR) and the modulus of elasticity (MOE) that are the main bending properties of the board. This standard is normally reserved for wood particleboards but we also applied it to gypsum boards, for an easier comparison. It is important to note that the MOR and MOE calculated here have not a physical meaning of stress because the board is a composite and the formulas used are valid for a homogenous material. These properties have to be considered as global criteria that it allows comparison of the materials on a common basis. Screw-withdrawal resistance was also tested following the ASTM D 1037-96 standard.

The thermal properties of the wood–cement particleboards were measured by the fluxmeter method [18]. The board was placed between two plates at a regulated temperature and a fluxmeter was glued on each side of it so that temperature and heat flux could be measured at the board surface which can be submitted to temperature variations. Heat capacity and thermal conductivity can be calculated from these four parameters (two temperatures, two heat fluxes).

2.4. Preliminary tests on gypsum boards

Preliminary tests were made on gypsum boards, in exactly the same conditions as those of the tests on our wood–cement boards, for comparison. Screw withdrawal-resistance was determined to be 330 N. The bending stiffness and the strength of the gypsum boards are mainly due to the finishing papers. The tensile stiffness and strength of these paper sheets is different along, and perpendicular to, the forming direction of the paper, so the bending tests were performed on samples oriented along these two directions.

Table 1 shows that the finishing paper sheets multiply by 5 the gypsum board resistance in the direction of the fibres.

2.5. Preliminary tests on mixing formulation

Preliminary tests were also performed on the wood–cement mixing formulation to obtain a final specific gravity of 0.7. Many formulations were tested to reach the target final specific gravity, mechanical properties and the appropriate texture of the wet mixture. The parameters tested were water-to-cement weight ratio (W/C), wood-to-cement weight ratio (wd/C), quantity of Welan Gum, quantity of set accelerating admixture and board curing time.

Panel density greatly influenced the mechanical properties. This is why the results presented in this paper are not a comparison of mechanical properties obtained for various formulations, but the results obtained for a formulation that led to an appropriate texture and the required specific gravity.

These preliminary tests led to the use of the following characteristics for the formulations in order to obtain a good consistency and a specific gravity of 0.7:

- Water-to-cement ratio: W/C = 1.15.
- Wood-to-cement ratio: wd/C = 0.5.
- Volume percent of Welan Gum (reference: volume of water) = 2%.
- Quantity of set accelerating admixture per kg of cement = 100 ml for Type 10 cement and 0 ml for Type 30 cement with 5% of aluminous cement.

Table 1
Bending properties of gypsum panels with and without finishing paper.

Orientation of the gypsum board	MOR (MPa)	MOE (GPa)
Along principal direction of paper fibres	5.5 (n = 5, s = 0.05)	2.0 (n = 5, s = 0.08)
Perpendicular to principal direction of paper fibres	1.6 (n = 5, s = 0.09)	1.4 (n = 5, s = 0.10)
Without paper	1.1 (n = 5, s = 0.13)	1.2 (n = 5, s = 0.11)

Table 2
Mixing sequence.

Added product	Time (min)	Mass of each component for about 1 L of mixture (g/L)
Dry materials (wood + cement)	0	180 g (wd) + 359 g (C)
Water (about 3/4)	1	285 g (3/4W)
Welan Gum (with the water remaining)	2	6.8 g + 96 g (1/4W)
Set accelerating admixture (liquid)	5	48.5 g
Mixing stop	7	

Using this formulation the volume of fresh cement paste is about 50%. The mixing consistency was tested with a slump cone for Type 10 cement. The measured value is about 16–17 cm, corresponding to a fluid consistency, according to the NFP 18-451 standard.

2.6. Method of fabrication

A wooden mould was used to make each panel. It could be closed with a removable cover that allowed the mixture to be poured to a thickness of 15 mm. The surface was then levelled off with a wooden stick to reduce the panel thickness to 14 mm. The inside dimensions of the mould were $560 \times 460 \times 15\ \text{mm}^3$ when it was open and $560 \times 460 \times 14\ \text{mm}^3$ when closed.

Mixing was very important. If the mixing characteristics changed, the texture of the wet mixture changed significantly. The mixing sequence retained after preliminary tests is presented in Table 2.

The wet mixture was poured into the mould, the surface was levelled off and the cover was fitted. The panel was drawn out of the mould 3 days later. The solid panel was then stored in a climate chamber at 23 °C with 60% relative humidity for 9–23 days before mechanicals tests.

The procedure used for making wood–cement panels finished with paper is as follows: the backing paper was placed in the bottom of the mould, the wet mixture was poured in and the surface was levelled off; then the top paper was placed on top and the mould was closed. Adhesion between the cover paper and cement was not investigated specifically at this stage, but based on experimental evidence, it develops satisfactorily with cement hydration, without any special means. Adhesion testing will be performed at a later stage using the gypsum board paper adhesion values as references.

Table 3
Evolution of panel specific gravity.

Stage	Specific gravity
Manufacturing (wet mixture)	0.95 (±0.02)
Mould removal (3 days after)	0.90 (±0.02)
Long term (more than 9 days after)	0.70 (±0.02)

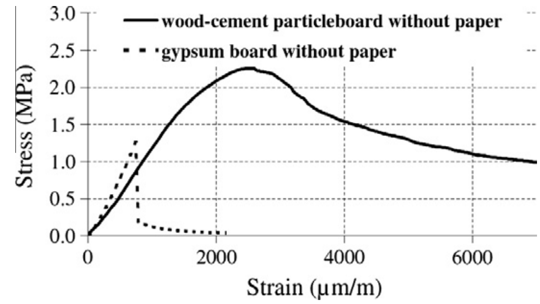

Fig. 1. Characteristic stress–strain curve for a three-point bending test of wood–cement particleboard and gypsum board without paper.

Table 4
Bending strength and stiffness of wood–cement particleboard and gypsum boards without finishing paper.

	Wood–cement particleboard (without paper)	Gypsum board (without paper)
MOR	2.2 MPa (n = 2, s = 0.1)	1.1 MPa (n = 5, s = 0.13)
MOE	1.3 GPa (n = 2; s = 0)	1.2 GPa (n = 5, s = 0.11)

3. Results and discussion

3.1. Change in density

The change in panel mass during curing (3 days in the mould) was measured to determine change in the panels' specific gravity (see Table 3). The specific gravity of the panel decreased by about 5% during the curing. The mould used was, thus, not perfectly impervious. Water was probably absorbed by the wooden mould itself. The panel mass reached a plateau about 6 days after removal from the mould, meaning that most of the free water of the cement paste had evaporated by then.

3.2. Bending properties of the raw wood–cement particleboard

Fourteen days after being made by the procedure described previously, the panels were tested in bending using the method described on Section 2.3. The results obtained were about the same for accelerated Type 10 cement and Type 30 cement with 5% of aluminous cement. Tests made on each of the two principal directions of the particleboard did not reveal any differences in this result.-Fig. 1 shows the bending behaviour of the wood–cement panel compared to gypsum board, both without paper. This test was

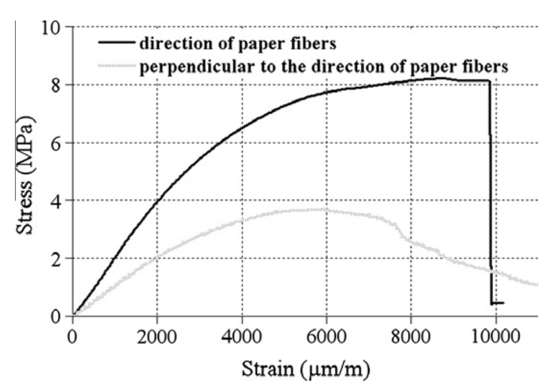

Fig. 2. Characteristic stress–strain curve for a three-point bending test of wood–cement particleboard with finishing paper.

Table 5
Mechanical properties of wood–cement particleboards and gypsum boards with finishing paper.

Property		Gypsum board	Wood–cement particleboard	
		–	12 days	26 days
Specific gravity		0.7 (±0.02)	0.7 (±0.02)	0.7 (±0.02)
In paper fibre direction	MOR	5.5 MPa ($n = 5$, $s = 0.05$)	7.1 MPa ($n = 4$, $s = 0.9$)	10.4 MPa ($n = 2$, $s = 1.8$)
	MOE	2.0 GPa ($n = 5$, $s = 0.08$)	1.6 GPa ($n = 4$, $s = 0.3$)	2.9 GPa ($n = 2$, $s = 0.4$)
Perpendicular to paper fibre direction	MOR	1.6 MPa ($n = 5$, $s = 0.09$)	3.5 MPa ($n = 2$, $s = 0.5$)	5.8 MPa ($n = 2$, $s = 0.4$)
	MOE	1.4 GPa ($n = 5$, $s = 0.10$)	1.2 GPa ($n = 2$, $s = 0.2$)	2.2 GPa ($n = 2$, $s = 0.1$)
Screw withdrawal resistance		330 N ($n = 3$, $s = 13$)	–	570 N ($n = 3$, $s = 50$)

Fig. 3. Front of rupture of a wood–cement particleboard cut with a knife (on the right side of the photo; the other side was cut with a saw).

stopped before rupture but it is clear that, unlike gypsum board, wood–cement particleboard has a ductile behaviour. Table 4 shows the mean results obtained on three test specimens compared to those of gypsum board. It can be seen that the MOR of wood–cement particleboards is 40% higher than that of gypsum boards.

3.3. Bending properties of wood–cement particleboard with finishing paper

For Type 30 cement with 5% of aluminous cement, the paper does not stick at all, so use of this kind of cement mix was abandoned for the rest of the study. The results presented below are those obtained with Type 10 cement.

Mechanical tests were carried out on paper-covered boards 12 days after fabrication with a curing time of 3 days. Each test was made on 3 specimens and the mean value is presented here. Two kinds of specimens were tested in the principal and in the perpendicular direction of the paper fibres. The strain–stress bending characteristics were completely different.

In paper fibre direction, the panel had a fragile behaviour, while in the perpendicular direction it was very ductile (Fig. 2). This is due to the tensile properties of the paper used that are much higher in the direction of the fibre. So, perpendicular to paper fibre direction, the paper failed at the beginning of the test and has not an important effect on bending test. That is why the panel have a ductile behaviour (as if there were no paper, see Fig. 1). In paper fibre direction, the paper has an important contribution on mechanical properties. It plays a role of reinforcement (as steel in reinforced concrete). When the reinforcement failed, the whole board failed; that is why the behaviour is fragile. Table 5 presents the mean mechanical properties obtained for wood–cement particleboards and gypsum boards.

Twenty-six days after mixing and at the same specific gravity as gypsum boards, wood–cement particleboards had a better MOR in the two directions and a 1.7 times higher screw-withdrawal resistance.

Table 6
Comparison of thermal properties of wood–cement and gypsum boards.

	Wood–cement particleboard	Gypsum board[a]
Conductivity	$0.11\ W\ m^{-1}\ K^{-1}$ ($n = 3$, $s = 0.04$)	$0.32\ W\ m^{-1}\ K^{-1}$
Volume heat capacity	$9.6 \times 10^5\ J\ m^{-3}\ K^{-1}$ ($n = 2$, $s = 1.4 \times 10^3$)	$6.8 \times 10^5\ J\ m^{-3}\ K^{-1}$

[a] Values given by "Placo" society for "Gyproc BA13" boards.

Regarding panel cutting, it can be done with a knife in the same way as for gypsum panels. Although the cut edge of the panel is not as neat as for gypsum (see Fig. 3), this is not a major problem because panel joints are usually filled with plaster and covered by paper tape.

3.4. Thermal properties

Table 6 shows the results obtained for the heat capacity and thermal conductivity of wood–cement particleboard and gypsum board using the test method described in Section 2.3. It is interesting to note that wood–cement particleboard has quite low thermal conductivity, about three times lower than that of gypsum board. It can contribute to reducing the heating loss of building walls even if the contribution of the board is relatively low, given the insulation of the wall. This low thermal conductivity is mainly due to the high porosity of the wood–cement material compared to gypsum porosity (the conductivity of immobile air is very low, about $0.025\ W\ m^{-1}\ K^{-1}$).

4. Conclusion

The aim of this project was to study the feasibility of replacing gypsum by wood–cement material in partition boards. These boards are fabricated by pouring the mixture directly on the covering sheet of paper that sticks with no glue, thanks to cement hydration. The mould used has a removable cover. The mixture is composed of jack pine particles obtained by refining wood residues, Type 10 cement, water, a set accelerating admixture to increase wood–cement compatibility and a viscosity modifying admixture to obtain a good wet paste texture.

It was shown that it is possible to make low-density (specific gravity of 0.7) wood–cement particleboard having better bending properties than gypsum board and having a screw withdrawal resistance that is 1.7 times higher. This point is very important because it means that no wall plug is needed to fix a screw if the load on this screw is not too high. These panels can be cut in the same way as for gypsum boards (with a knife), so that the set up process can be the same. Moreover, the thermal conductivity measured is about three times lower than the one of gypsum board thanks to its high porosity. It is important because it allows increasing thermal resistance of the wall and then lowering building heating demand.

Future work should include a fire-resistance assessment which could be a critical point. Other physical properties such as acoustic, dimensional stability and water resistance should also be determined. The formulation and the processing phases could be adapted for a better control on the final result and to develop a continuous manufacturing process. Finally, the economics and life cycle of the product should be assessed.

Acknowledgements

The authors gratefully thank François Paradis and Maxime Morency who, with their expertise in light concrete, have helped this project to progress. Thanks are also given to Thierry Chartier and Laurent Zalewski for the thermal characteristics measurement and to Aryl Joye for complementary tests on gypsum boards.

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