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Evaluation of using waste timber railway sleepers in wood–cement composite materials

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ABSTRACT

In present study, the suitability of using waste timber railway sleepers (WTRSs) as filler in wood–cement composites was investigated. The effects of two variable factors namely press temperatures (25 and 60 °C) and calcium chloride contents (3%, 5% and 7% w/w cement) on some physico-mechanical properties were also investigated. The following experimental parameters were constant: wood/cement ratio (40:60), board thickness (15 mm), press pressure (40 kg/cm^2), and press time (5 min). Press temperature, calcium chloride and the interaction of both variables had significant effects ($p < 0.01$) on all the studied properties. Test results showed that addition of calcium chloride tends to enhance both the physical and mechanical properties of boards. All properties of the boards were improved when the calcium chloride content was increased from 3% to 7%. The results also showed that as the press temperature was increased from 25 to 60 °C, significant increased in water absorption and thickness swelling occurred. Water absorption and thickness swelling (at 2 h and 24 h) compared favorably with values reported for cement-bonded composites produced from virgin wood particles. In general, the strength properties of the boards were found to be a maximum when press temperature and calcium chloride were 25 °C and 7%, respectively. These properties can be exploited in many applications where lightweight concretes are required. Therefore, WTRS is technically suitable for building construction such as paneling, ceiling and partitioning.

1. Introduction

Traditionally, wood has been an essential construction material. However, with the invention of reinforced concrete, its application has been reduced [1]. In recent years, there has been a growing interest in utilizing wood for making low-cost building materials [2–5]. The primary advantages of using woody materials as fillers in cement are the low density, low cost, nonabrasive nature, high filling levels possible, low energy consumption, and wide variety of wood species available throughout the world [6]. On the other hand, increasing demand for forest resources in various applications has led to the shortages of wood supply. Thus, there is a need to look for innovative ways of using non-traditional forest resources to substitute wood raw materials for wood-based industries. Among the possible alternatives, using recycled wood is currently at the center of attention [1,7–9]. Every year, a large number of old and deteriorated structures such as railways, buildings, fencing poles, furniture items and bridges are being demolished. Most of the timbers used in construction are being treated with chemical preservatives (such as chromated copper arsenate and creosote) during their service life to protect them from biological deterioration. These chemical materials contain toxic or polymeric substances which are not easily biodegradable. Presently these wastes are either burnt or land filled. These approaches cause various environmental issues like air pollution, emission of green house gases and occupation of useful land. The increasing charges of landfill are further aggravating the problem. Moreover, these methods of disposal are certainly wastage of a primary natural resource. Therefore attempts have been made by researchers, both in industry and academia, to reuse these wastes as the building materials (i.e. wood–cement composites) [1,6].

Studies on the waste wood in the forms of fibers, particles or strands suggest that these materials have the potential for use as reinforcing agent or filler in cement composites. Kasai et al. [10] used wood particles from construction waste in Japan for making wood-chip concrete. They made concrete with a density range of 0.92–1.25 g/cm^3. They found the flexural strength of the product in the range of 4–7 MPa and compressive strength 5–8 MPa. The ratio between flexural strength and compressive strength was 0.5–0.9, greater than that for normal concrete. This indicates the reinforcing effect of wood particles. They further reduced the density to about 0.78 g/cm^3 by adding synthetic lightweight aggregates. This resulted in comparatively lower bending and

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compressive strength values at 2.05 and 2.2 MPa, respectively. In another study by Wolfe and Gjinolli [11] on the use of southern pine wood particles derived from construction waste, it was found that the toughness index, which is used to compare the energy absorption capacity during failure of a material, was greater than whereas the average value of toughness index for other fiber reinforced concrete products is 5. Therefore, they achieved a better toughness index.

A number of studies have reported the effects of virgin or waste wood particles on the properties of cement composites [9,12–15]. However, no published reports are available that evaluate effects of waste timber railway sleepers (WTRSs) on the strength and sorption properties of cement-bonded composites. In addition, reutilization of WTRS has advantages for economy and environment. The main objective of present work is to evaluate the suitability of using WTRS as reinforcing agent in the cement composites. Further, the effects of two variable factors namely press temperatures and calcium chloride contents on the selected physical and mechanical properties were investigated.

2. Experimental procedures

2.1. Materials

The woody material used in this work was WTRS which was collected from a local railway station, Karaj, Iran. They have been preserved by pressure treatment with an EPA-registered pesticide containing creosote to protect them from insect attack and decay. The WTRSs were initially chipped using a laboratory-scale drum chipper (Pallmann PHT). The chips were then reduced into smaller pieces using a laboratory-scale ring flaker (Pallmann PZB). Dried particles with 5% moisture content were screened to eliminate oversized particles. The weight distributions of wood particles are presented in Table 1.

The binding agent employed was commercial grade of Portland cement (type II). Calcium chloride ($CaCl_2$) was used as cement setting accelerator. It was an analytical grade from Merk Co, Germany.

2.2. Preparation of boards

All the boards were made with 40:60 weight ratio for wood/cement, and a 1:0.6 weight ratio for cement/water (the amount of water in the wood particles was included). The wood/cement ratio was selected based on commercially produced wood–cement composites. Two process variables considered in this study include $CaCl_2$ contents (3%, 5% and 7% w/w cement) and press temperature levels (25 and 60 °C). Control samples contained neat cement and water. Board thickness (15 mm), press pressure (40 kg/cm^2) and press time (5 min) were kept constant in all experiments. Table 2 presents the formulations and abbreviations of the boards produced.

The wood particles for each board were first sprayed evenly with the dilute aqueous solution of $CaCl_2$. Consequently, the cement and WTRS were uniformly blended and then immediately transferred into a mould of 450 mm × 450 mm × 15 mm. The mixture was evenly distributed and flattened using a wooden block, the mould removed and a piece of plywood placed on top of the mat. The resulting assemblage was pre-pressed to reduce its height while the mat for the next board was mixed. This stack of mats was placed between two steel plates and pressed. The pressed mats were kept under compression for 24 h by bolting the two steel plates together using four 15 mm thick bolts. After 24 h, the boards were declamped, stacked vertically and conditioned for 28 days at 35 ± 1 °C and 90 ± 5% RH to allow the cement to cure and gain strength. The specimens were conditioned in a controlled room for 28 days at 25 °C and 65% RH.

2.3. Test procedure

Mechanical and physical properties were determined following ISO 8335:1987. It is a procedure for boards of Portland or equivalent cement reinforced with wood particles.

Table 1
Distribution of wood particles.

Size (mm)	Percentage
<0.4	3.2
0.4–1	3.4
1–2	8.4
3–4, >4	82.1

Table 2
Mixing ratios of raw materials and their abbreviations.

Code	Press temp. (°C)	$CaCl_2$ (%)	Cement (%)	WTRS (%)	Replications
A_1B_1	25	3	60	40	3
A_1B_2	25	5	60	40	3
A_1B_3	25	7	60	40	3
A_2B_1	60	3	60	40	3
A_2B_2	60	5	60	40	3
A_2B_3	60	7	60	40	3
C_1	25	0	100	0	3
C_2	60	0	100	0	3

2.3.1. Physical properties

Physical properties in terms of apparent density (AD), water absorption (WA) and thickness swelling (TS) were evaluated. The specimens for WA and TS (50 × 50 mm^2) were completely submerged horizontally under distilled water maintained at 25 °C for 2 h and 24 h. After soaking, the samples were drained on paper towels for 10 min to remove excess water. The WA and TS were calculated from the increase in weight and thickness of the specimen during submersion, respectively. At least three specimens of every board were tested to obtain a reliable average and standard deviations.

2.3.2. Mechanical properties

Conditioned boards were sawn into test samples for modulus of rupture (MOR) modulus of elasticity (MOE) and internal bonding (IB) strength. Three-point flexural testing was carried out using an Instron Universal Testing Machine, with a span of 180 mm and crosshead, bearer diameter of 25 mm and loading speed of 5 mm/min.

2.4. Statistical analysis

The experimental design consisted of two treatments – press temperature and percentage concentration of $CaCl_2$ – and three replications per treatment. Data for each treatment were statistically studied by analysis of variance (ANOVA). When the ANOVA indicated a significant difference among factors and levels, a comparison of the means was done employing Duncan's multiple range test to identify the groups that were significantly different from others groups at 99% confidence level.

3. Results and discussion

The results of the physical and mechanical tests, with statistical analysis, are shown in Tables 3–5 for all the fabricated materials.

3.1. Physical properties

The wood–cement composites with low board density (⩽1 g/cm^3) would be preferred for applications that require boards of light weight such as ceiling and roofing for easy installation. In addition, the composites with low cement/wood ratio would be more economical because a small quantity of cement is required with a large quantity of particles used in this study (WTRS) during CBB production. It must be noted that cement is more expensive to procure than WTRS. According to Adhikary et al. [16] the water absorption and swelling rate increased linearly with the decreasing of the composite board density.

In general, the characteristics that make wood–cement composites desirable to construction applications are low water absorption and good dimensional stability. On the other hand, water absorption can affect on the mechanical properties. As Tables 3 and 4 present, a significant difference in water absorption was observed for the 8 types of boards after 2 h and 24 h of immersion. A_1B_1, A_1B_2 and A_1B_3 boards showed intermediate values of water absorption which increased with immersion time. A_1B_3 board showed the lowest values of water absorption among the studied boards. However, water absorption of wood–cement composite boards was significantly higher than control samples (C_1 and C_2). This could be attributed to their lower bulk density and hence higher porosity already alluded to (Table 3). Asasutjarit et al. [17] reported that the low density wood–cement boards have more void spaces than dense ones so that more water can be absorbed.