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Use of tree pruning wastes for manufacturing of wood reinforced cement composites

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Tree pruning wastes from six woody species, namely *Acacia salicina*, *Conocarpus erectus*, *Ficus altissima*, *Leucaena glauca*, *Pithecellobium dulce* and *Tamarix aphylla*, were used to manufacture high-quality wood reinforced cement composites (WRCCs). Hydrations experiments were conducted to screen the compatibility of the selected tree pruning wastes with cement. Additionally, various particle pre-treatments and chemical additives were applied to enhance the compatibility of wood with cement. The best treatment for each species was selected and used to manufacture the WRCCs. The panels were produced under specific manufacturing variables and the mechanical properties and dimensional stability of the panels were determined. The results indicated that both board density and wood/cement (W/C) ratio had significant effects on the properties of WRCCs. With few exceptions, a W/C ratio of 1/2 and either 1200 kg m^{-3} or 1300 kg m^{-3} produced the optimal strength properties. The tree pruning wastes are suitable for use as raw materials in the manufacturing of WRCCs after pre-treatment of the wood particles with either cold or hot water and with addition 3% of $CaCl_2$, $Al_2(SO_4)_3$ or $MgCl_2$. Therefore, these wastes could be used as an alternative wood source for WRCCs.

1. Introduction

The negative environmental impact of deforestation necessitates alternative biomass sources for the manufacture of wood products led to a search for viable alternatives biomass sources [1–3]. Residues such as wood wastes, agricultural residues, fast growing tree, low-grade wood species and non-woody materials were used significantly as materials for production of wood-based composites by many researches around the world *i.e.*, sugarcane bagasse [4,5], arhar stalks [6], date palm midrib [7], flax [8], shell of babaçu [9], vegetable fibers [10], vine stalks [11], wheat straw [12], and rice husk ash [13].

In developing countries most of these residues are mostly ploughed into the soil or burnt in the field [14], however, in developed countries these residues are used to produce wood composites [15,16]. Open burning of these wastes has contributed to the degradation of the surrounding environment and the use of wood wastes in the production of wood-based materials has been considered environmentally sustainable, economically viable and socially acceptable [17].

Recently, attempts have been made to reduce the use of wood in particleboards by introducing other materials, which are available in the form of tree pruning wastes [1,18,19].

During the last two decades in Saudi Arabia, many multipurpose tree species, *i.e.*, *Acacia salicina*, *Conocarpus erectus*, *Ficus altissima*, *Pithecellobium dulce* and *Leucaena glauca* were imported and planted for biomass production as fast-growing tree species [20]. Subsequently, there are a huge quantities of biomass annually resulted from the seasonal pruning of woody tree species, through the regular agricultural practice of these plantations in the public garden and streets, which could be, form a suitable cheap secondary resource [1,21]. Unfortunately, no data were available in this field about the estimation of these quantities.

Wood reinforced cement composites (WRCCs) are wood or non-wood particles or fibers used as reinforcement materials and an inorganic binder such as ordinary Portland cement bonds them

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together. These panels can be molded to a specific shape or constructed in the form of compressed blocks and panels, and they can contain approximately 30–70% wood by weight in various forms [22]. WRCCs have excellent sound insulation and are highly resistant to water and termites and excellent for outdoor use, which has led to wide potential applications for replacing traditional building materials and conventional wood composites as roofing and wall materials, flooring parts, and noise insulation [23]. Portland cement is the most important binder for this industry because of its high quality and global availability.

To avoid hitch-production in a large scale, WRCCs are generally composed of wood species that have been tested for suitability [24]. Thus, wood species from different countries have been screened, tested and classified according to their suitability for WRCC production using various methods and techniques [25–27].

The compatibility of wood with Portland cement can be determined by testing its exothermic behavior during the hydration process [26] or measuring strength properties of the wood-cement mixtures [28]. However, hydration characteristics have been commonly used to assess the compatibility between cement and potential wood species. The suitability of these species has been classified according to the extent to which they retarded cement hydration at a maximum temperature (T_{max}), compatibility factor (C_A) and inhibitory index (I) according to [28–30]. A number of researchers have conducted a series of tests to enhance the compatibility of wood and cement by using pretreatments [31,32] and chemical additives [23,30].

A number of processing factors affect the properties of WRCC composites, and the most important are the type of raw material, particle size of the wood, density of the board and ratio of wood to cement. Previous studies have revealed that not all wood species react favorably with cement because of adverse effects caused by certain extractives on cement setting [6,22,26,27,31]. In the composition industry, *i.e.*, particleboard including WRCCs, selecting the proper panel density is an important step that can be determined based on the intended application requirements. The wood particle size has a large effect on the properties of WRCC [19,26]. The effect of board density factor have been studied worldwide for many types of lignocellulosic materials [24,26,33,34], and stronger and heavier WRCC may be produced by increasing the board density. The wood/cement ratio (W/C ratio) is one of the most important manufacturing process variables and tends to have a predominating influence on the properties of the final WRCCs, including the mechanical properties and dimensional stability [6,34–36]. These factors significantly affect the properties of WRCC.

Several studies have been undertaken to test the suitability of some wood species and agricultural residues that are available for WRCCs manufacturing [7,11]. These studies determined the suitability of the woody materials using hydration tests as well as pretreatments and chemical additives to enhance the compatibility of the materials with cement. They concluded that with some pretreatment and specific chemical additives, most of the woody materials are suitable for WRCCs manufacturing. However, the properties of WRCCs manufactured from these woody materials at different manufacturing factors have not been determined.

As a part of a large project to manufacture high-quality WRCCs from some agricultural residues and tree prunings available in Saudi Arabia, Nasser et al. [19] studied the effect of wood particle size on the properties of WRCCs panels made from the tree pruning of six hardwoods. However, the effects of other some manufacturing factors on the properties of WRCCs panels have not been studied.

Accordingly and for managing the tree pruning wastes, the objective of the current study was to evaluate the properties of the WRCC panels made from the tree pruning wastes of six wood species under certain manufacturing factors, *i.e.*, wood species, board density and wood to cement ratio.

2. Materials and methods

2.1. Raw materials and preparation

Wood reinforced cement composites (WRCCs) were manufactured from six tree pruning wastes from Riyadh City collected in 2011 from the following wood species; *Acacia salicina, Conocarpus erectus, Ficus altissima*, *Leucaena glauca*, *Pithecellobium dulce* and *Tamarix aphylla*. The raw materials were characterized according to our previous study [19]. After collecting and air-drying the materials, they were cut into small pieces using a band saw and fed through a laboratory hammer mill using a 5-mm screen. The particles passed through a 0.8-mm sieve (20-mesh) and retained on a 0.4-mm sieve (40-mesh), were used for WRCC manufacturing, whereas the particles that were passed through a 0.4-mm sieve (40-mesh) and retained on a 0.27-mm sieve (60-mesh) were used for the chemical analysis. Before WRCC manufacturing, the particles (20/40 mesh) were pretreated by either cold-water soaking or hot-water extraction [31]. Type I Portland cement was used as a binder, which was manufactured by the Yamama Saudi Cement Company Limited, Riyadh, Saudi Arabia and meets ASTM specifications.

2.2. Chemical analysis of wood species

Based on oven-dried weight, the percent of total extractives presented in the six samples (−40/+60 mesh) were determined according to ASTM D-1037 [37]. The content of cellulose, hemicellulose, and lignin was determined using a free-extractives meal [37]. In addition, the ash content was determined according to NREL [38].

2.3. Water quantity for WRCCs manufacturing

The water quantity needed to produce the WRCCs was determined using the previously developed formula [39,40]. The water requirement in this formula is divided into two parts, one for wood and the other for cement. According to Simatupang [40], the water requirement of each gram of oven-dried wood is 0.30 ml to attain the fiber saturation point of wood (30%). However, we found that the optimum water was 0.55 ml per gram of wood, which was previously determined from a primary experiment carried out before WRCC manufacturing. The optimum water of each gram of cement to complete its hydration (0.28 ml g^{-1}) was determined by the hydration test and calculated by the uniform mixing index according to Hachmi et al. [28].

2.4. Hydration experiment

To assess the compatibility of the pruning wastes from six wood species with cement, a preliminary hydration experiment was conducted using a 2-L Dewar flask according to Hachmi et al. [28]. Twelve treatments including three pretreatments (untreated, cold and hot water) and four chemical additives (none, $CaCl_2$, $Al_2(SO_4)_3$ or $MgCl_2$) were used and tested. The hydration data were obtained, and inhibitory indices were calculated [31]. The wood materials were found to mitigate the temperature increase that occurs during the setting process of cement. According to the results of this experiment and methods presented in Table 1, the optimal treatment for each species was selected and used for WRCCs manufacturing.