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Wood cement composites reinforced with polypropylene fibre

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ABSTRACT

Purpose: This paper presents basic investigation into the effect of different lengths of polypropylene fibres in surface layers of wood cement boards is investigated on their physical and mechanical properties including density, moisture content, thickness swelling, modulus of elasticity, modulus of rupture, internal bond strength and screw withdrawal strength of the samples.

Design/methodology/approach: Wood cement composites with a dimension of 400x400x10 mm were produced using three different lengths of PPF and with a constant wood/ement ratio (1/3 by weight) and target density (1.2 g/cm^3).

Findings: The results showed that PPF usage had statistically significant effect on the properties of wood cement composite. The highest mechanical properties were obtained from samples of control-WCB group while the lowest moisture content and thickness swelling were observed in PPF reinforced cement boards.

Research limitations/implications: It was observed that the PPF usage decreased thickness swelling values of the boards up to 80%, according to wood. Using wood and PPF together resulted in better mechanical values of the boards compared to using PPF alone and higher MOR and MOE values than the EN 634-2 standards. Physical properties of all the boards satisfied the minimum requirements for the EN 634-2 standard.

Originality/value: The results can be assessed as novel in the range of usage a modified material in wood cement board.

Keywords: Wood cement composite; Polypropylene fibre; Mechanical properties; Physical properties

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PROPERTIES

1. Introduction

Major disadvantages of cement based materials such as concrete and mortar are low tensile strength and susceptible to cracking due to their brittle natures. Studies in recent years have focused to improve this brittle property of cement based materials. Especially, the studies on synthetic and natural fibres reinforcement in cement matrix are gaining more importance in respect to an effective and economical way to produce a tough and ductile cementitious material [1-5].

Wood cement boards (WCB) produced from natural fibres and lignocellulosic materials show good dimensional stability and high resistance against external weather conditions or accelerated aging [6]. Also, the WCBs have higher fire retardancy, fungi and insect protection when compared to organic adhesive bonded wood panels such as particleboard, fibreboard, oriented strand board etc. [5,7]. WCBs are excellent buildings materials for use in external cladding surfaces, siding panels, roof shakes, a wall lining in public buildings, specialized flooring, thermal and acoustic insulation purposes [3,8-12].

Synthetic fibres based polyethylene and polypropylene are used in cement composites as reinforcement because of its high strength, excellent ductility, excellent durability and low price [13,14]. Recent developments have recommended a new fibre system called "fibre hybrid systems" [15]. The aim of the systems is to increase the performance of cement composites with combining of different fibres about to benefit from each of their properties. There have been limited studies on this hybrid system so far [16-18].

In this study, effect of different lengths of polypropylene fibre in surface layers of wood cement boards is investigated on their physical and mechanical properties including density, moisture content, thickness swelling, modulus of elasticity, modulus of rupture, internal bond strength and screw withdrawal strength of the samples.

2. Description of the approach, work methodology, materials for research, assumptions, experiments etc.

In this work, CEM II B-M (P-LL) 32.5 R type of Portland cement were supplied by Askale Cement Co. in Turkey. Calcium chloride ($CaCl_2$) (5 wt % based on weight of cement), supplied from Tetra Chemicals Europe AB, was used as an accelerator for process. Spruce (Picea orientalis (L.)) wood was obtained from a small timber factory as waste of timber, in Trabzon. The spruce timber waste was grinded into smaller particles in a plane machine and they were screened into different fractions with 0.5, 1.5 and 3 mm screens to detract from the large sized particles and dust. The spruce particles on the 0.5 and 1.5 mm screens were used for surface layers and core layer of the cement board productions, respectively. Their moisture contents were determined by means of a moisture analyser to take account in calculating the total water used for cement board production.

The manufacture design of PPF-wood-cement boards is shown in Table 1. The wood/cement ratio was used as 1/3, based on the oven dry weight for the three-layer WCBs manufacture. Reinforcement of PP fibre in face layers were done by stable cement amount for all PPF-WCBs. Also, PPF-cement boards were made for each fibre length of PP without wood.

The spruce particles, PP fibres, distilled water, cement, and $CaCl_2$ were blended until the cement paste completely hydrated. According to the formula founded in Simatumpang et al. [19], the amount of distilled water was adjusted.

$$\text{Water (litre)}=0.35C+(0.30-MC)W$$

where C is the cement weight (kg), MC is moisture content (oven dry basis) of wood particles, and W is oven dry wood particle weight (kg). Hand formed the cement mats, with dimension of 40 cm by 40 cm by 1.0 cm with an average target density of 1200 kg/m^3, were compressed in a computer controlled hot press using a pressure of 18-20 kg/cm^3 for 24 hrs. In the first 8 hrs of the pressing process, a temperature of 60°C was carried out. To complete hydration of cement that each cement boards was conditioned in a climate room with a temperature of 20°C and a relative humidity of 65% for 28 days before test samples were cut based on European Standards.

Modulus of elasticity, modulus of rupture, internal bond strength and screw withdrawal strength of the samples were determined on a Zwick/Roell Z050 Testing Machine having 2000 kg capacity load cell based on EN 310, EN 319 and EN 320, respectively [20-22]. Thickness swelling of the cement boards was also evaluated using EN 317 [23].

All tests were performed on ten samples for each type of boards. The analysis of variance test One way ANOVA and Duncan's mean separation tests were used to determine homogeneity groups of the all cement boards according to SPSS 23.0 statistical package software.

Table 1.
The Manufacture design of the PPF /Wood-Cement Boards

ID	PPF length	Core layer		Surface Layer		
		Wood	PPF	Wood	PPF	
Control-WCB	-	*		*		Wood /PPF: Cement ratio 1:3 by weight Surface Layer/Core Layer: 30/70 by percentage Target Density: 1.2 g/cm^3
Control-PPF19-CB	19 mm		*		*	
Control-PPF12-CB	12 mm		*		*	
Control-PPF6-CB	6 mm		*		*	
PPF19-WCB	19 mm	*			*	
PPF12-WCB	12 mm	*			*	
PPF6-WCB	6 mm	*			*	

Table 2.
The physical properties of the PPF /Wood-Cement Boards

ID	Density, g/cm^3	Moisture	TS-2 hrs	TS-24 hrs
Control-WCB	1.25^a* (0.01)**	7.88^a(0.21)	1.36^b (0.23)	1.79^b (0.44)
Control-PPF19-CB	1.13^{bc} (0.07)	5.06^c (0.47)	0.26^a (0.21)	0.39^a (0.34)
Control-PPF12-CB	1.11^c (0.05)	4.24^d(0.42)	0.38^a (0.19)	0.54^a (0.34)
Control-PPF6-CB	1.13^{bc}(0.01)	5.52^{bc}(0.46)	0.24^a (0.14)	0.43^a (0.30)
PPF19-WCB	1.20^{ab} (0.04)	6.05^b(0.35)	1.47^b (0.44)	1.75^b (0.22)
PPF12-WCB	1.15^{bc} (0.01)	7.27^a(0.27)	0.79^b (0.37)	1.65^b (0.18)
PPF6-WCB	1.18^{abc} (0.03)	8.04^a (0.53)	0.91^b (0.34)	1.46^b (0.18)

*: Groups with same letters in column indicate that there is no statistical difference ($p < 0.001$) between the samples according to Duncan's multiply range test.
**: The values in the parentheses are standard deviations.

3. Description of achieved results of own researches

3.1. Physical properties

The physical properties of PPF/wood-cement boards including density, moisture content and thickness swelling are shown in Table 2. Usage of PPF had a significant effect on the physical properties of samples according to the results of the statistical analysis. The homogenous subsets of the boards are also presented in Table 2.

A small decreased density of PPF reinforced cement boards was observed when comparing those of WCB-control group. Polypropylene fibres may tend to spring back after hot-pressing process because it was indicated also an increase in the thicknesses of PP reinforced boards. The spring-back in fibre reinforced composites becomes more important for PP based materials as thermo-mechanical behaviour [24].

The lowest values of moisture content and thickness swelling were obtained from PPF cement boards. Also, PP fibre-wood cement boards are lower moisture content and thickness swelling than WCB-control group. This is related to having the hydrophobic-polypropylene nature of their surfaces [25].

EN 634-2 standard requires the minimum thickness swelling-24 hrs of 1.5% for Ordinary Portland Cement-OPC bonded particleboards [26]. In this study, the thickness swelling values for 24 hrs were range from 0.39-0.54% and 1.46-1.79% for PP cement boards and PP wood cement boards, respectively. The PPF6-WCB group samples were over the requirement by the standard while TS-24 hrs of the other WCBs are near 1.5%.

3.2. Mechanical properties

The mechanical properties of PPF/wood-cement boards are shown in Figures 1-4. The use of polypropylene fibre in cement matrix had not sufficient improvement on mechanical properties of the cement boards while the use of two types of reinforces as wood particles and PP fibres in a suitable combination resulted in the mechanical performance. The hybrid performance exceeded the sum of individual PP fibre performance on mechanical properties of the cement boards.

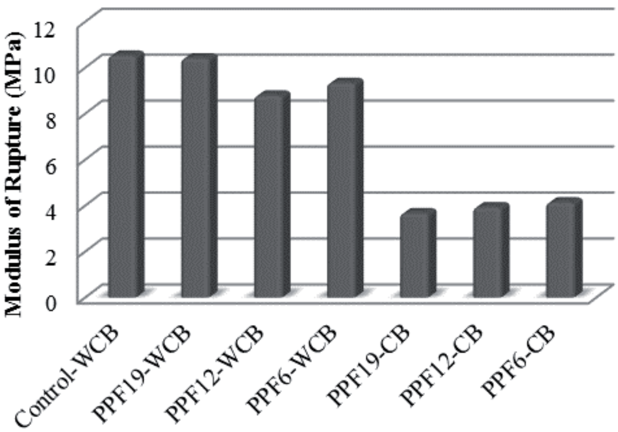

Fig. 1. Modulus of rupture of the PPF reinforced boards

The mechanical properties of the boards varied according to polypropylene fibre length. The highest modulus of elasticity and internal bonding values were obtained from samples with 6 mm fibre length while the samples with 19 mm of PPF had higher rupture of modulus and screw withdrawal strength.

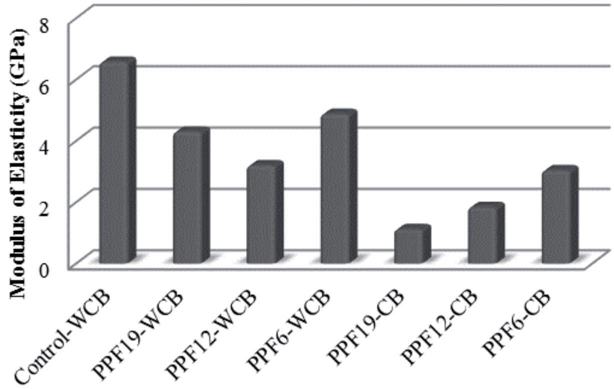

Fig. 2. Modulus of elasticity of the PPF reinforced boards

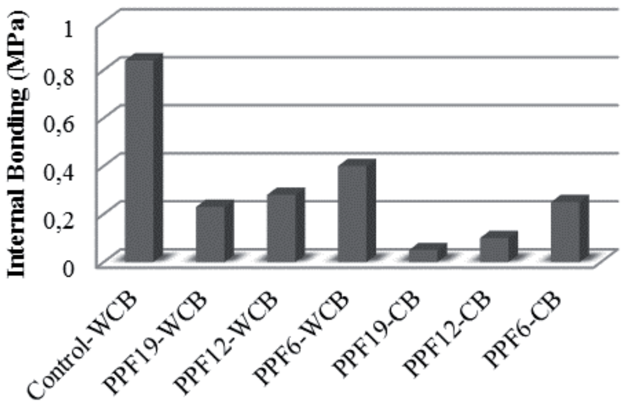

Fig. 3. Internal bonding of the PPF reinforced boards

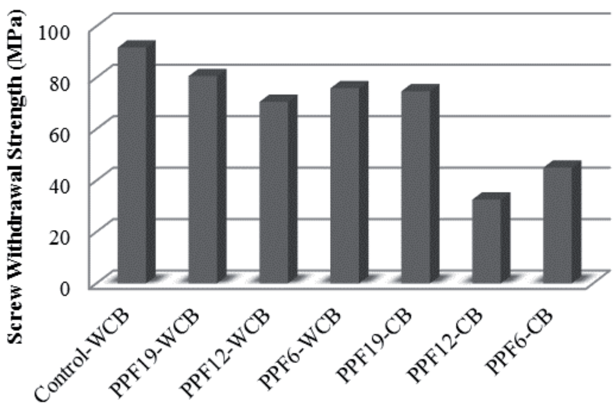

Fig. 4. Screw withdrawal strength of the PPF reinforced boards

Tanoli et al. indicated that when use of combination of PP and cellulose fibres in cement has two different responsibilities, PP responsible to maintain toughness for long term while cellulose captures the cement particles during production process [14]. It is reported that polypropylene fibre reinforced cement had high long term stability as excellent strength retention obtained from PP fibre reinforced cement composites after 18 years of natural weathering and storage under water [27]. However, the use of wood particle in cement boards showed high performance on mechanical properties in this study. But considered wood represent deteriorate effect on those of the properties in long term outdoor and water exposure due to its hygroscopic nature [28].

According to the results of variance test -one way ANOVA- and Duncan's mean separation tests, use of PPF in cement matrix and surface layers of WCB had a significant effect on MOR and MOE of samples. The results of homogenous subsets are shown in Table 3.

Table 3.
The mechanical properties of the PPF/Wood-Cement boards

ID	MOR	MOE	IB	SWS
Control-WCB	a*	a	a	a
Control-PPF19-CB	c	f	d	b
Control-PPF12-CB	c	e	d	c
Control-PPF6-CB	c	d	c	c
PPF19-WCB	a	c	c	ab
PPF12-WCB	b	d	c	b
PPF6-WCB	b	b	b	b

MOR: Modulus of Rupture; MOE: Elasticity of Modulus; IB: Internal Bonding; SWS: Screw Withdrawal Strength
*: Groups with same letters in column indicate that there is no statistical difference ($p < 0.001$) between the samples according to Duncan's multiply range test.

4. Conclusions

With reinforcement, polypropylene fibre, moisture content and thickness swelling properties of the cement boards improved, however the density and mechanical properties was decreased compared to control-WCB. PPF provided a decrease up to 80% in thickness swelling values of the cement board. Samples made from combination of wood particles and PPF in cement depending on the fibre length had similar results with control-wood cement boards, and having higher MOR and MOE values than the EN 634-2 standards. The use of wood particle in cement boards showed high performance on mechanical properties in this study. But wood can be expanding and shrinking in long term outdoor and water exposure due to its hygroscopic nature and is not resistance against fungi and insect attack. Polypropylene fibre has much more resistance against fungi and insect attack and expansion-shrinkage compared to wood. In addition, in contrast to wood, polypropylene fibre does not contain harmful chemicals on cement hydration. Therefore, more researches should be done on PPF reinforced cement board. In future works, the long-term durability and thermal properties of PP reinforced wood cement boards would be investigated.

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