

## Development of Sawdust in Cement Particle Board Using Eco-Friendly Process

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### Abstract:

Environmentally sustainable and effective methods of recycling industrial waste are needed due to its continuous rise. This study therefore looked at whether sawdust waste might be used to make cement-bonded particleboards and how to improve the sawdust's compatibility with cement through the use of physical pretreatment techniques, the addition of nano slag, and rapid carbonation curing. Each test was conducted using a separate set of manufacturing setups, including treated and untreated wood, CO<sub>2</sub> solidification, nano-slag addition, and sawdust/cement ratios of 20%, 30%, and 40%. The mechanical properties of the produced particleboards were experimentally evaluated, including density (D), water absorption (WA), thickness expansion (TS), and flexural strength (BS). The microstructure of the cement particleboards was analyzed using SEM or scanning electron microscopy. The results showed that employing the accelerated CO<sub>2</sub> curing procedure for sawdust particleboards improved the mechanical and microstructural properties of the sawdust-treated cement bonded particleboards. The SEM micrographs demonstrate that some of the carbonate crystals both protruded from sawdust surfaces and diffused into the cell walls and cavities.

## 1. Introduction

Human activities generate large amounts of wood waste each year, which can be used as industrial and agricultural residues. If water is excluded, wood-cement particleboard consists of 60-90% by weight of cementitious materials (20- 55% by volume) and 10-40% by weight of wood (45 - 80% by volume) [1, 2]. Almost all studies on wood-cement composites support the hypothesis that wood hinders the setting and solidification of cement. Compounds that negatively affect cement hydration include sugars, tannins and starch [3]. The topic of sustainable development has become increasingly important since the beginning of the industrial revolution in the 19th century. The CO<sub>2</sub>-

accelerated curing process has revolutionized the production of wood-cement composites [4].

Carbonation has been accepted as an accelerated curing process in cement-based composites because it is a CO<sub>2</sub> sequestration technology that can improve product quality. CO<sub>2</sub> can be used to accelerate the curing of cementitious matrices to improve the long-term strength and durability of composites including sawdust particles, as the matrix's alkalinity is reduced and its hostility to wood particles is reduced [5]. The compatibility of wood and cement is a fundamental issue in wood-cement composites. Many types of wood cannot be used with cement because soluble carbohydrates and certain wood extractives prevent cement from setting and hardening [6]. In general, lignin appears to have little effect on cement

hydration, while sugars, acids hemicelluloses, etc. tend to greatly alter cement hydration [7]. It is a good approach to sign When gassing is the objective of this g is carried out by treating wood to turn it into carbonaceous materials since carbonized wood cementitious products have potential in the future for the compatibility of excellent Wood Cement methods. Because the setting time of the cement material is very short (8), wood inhibitory substances have comparatively little effect on cement hydration process (8). Another method is to use chemicals or hot water to removes the wood before mixing. Indeed, this is currently the most commonly used technique at work in order to cut out the adverse impact of wood there are two methods. Hydration enhances and the delay of initial energy by using silica fume or rice husk ash. In addition, these methods will also enhance strength. Adding fly ash has resulted in improved mechanical and physical properties for particleboard. Eleven With wood and cement as raw materials, composite products have the best characteristics of both. It is famous for having something of good the strength and stiffness resistant to water, fire and decay strong while it also can be cut smoothly to size. Perfect heat sound insulation properties or high resistance to impact were concluded. Both during use and in the course of processing, these items are completely safe for the environment. Besides, Arenga Pinata fibers 98 reatomicity and lightness [12].

percentages (0.6–0.8) demonstrated a 120% increase in flexural toughness over those in larger volumes [13]. When the cement/wood ratio increases from 0.75 to 1.5, the flexural strength properties of the board improve [14]. In addition, when the cement/wood ratio increases above 2.0, the flexural stiffness of the wood particleboard decreases [15]. The aim of this study was to improve the mechanical properties of cement-bonded particleboard. The properties of cement-bonded particleboard were also examined with sawdust additives, nano-slag, and faster carbonization. In addition, the release of carbon dioxide gas into the atmosphere was studied.

## 2. Materials and methods

### 2.1 Properties of Materials

The main raw materials used were Type I cement, microsilica fume, natural fine aggregate, tap and distilled water, superplasticizer, nano slag and sawdust particles. The particleboard was made of ordinary Portland cement (I.Q.S. 5/1984 corresponding. Table 1 shows the chemical composition of nano slag and microsilica fume (manufactured by BASF). Microsilica pozzolanic additive was used with an accelerated pozzolanic

strength activity index of 135%. The results showed that the microsilica fume and nano slag used in this study met the ASTM C-1240-05 and ASTM C-618 standards. The combination used Sika ViscoCrete 5930, third generation premium HRWR (SP), with a density of 1.095 g/cm<sup>3</sup>. Type G is the classification specified by ASTM C494-03 for this superplasticizer. The sawdust particles were purchased from an Iraqi timber company. After further grinding, the sawdust was sieved to a mesh size of 4 mm in a lobster mill as shown in Figure 1. Table 2 lists the physical properties of sawdust particles. Physical particle preparation (keratinization) was performed to remove Extrac tables that hinder cement reaction. Toxic Extrac tables were eliminated by heating the sawdust in 20% Ca(OH)<sub>2</sub> saturated water for 60 min [16]. Table 3 shows the particle sizes of sand and sawdust used in this study. In this study, natural sand with I.Q.S. No. 45/84, zone 3, with a maximum size of 4.75 mm was used as fine aggregate.



Figure 1. The humming machine for producing sawdust.

### 2.2 Experimental Setup

Equations 1 and 2 illustrate how the amounts of raw materials required to create the particleboard were calculated using the Japanese industrial standard for particleboards (JIS A 5908: 2003):

$$G = \frac{DV\delta}{(1+B+R)} \quad (1)$$

$$P = GB(1+M) \quad (2)$$

The variables in these equations are: G = mass of cementitious material used to make particleboard; P = mass of sawdust used to make particleboard; D = target board density (D = 1400 kg/m<sup>3</sup>); V = target board volume (m<sup>3</sup>);  $\delta$  = raw material loss coefficient during production ( $\delta = 1.1$ ); B = sawdust-cement mass ratio (%); M = moisture content of sawdust particles (%); R = water-cement ratio (%). According to ASTM C1185-12 standard, cement-bonded particleboards made of treated and untreated sawdust particles with a density of 1400 kg/m<sup>3</sup> were used in this study and examined after

**Table 1.** Micro silica and nano slag's chemical structure.

Constituent	Micro Silica (%)	Nano Slag(%)	Limits of ASTM C-618/05
CaO	1.27	1.16	
SiO <sub>2</sub>	89.36	67.95	
Al <sub>2</sub> O <sub>3</sub>	0.81	20.75	≥ 70 %
Fe <sub>2</sub> O <sub>3</sub>	0.52	3.50	
SO <sub>3</sub>	1.04	0.01	≤ 5
NaOH+KOH	1.33	0.50	
Loss on Ignition	4.7	-	≤ 6 %
Fineness	≥ 15000 cm <sup>2</sup> /gm	= 63 nm *	

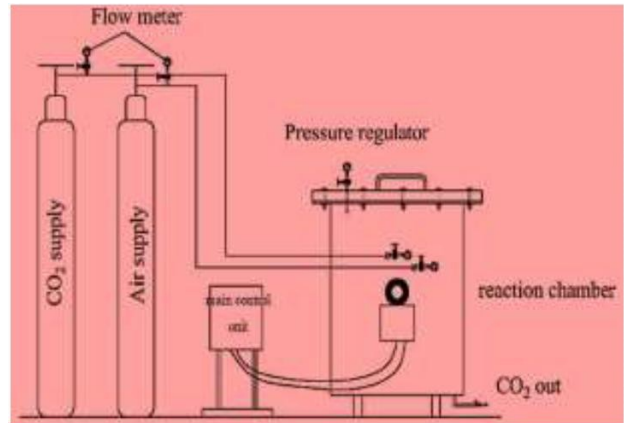
28 days. Based on previous studies, the experimental factors were as follows: Sawdust/cement: 20%, 30%, 40%; treated and untreated wood; CO<sub>2</sub> hardening; addition of nano-slag with a constant water-cement ratio of 30%; addition of 1% SP by weight of cement; nano-slag added at 0.2% by weight of cement; and replacement of 20% of the weight of cement with microsilica. The 305 x 152 x 20 mm samples were all stored in the mold and covered with a moist burlap wrap for a whole day. The particleboard was then carefully removed from the mold, dried at 105 ± 2 °C for 30 minutes and cured using the prescribed method. This drying process ensured a clear path for CO<sub>2</sub> production. The samples in the curing chamber were soaked with 6.9 MPa (1000 psi) of CO<sub>2</sub> gas at 55°C for 2 hours as shown in Figure 2. Sample preparation for this and subsequent parts included applying a vacuum for 20 minutes before injecting CO<sub>2</sub> with a CO<sub>2</sub> flow rate of 10 L/min. Structural analysis of the fracture surfaces of all samples was performed using a SEM model: TESCAN-VEGA/USA, equipped with a tungsten source and a 20 mm detector to confirm whether accelerated carbonation occurred. Similarly, X-ray diffractometer (XRD) analysis was used to characterize the reaction products of concrete samples of different mixtures. XRD is an ideal analytical technique for concrete research due to its easy operation and fast test speed. The method is non-destructive and requires only a few grams of material to examine, making it an effective tool for studying crystal structures.

**Table 2.** Sawdust particles' appearance.

Features	Values
Specific gravity	0.65
Water absorption (%)	189
Moisture content (%)	62
Dry density (kg/m <sup>3</sup> )	627

**Table 3.** Grading of sawdust and sand particles.

Type	Sieve size (mm)						
	10	4.75	2.36	1.18	0.6	0.30	0.15
Sawdust	100	79	38	13	5	4	1
Sand	100	92	80	54	42	13	5



**Figure 2.** Experimental setup for CO<sub>2</sub>-curing.

### 3. Results and Discussion

#### 3.1 SEM Micrographs Outcomes

Figure 3 shows sawdust particleboard with fractured surfaces captured in SEM micrographs before and after various acceleration effects. Five representative pictures were taken for each sample, and only one SEM micrograph was selected from the set. Ca(OH)<sub>2</sub> appears to be clearly coated on the surface of the sawdust particles (arrow 1/a). Moreover, it is clear that after sawdust pretreatment, there is a strong bond between the sawdust particles and the cement paste, which is why the cracks form far away from the ITZ (arrow 2/a). Therefore, the fracture cracks start when failure occurs within the ITZ and on the sawdust particles. At the same time, the cross-section of the sawdust particles used here consists of empty black holes (arrow 3/b). In the non-carbonized samples, these black holes are not filled; however, for the carbonized boards, they are completely filled with CaCO<sub>3</sub>. After CO<sub>2</sub> curing, plate-like CaCO<sub>3</sub> can be seen on the particle surface and around the fiber pores (arrow 4/c). To this end, the carbonized cementitious matrix is denser than the control mixture, which can improve the interfacial transition zone between the particles and the cementitious matrix, undoubtedly increasing the flexural strength of the final composite. Also, from these micrographs, it can be seen that the addition of nano-slag to the cementitious matrix resulted in a

denser and more compact cementitious matrix, as shown by (arrow 5/d). This improved contact between the sawdust and cementitious matrix can improve the adhesion between the two, reduce the ITZ thickness, and increase the panel density. This is due to the filling effect of carbonate crystals

produced by carbonation and nano-slag. Figure 4 shows the results of X-ray diffraction spectra. Four representative mixtures - untreated test matrix, treated, carbonized, and including nano-slag - are represented by the data. For each of the

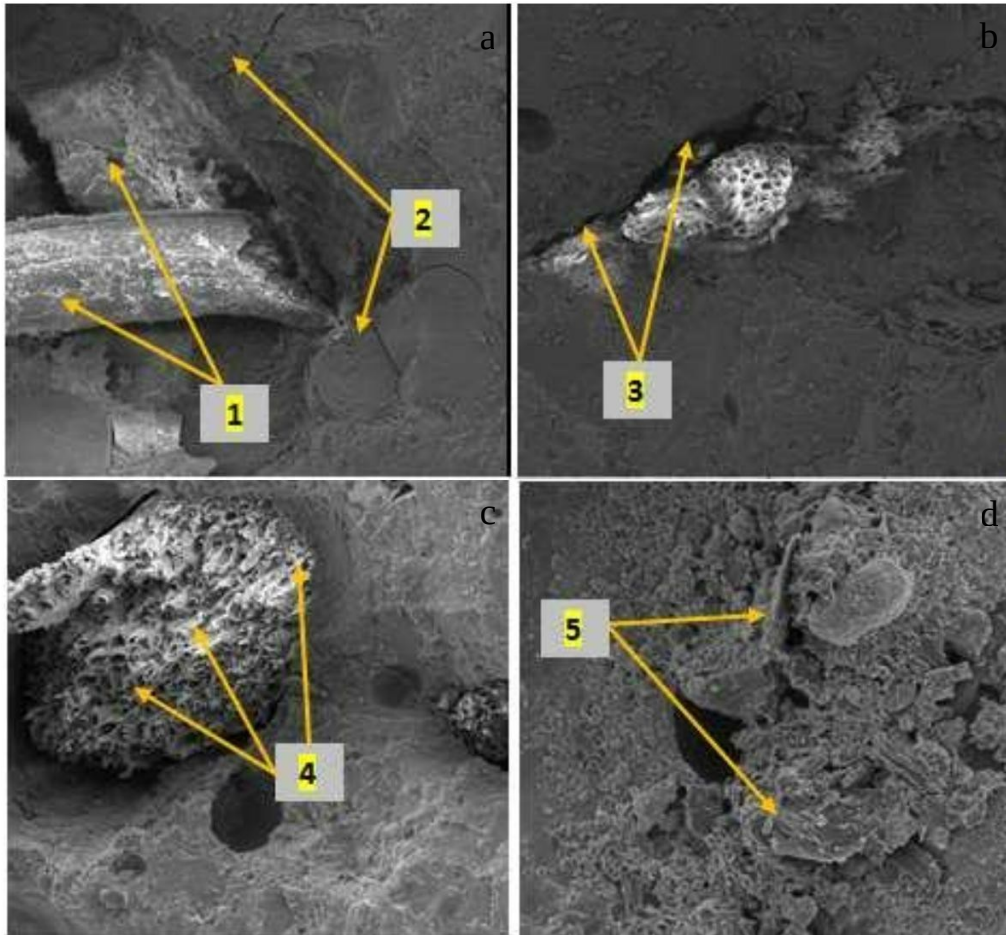


Figure 3. SEM micrographs of the broken surfaces of the following: (a) treated, (b) untreated, (c) CO<sub>2</sub> cured, and (d) added nano slag.

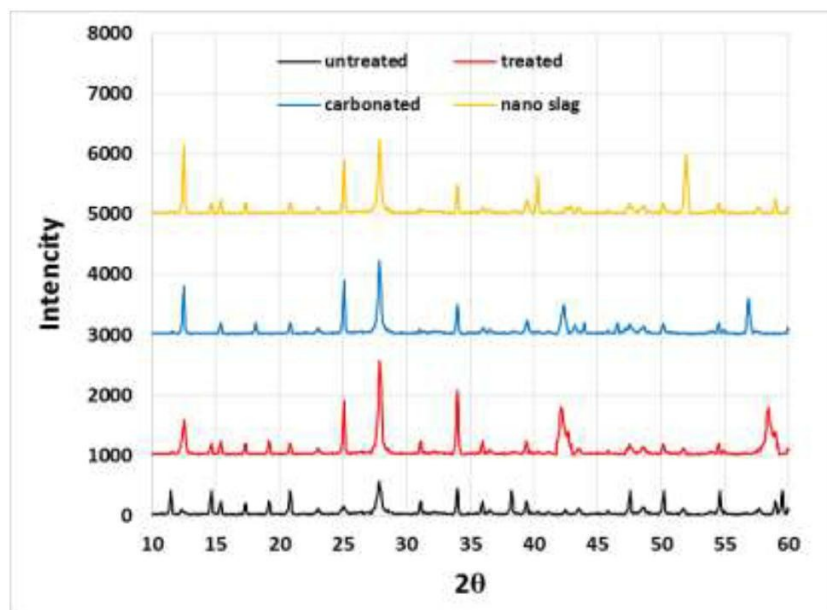


Figure 4. X-ray diffraction results for the following conditions: (a) untreated; (b) treated; (c) carbonated; and (d) with nano slag.

studied mixtures, large humps ( $\text{CaCO}_3$  and CSH) were observed in the diffraction pattern between  $13^\circ$ ,  $25^\circ$ , and  $30^\circ$   $2\theta$  values. At the same time, small peaks in the diffraction pattern were observed between  $34^\circ$ ,  $43^\circ$ , and  $52^\circ$   $2\theta$  values ( $\text{Ca}(\text{OH})_2$  and quartz Qz). This could be due to the presence of amorphous glassy material due to increased cementitious activity (in the case of treated sawdust), carbonate hardening or the presence of carbonate crystals due to pozzolanic activity (related to the addition of nano-slag). It was found that the crystallinity of the untreated sawdust particleboard samples was lower than that of the treated carbonate and nano-slag samples. These humps indicate the formation of aluminosilicate hydrate gel C-A-S-H, which was identified as the main reaction product of the hydration process in the specific diffraction pattern.

### 3.2 Mechanical and Microstructural Features Outcomes

The data analysis with the above testing methods is instructive in order to know quantitatively the influence of different parameters on the mechanical, microstructure and physical properties of CPB. The treated and untreated sawdust particleboard differs significantly in the results. Composite board of the treated sawdust has greater flexural strength and density than untreated board. Moreover, all the treated sawdust particleboards exhibit lower moisture absorption and thickness swelling compared to that of treated wood. Carbon dioxide cured particleboard All of the  $\text{CO}_2$  cured particleboards had higher MOR and density, but lower MA and thickness swelling rates than those for uncured particleboard. That is to say, the amount of rebound decreases after immersion in water for carbon dioxide-cured products and those hardened after 28 days resulting from flowing are higher than those prepared by conventional method. Figures 5 and 6 depict the relationship in sawdust-cement's ratio vs. thickness expansion rate, and moisture absorption rate under different treatment conditions. Thickness swelling rate, moisture absorption rate and ratio of sawdust to cement of all the panels were significantly increased by 210% and 66%, respectively after 24 h immersion. This is due to the relatively high permeability of wood particles in the board. Also, with the addition of wood chip treatment 20%, carbonization 43%, and nano-slag 24% reduction rate in moisture absorption ratio, thickness expansion ratio were observed as a value of 24%.

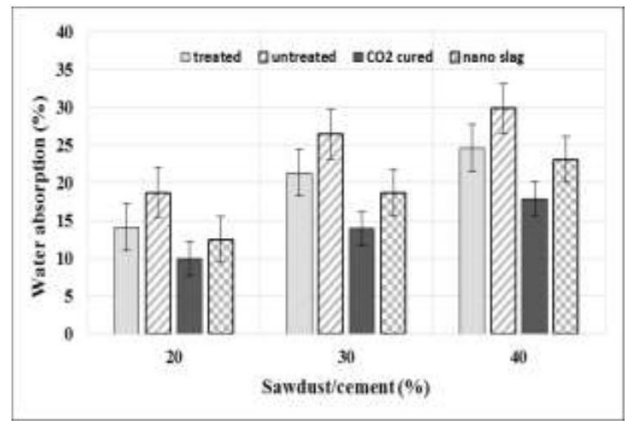


Figure 5. Cement-bonded particleboard's water absorption.

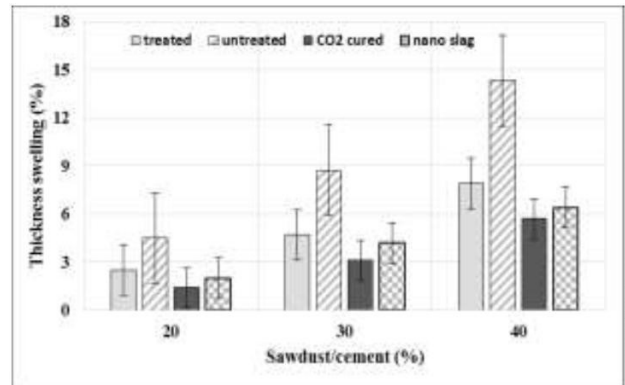


Figure 6. Swelling of cement-bonded particleboard thickness.

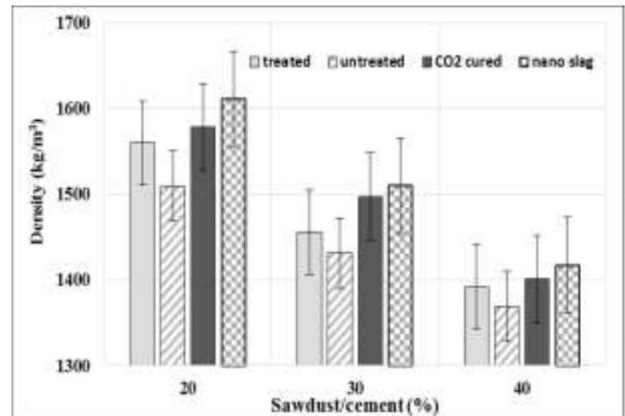


Figure 7. Density of particleboard bound with cement.

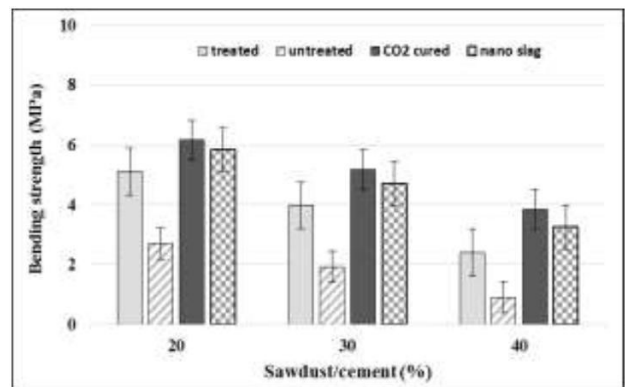


Figure 8. The bending strength of particleboard bound with cement.

respectively, compared to untreated sawdust particleboards. The elimination of extractable materials and the filling effect of nano-slag and its pozzolanic reaction could be the main reasons for these improvements. As can be seen in Figures 7 and 8, the denser particleboards did not result in higher flexural strength. This could be due to the petrification of sawdust particles due to carbonization solidification and improved interfacial transition zone, as shown in the subsequent SEM micrographs, and CO<sub>2</sub> solidification improved the bond between sawdust particles and the matrix. As a result, the bond between sawdust particles and the matrix increased, and the ITZ became thicker and stronger. Panels made from treated particles had higher density and flexural strength values compared to those made from untreated particles. Moreover, the density and flexural strength decreased the most (6%, 11%) and (17%, 48%), respectively, when the sawdust/cement ratio increased from 20% to 30% and 40%. However, after sawdust treatment, carbonization hardening and addition of nano-slag, the increase rates of density and flexural strength were 4%, 5% and 7%, 100%, 134% and 126%, respectively. In conclusion, these results all indicate that sawdust pretreatment, board carbonization and the addition of nano-slag help to improve the compatibility of sawdust particles with cement, thereby improving the strength of the final product.

#### 4. Conclusions

The density, bending strength, and water absorption of treated particleboard are greater than those of untreated particleboard, but the value of decrease in thickness is less than that from untreated boards when Portland cement mixed with treated sawdust. The sawdust and particle board matrix itself seem to be enhanced by the carbonate hardening. A few carbonate crystals were observed that appeared on the surface and in the volcanoes and cell walls of the sawdust. When continuedly carbonized, the densification of interface replacement area enhanced the hardness of culm. Petrified sawdust on the fracture surface with a higher adhesion force broke instead of sheared. High adhesion petrified sawdust typically broke rather than splitting homo at the fracture surface. The X-ray diffraction spectra showed two types of peaks: large and small. The CSH peak became more clear in the X-ray diffraction spectrum after sawdust treatment. Carbonate crystals were formed from carbonate hardening. The CSH Qz peaks appear obvious with the presence of nano-slag.

#### Author Statements:

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