Mechanical Properties of Wood Shavings-Cement Lightweight Composites

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Abstract

The use of wood shavings, as a recycled waste product from the wood furniture industries is an interesting technique to produce lightweight cement composites. This study aims at examining the mechanical properties of wood shavings-cement lightweight composites. First, the wood shavings were pre-treated with water or superplasticizer or Cement Based Bitumen Emulsion (CBBE). Then, the compressive strength and tensile strength of the wood-cement matrix were experimentally evaluated. Finally, it is shown that the addition of wood shavings to cement paste gives a composite with satisfactory mechanical strengths with respect to its weight and higher toughness in addition to environmental and economic benefits.

Keywords: - compressive strength, lightweight composite, tensile strength, toughness, wood shavings.

الخواص الميكانيكية لمركبات رقائق الخشب والسمنت خفيفة الوزن

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الخلاصة

استخدام رقائق الخراطة الخشبية الناتجة من مخلفات صناعات الاثاث الخشبية تعتبر اسلوبا تقنيا ممتعا لأنتاج مركبات خفيفة الوزن. هذه الدراسة تهدف اختبار الخواص الميكانيكية للمركبات الخفيفة الوزن الناتجة من رقائق الخشب-السمنت. بداية تم معالجة رقائق الخشب بالماء أو بالملدنات الفائقة أو بالمستحلب القيري ذو الاساس السمنتي. ثم تم تجريبيا تحديد مقاومة الانضغاط، مقاومة الشد للمزيج الخشبي-السمنتي. أخيرا، فقد أظهرت النتائج أن إضافة الرقائق الخشبية الى عجينة السمنت تنتج مركبا ذو مقاومة ميكانيكية مرضية نسبيا مع وزنه وصلابة عالية بالاضافة إلى مزايا اقتصادية وبيئية.

الكلمات الدالة: مقاومة الانضغاط، مركب خفيف الوزن، مقاومة الشد، الصلابة، رقائق خشبية.

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1. INTRODUCTION

In many countries, the wood industries generate a large amount of waste products in the worldwide. The low costs, the proximity of the sources and the potential pollution from wood wastes have led to studies into the possible use of the wood shavings as fibers in concrete. These types of materials have several potential applications such as acoustic and thermal insulation, fire resistance cladding etc. Soroushian et al. [1] reported that the flexural strength and flexural toughness values of wood fiber-cement composites were higher than the values for neat cement. In the same study, they also reported that the dynamic modulus of elasticity of neat cement decreases with increasing freezing and thawing cycles while the dynamic moduli of wood fiber-cement composites remains relatively constant over the same number of freezing and thawing cycles. Several studies mention the use of wood-ash as fillers in concrete or mortars [2, 3], without revealing a great improvement in mechanical properties.

Jennifer et al. [4] studied the effects of the aqueous in organic compound treatments on newspaper and Kraft fibers for enhancing some selected mechanical properties of wood fiber-cement composites. Their study indicated that certain chemical treatments react better with different wood fiber types resulting in selected mechanical property enhancement.

In another study, Soroushian and Marikunte [5] reported the effects of moisture on the flexural properties of wood fiber-cement composites. Flexural strength decreased with increasing moisture contents. In addition, dry wood fiber-cement specimens appeared to have lower flexural toughness values compared to wet wood fiber-cement specimens. Lee and Hong [6] and Blankenhorn et al. [7] used compressive strength as an indicator of wood fiber-cement compatibility. Lee and Hong showed compressive strength to be linearly proportional to the maximum hydration temperature, but independent of hydration time. While, Blankenhorn et al. indicated that as hydration time increased, compressive strength increases. In 1986, Rowlands et al. [8] found that strength and stiffness are increased in both tension and flexure by adding wood fiber reinforcement.

In this paper, the effects of wood/cement ratios and addition of a superplasticizers or binder emulsion with different ratios on the mechanical properties of lightweight wood-cement composites were studied. The strengths, toughness, density and permeability of these composites were tested.

2. SAMPLE PREPARATION

2.1.Materials

2.1.1. Cement

Locally available cement (equivalent to Ordinary Portland Cement (O.P.C.) type (I)) manufactured by Kirkuk cement Factory was used. The chemical composition of this cement is given in **Table 1**, while its mechanical properties are summarized in **Table 2**.

Table (1): Chemical composition of the used cement*

Property	Test result, %	Standard IQS, No.5-1984**
1. Oxide composition		
Alumina, Al_2O_3	5.1	
Silica, SiO_2	21.89	
Ferric Oxide, Fe_2O_3	3.4	
Lime, CaO	63.11	
Sulphate Anhydride, SO_3	2.22	Max. 2.8%
Magnesia, MgO	3.04	Max. 5%
2. Compound composition		
C_3A	7.77	
C_2S	29.00	
C_3S	45.03	
C_4AF	10.34	

* Manufacturer analysis

**IQS-Iraqi quality standard No.5.

Table (2): Physical properties of the used cement*

Property	Test result	Standard IQS, No.5-1984**
Specific surface “Blaine” , m^2/kg	334.8	230
Initial setting time, min.	150	Min. 45 minutes
Final setting time , min.	245	Max. 10 hours
Compressive strength, MPa.		
At 3 days	26.79	15 MN/m^2
At 7 days	36.21	23 MN/m^2

* Manufacturer analysis
** IQS-Iraqi quality standard No.5.

2.1.2 Wood shavings

White wood (almost Pine wood) shavings, a furniture industrial waste product, display a continuous grading between 5 and 60 mm length, 5 to 25 mm width, and about 0.5 mm thickness. The fibrous nature of the shavings is shown in **Figure 1**. The wood-shavings soaked with superplasticizer solution is shown in Figure 1(a) before mixing with cement and shown in Figure 1(b) after mixing with cement powder. The capillary network in wood, which allow liquid circulation, is responsible for hydrophilic nature of wood. Tamba and co-workers [9] proposed saturation of the wood shavings with water. It is kwon when cement mixed directly with wood shavings, the water available for hydration of cement could be limited due to immigration of water into the wood particles. The kinetic of water absorption is estimated as 260% of wood shavings weight after 30 minutes saturation with water according to ASTM D4442-92 [10].

(a) **(b)**

Fig. (1): The wood-shavings: (a) soaked with superplasticizer solution, (b) after soaking mixed with cement.

2.2 Saturation Treatment

As stated in 2.1.2 previously, Tamba et al. [9] indicated that wood shavings must be saturated with water before mixing with cement in order to achieve adequate moisture for hydration of the cement. However, to improve the interface bond between cement and wood, the workability of the matrix, and the hardness of the final product, two types of solutions were prepared and used. The first was water-superplasticizer and the second water-CBBE emulsion solutions. The properties of the added superplasticizer and the silane are shown in **Table 3**. The concentrations of the solutions are presented in **Table 4**. The wood shavings were immersed in one of these solutions for 30min. prior to their use in wood shave-cement composite.

Table (3): Properties of the Superplasticizer and the CBBE emulsion

a) Superplasticizer	
Trade name	Sikament RMC-219
Type	Modified polymer based liquid
Colour	Brown liquid
Density	1.15–1.19 kg/l, at 20°C
Dosage	Recommended dosage rate is between 0.5 % and 1.5 % by weight of binder
b) Cement-based bitumen emulsion	
Trade name	Poly coat
Type	Cement-based bitumen emulsion, cold applied
Density, kg/m^3	1600
Colour	Grey-black

2.3 Specimens Preparation

Cementitious composite samples 100x100x100 mm cubes were manufactured using a mix of cement, wood shavings and water. The wood/cement ratio varied in these tests as given in **Table 4**. Cement was added on wet saturated wood shavings and mixed in a pan mixer following ASTM C 305-94[11]. The water and plasticizer or CBBE-emulsion solutions were added to wood shavings and soaked for 30 minutes before mixing. The mixtures were then poured into the molds in two layers each of them subjected to 0.06 MPa pressure forming the cube specimens [12]. The specimens were demolded after 24 h and placed in limewater bath and continued to cure for an additional 27 days. The temperature of the water bath was ranged (23+1.7 ^{o}C) in accordance with ASTM C 192 / C192M-98[13]. The samples were taken out from the curing tank and conditioned in the laboratory atmosphere (about 33 ^{o}C & 43% RH) for 7 days to change to air-dried specimens prior the test. The compressive strength and split tensile strength tests were conducted using a 3000 kN compression testing machine type Alpha. These tests were conducted according to BS 1881: 116: 1983 [14] and BS 1881: 117: 1983 [15]. The equilibrium air-dried density and normalized toughness were tested following the ASTM C567-05a [16] and ASTM D5873-14 [17].

Table (4): Mixture proportions used in investigation

a) Samples treated with Sika Superplasticizer

Sample	Cement/wood Ratio	Superplasticizer /Cement percentage (%)	Percentage of components weight (%)			
			Cement	Wood	Water	Superplasticizer
AS	1.0	0.0	21.69	21.69	56.62	0.00
AS-1	1.0	1.0	21.69	21.69	56.40	0.22
AS-2	1.0	1.5	21.62	21.62	56.44	0.32
AS-3	1.0	2.0	21.64	21.64	56.29	0.43
BS	1.5	0.0	29.35	19.57	51.08	0.00
BS-1	1.5	1.0	29.35	19.57	50.79	0.29
BS-2	1.5	1.5	29.23	19.48	50.85	0.44
BS-3	1.5	2.0	29.18	19.46	50.78	0.58
CS	2.333	0.0	39.25	16.83	43.92	0.00
CS-1	2.333	1.0	39.26	16.83	43.52	0.39
CS-2	2.333	1.5	39.28	16.84	43.29	0.59
CS-3	2.333	2.0	39.21	16.80	43.21	0.79

b) Samples treated with CBBE emulsion

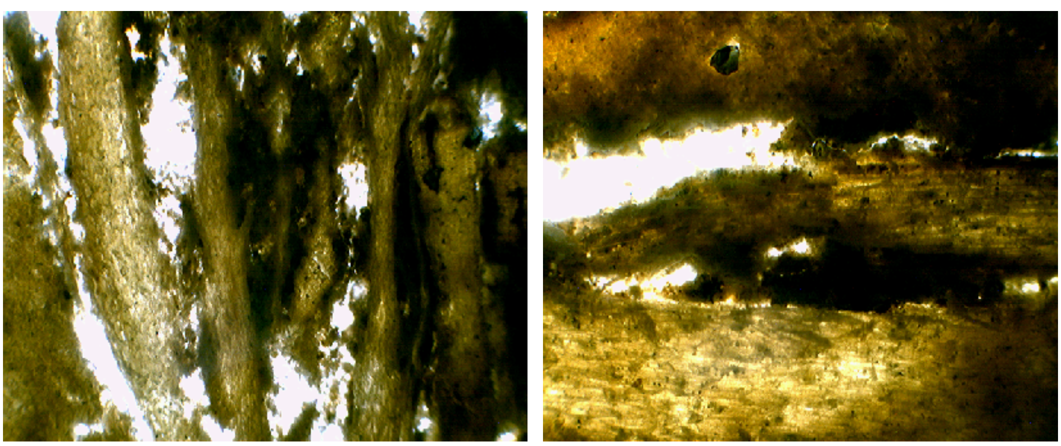
Sample	Cement/Wood Ratio	CBBE emulsion/ Cement percentage (%)	Percentage of components weight (%)			
			Cement	Wood	Water	CBBE emulsion
BF-15	1.5	15	28.93	19.29	47.44	4.34
BF-25	1.5	25	28.66	19.10	45.07	7.17
BF-35	1.5	35	28.38	18.93	42.76	9.93
BF-50	1.5	50	27.99	18.65	39.37	13.99

3. RESULTS and DISCUSSION

It was difficult to ascertain average mechanical properties values between different treatment levels and types due to the following reasons:

1. Wood shavings being a biological material had inherent variability in chips size and properties;
2. The distribution of wood shavings and direction of fibers in the matrix of specimens in relatively small sample had a statistical effect;
3. The difficulties to keep the entire depth of the specimens pressed under a certain pressure without adding any accelerator to accelerate the setting of the cement;
4. The intensive lightweight and large pores in microstructure of the hardened matrix gives a trend to different test results.

The observations of **Figure 2** show the fibrous nature of the wood, which allows accommodating the deformations and provides good adhesive on the matrix.



(a) (b)

Fig. (2): Polarized electronic microscopy images of a BF sample (40 x): (a) parallel to load shaving surface and cement matrix, (b) perpendicular to load shaving surface.

3.1 Wood-cement Composites Treated with Superplasticizer

The average compressive strength, indirect tensile strength, equilibrium air-dried density and normalized toughness for the untreated and treated with superplasticizer wood shavings-cement composites were presented in **Table 5**. In general the results of compressive and indirect tensile strengths for untreated composites were slightly higher than most levels of superplasticizer treated wood shavings-cement composites. The composite BS-1 has 10% increase in compressive strength and 34% in indirect tensile strength, while CS-1 has only 12% increase in indirect tensile strength compared with strengths of untreated specimens.

The marginal improvement in compressive and tensile strengths of treated wood-cement composites with superplasticizers may be attributed to two reasons: a) the weak interfacial bond between fibers and cement paste due to the smoothened surface characteristics of the wood shavings due to saturation treatment, b) the decrease of effective w/c ratio needed for hydration of the cement and increase in free w/c ratio. The strength of the bond between wood fiber and cement determines the composite properties and depends on the wood species, fiber treatment, and additives in the mixture [6].

However, this treatment of the wood-cement composites had increased the density for groups AS, BS and CS specimens up to 25% and 33% respectively and the average normalized toughness values had increased for specimens AS, BS and CS up to 58%, 95% and 100% respectively. These increases in density and enhancement in toughness may be explained by decreasing the voids space per unit volume and increasing in cement/wood ratio.

3.2 Wood-cement Composites Treated with CBBE Emulsion

The average compressive strength, indirect tensile strength, equilibrium air-dried density and normalized toughness for the untreated and treated with CBBE emulsion wood shavings-cement composites were presented in **Table 6**. Comparing the wood –cement composites treated with CBBE emulsion and that treated with Superplasticizer, their mechanical properties produce some interesting results. The average of relative compressive strength and tensile strength per specimen density were higher when treated with CBBE emulsion by about 6% and 3%, respectively.

However, all of the treated wood-shavings average compressive strength and tensile strength values were lower than the untreated values except for the treated composite BF-50, which shows a 10% increase in compressive strength.

3.3 Permeability of Specimens

The permeability determination of wood-cement composites was tried according to the United States Bureau of Reclamation Procedure [18]. Performing a water-tighten acrylic sealant cover over the specimens cubes was failed due to the difficulties in cleaning the wood dust and the oil from specimens surfaces and so a weak bond produced between the silicone and wood-cement composites. However, a high permeability was observed in this type of composites.

4. Conclusions

For most of the measured properties, the lower percentage treatment agent shows better properties for wood-cement composites when treated by superplasticizer, while composites treated with CBBE emulsion have higher average values at higher percent levels.

The test results indicate that a lightweight mortar having equilibrium air-dried density less than 840 kg/m^3 and compressive strength above 3.2 MPa, except for AS-2 is 2.55 MPa, can be produced.

According to the compressive strength criteria, the specimens with cement/wood ratio of 2.0 have best results than the lower cement/wood ratios of 1.5 and 1.0 for all specimens treated in various levels.

Table (5): Strength properties and density of wood-cement composites treated with superplasticizer

Samples	Compressive strength (MPa)	Indirect tensile strength (MPa)	Equilibrium air-dried density (kg/m^3)	Normalized toughness
AS	4.19	0.4	440	1.00
AS-1	3.76	0.27	480	1.58
AS-2	2.55	0.16	550	1.58
AS-3	3.38	0.24	520	1.54
BS	3.88	0.35	550	1.65
BS-1	4.26	0.47	560	1.85
BS-2	3.2	0.22	690	1.95
BS-3	4.11	0.26	610	1.86
CS	5.97	0.58	630	1.81
CS-1	4.41	0.65	740	1.97
CS-2	3.41	0.32	840	2.00
CS-3	5.42	0.32	670	1.96

Table (6): Strength properties and density of wood-cement composites treated with CBBE emulsion

Samples	Compressive strength (Maps)	Indirect tensile strength (MPa)	Equilibrium air-dried density (kg/m^3)	Normalized toughness
BF-0	3.88	0.35	550	1.65
BF-15	3.14	0.23	550	2.04
BF-25	3.48	0.34	540	2.04
BF-35	3.76	0.26	570	1.93
BF-50	4.28	0.34	560	1.73

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