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Using wood fiber waste, rice husk ash, and limestone powder waste as cement replacement materials for lightweight concrete blocks

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HIGHLIGHTS

- Effects of partial replacement of Portland cement by WFW, RHA, and LPW were studied.
- The interactions of variable parameters were highly significant on properties.
- The increase of RHA content induced the reduction of bulk density of the blocks.

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ABSTRACT

This work presents a parametric experimental study, which investigates the effects of partial replacement of Portland cement by wood fiber waste (WFW), rice husk ash (RHA), and limestone powder waste (LPW) for producing a lightweight concrete block as a building material. Some of the mechanical and physical properties of block materials having various levels of WFW, RHA, and LPW are studied. The compressive strength of the concrete blocks due to the filler effect decreased with increasing cement replacement. However, the results show the effect of 25 wt% replacement of RHA and LPW with Portland cement do not exhibit a sudden brittle fracture even beyond the failure loads, indicates high energy absorption capacity, reduce the unit weight dramatically. As expected, the increase of the RHA content induced the reduction of bulk density of the concrete blocks. Statistical analysis showed that the interactions of above-mentioned variable parameters were significant on both mechanical and physical properties at 5% confidence level. The optimum replacement level of WFW, LPW, and RHA was 25% by weight; this replacement percentage resulted in good physico-mechanical properties. Recycling of WSW, RHA, and LPW as promising raw material supplements appears to be viable solution not only to the environmental problem but also to the problem of the economic design of buildings.

1. Introduction

In the coming years, the construction industry has the challenge of incorporating sustainability in their production processes, either by searching for new raw materials and products more environmentally friendly and/or contributing for the reduction of CO_2 into the atmosphere. The possibility of incorporating waste from other industrial activities in their production processes can help with this goal [1]. Currently, cellulosic fiber reinforced cementitious materials are the most widely used for exterior products such as siding and roofing materials, for residential construction. Previously, this class of construction composites contained asbestos fibers. Asbestos fibers were used due to their high strength-to-weight ratio. However, due to the carcinogenic nature of asbestos, alternative fibers were sought and cellulosic fibers were determined to be a viable alternative [2]. However, the application of wood fiber is not without its own drawback concerns. The two main disadvantages of using wood fibers in cement are the high moisture absorption of the fibers and the low compatibility between fibers and cement [3]. Wood fibers contain a wide range of carbohydrates such as hemicellulose and extractives which are known to inhibit normal setting and strength development properties of the cement matrix [4]. The recycling of various types of wood pulp fibers for the production of fiber cement has shown a significant effect on the mechanical properties and absorption. Yadollahi et al. [5] found that relatively denser, stronger, and stiffer composites were obtained from the boards made with 40% pulp and paper sludge.

To use alternative binders by the inclusion of pozzolanic additions are necessary to reduce the alkalinity of the matrix and the content of calcium hydroxide (portlandite), avoiding the long-term degradation in non-conventional fiber cement material employing

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cellulosic fibers as reinforcement. The ash production is generated by the burning process of rice husk as sources of energy and cogeneration for power. If adequately processed, the ash becomes a pozzolan predominantly amorphous, which is soluble in an alkaline medium and reacts in an aqueous solution with Ca^{2+} and OH^- ions [6]. The final result of the reaction is the calcium silicate hydrate, the main product of hydration of the ordinary Portland cement. The rice husk ash (RHA) is a pozzolanic material and can be used as a supplementary cementitious material to replace Portland cement by up to 30% [7]. The benefits of RHA utilization in cement are twofold. First is the economic gain obtained by replacing a substantial part of the Portland cement by cheaper natural pozzolan. A second advantage is the durability improvement of the end product [8].

Currently, the blocks of limestone are extracted via chain saw, diamond wire and diamond saws from quarries and then the blocks are cut into smaller suitable sizes to be used as building material. The processing limestone that includes crashed limestone production is results in approximately 20% limestone powder waste (LPW) [9]. Disposal of LPW causes dust, environmental problem and pollution because of its fine nature. It contaminates the air with the storms in the summer and spring seasons and therefore causes serious health hazards including specifically asthma. The industry suffers to store LPW due to the costs of storage [10]. On the other side, the effect of limestone powder on ordinary Portland cement (OPC) is twofold. Fine limestone powder exerts a physical filler effect on the cement hydration. Replacing part of the OPC with limestone will increase the effective water to OPC ratio, and provide additional surface for precipitation of hydration products, thereby promoting the early age hydration of the OPC. Besides the filler effect, there is also a chemical effect: the calcium carbonate of the limestone powder can interact with the aluminate hydrates formed by OPC hydration [3].

The present study evaluated the use of cementitious matrix modified by partial replacement of the ordinary Portland cement by wood fiber waste (WFW), rice husk ash (RHA), and limestone powder waste (LPW) for the production of lightweight concrete blocks as a building material. The effects of above-mentioned waste materials on the compressive strength, water absorption, bulk density before and after soaking were investigated. These wastes utilized in this research are widely available in large amounts from the forest and limestone industries. Therefore, the acceptable solution of this problem with a commercial value is crucial.

2. Materials and methods

2.1. Materials

The fibrous raw material used in this study was fibers derived from fiberboard. The chemical and morphological characteristics of the WFW were as follows: cellulose 50.3 ± 1.8%, lignin 24.3 ± 1.6%, hemicellulose 19.1 ± 1.9%, ash 3.3 ± 0.7%, fiber length 0.8 ± 0.14 mm, and fiber width 23.5 ± 2.2 μm.

The ground rice husk was burned in suspension at a temperature of 700 °C in complete combustion. The well-mixed white RHA was subsequently sieved to remove the large particles and any incompletely combusted materials, and only particles passing through 150 μm-sieve were used.

LPW used in the block samples was produced during quarrying operations in the region. The binding agent employed was commercial grade of ASTM type II ordinary Portland cement (OPC), a product of Khazar Cement Co., Iran. The results of chemical and physical analysis of LPW and cement are given in Table 1. Graded river sand (GRS) with fineness modulus of 2.5 and adsorption of 0.7% conforming to ASTM C33 [11] was used as fine aggregate.

Calcium chloride ($CaCl_2$) was used as cement setting accelerator. It was an analytical grade from Merck Co., Germany. The properties of the tap water used in this study were of pH 6.4, 5.3 mg/L sulfate content and have a hardness of 3.5.

2.2. Mixing and fabrication of blocks

Fig. 1 shows the experimental work steps and mixture proportions of the raw materials are summarized in Table 2. Six different types of mixtures were prepared in the laboratory trials. The water proportion in the mixes was taken as constant to determine the effect of various variable parameters. The replacement ratios between WFW, RHA, and LPW were taken by the percentage weight in the mix design. All block specimens were made with 1.00:0.55 weight ratio for cement-to-water. The $CaCl_2$ was used at constant dosage of 5 wt% as accelerator for hydration process. For comparison purposes, control samples with no ash added were used.

Table 1
Chemical and physical analysis of LPW and OPC.

Properties	(Percentage by weight)	
	LPW	OPC
SiO_2 (%)	0.32	25.00
CaO (%)	61.22	67.02
MgO (%)	0.13	1.21
Al_2O_3 (%)	0.29	2.85
Fe_2O_3 (%)	0.26	0.51
SO_3 (%)	0	3.74
Cl (%)	0	0.01
Density (g/cm^3)	2.48	3.25
Surface area (m^2/kg)	138	260

In the mixing process, raw materials using the mixture proportions given in Table 2 were placed in a concrete mixer and mixed for 3 min, and then the dilute aqueous solution of $CaCl_2$ and water were added. In order to obtain more homogeneous mixes, the paste was mixed for another 2 min. Consequently, the blended mortars were immediately fed into the steel moulds ($150 \times 150 \times 150$ mm^3). The cast moulds were vibrated for 1 min to achieve adequate compaction. Afterward, the cast specimens were covered with plastic to prevent water loss. The resulting assemblage was pressed to reduce its height while the mat for the next board was mixed. After 24 h, the blocks were declamped, and conditioned for 28 days at 25 ± 1 °C and 65 ± 5% RH to allow the cement to cure and gain strength (Fig. 2).

2.3. Tests methods

The series of tests were carried out according to ASTM C67 [12] to determine the compressive strength, water absorption, and bulk density of the block samples.

2.3.1. Compressive strength

The composite specimens were prepared in accordance with ASTM C109 [13]. Each compressive strength value reported is the average of three samples. The dry compression strength was determined using an Instron Universal Testing Machine (Model 4486), with a loading speed of 10 mm/min.

2.3.2. Water absorption

Water absorption was carried out using ASTM C642 [14]. The cube specimens for water absorption were completely submerged horizontally under distilled water maintained at 25 °C for 24 h. After soaking, the samples were drained on paper towels for 10 min to remove excess water. The water absorption was calculated from the increase in weight of the specimen during submersion. At least four specimens of every treatment were tested to obtain a reliable average and standard deviations.

2.3.3. Bulk density

Specimens were tested following ASTM C29 [15] for bulk density. The densities of the composites were determined by measuring the mass and volume of each sample. The air-dried samples were oven-dried up to 103 ± 2 °C until they reached constant weights. Then, the samples were cooled in a desiccator containing calcium chloride and weighed in an analytic balance with ±0.01 g sensitivity. The mass of each sample was obtained by calculating the arithmetic mean of the mass of all of the test samples taken from the same panel. Afterward, the dimensions of the specimens were measured using a digital caliper with ±0.001 mm sensitivity and the volumes were determined by the stereo metric method. The density (D) was then calculated using the following equation:

$$D = \frac{M_0}{V_0} \tag{1}$$

where M_0 is the oven dry weight (g) and V_0 is the dry volume (cm^3) of the sample.

2.3.4. Data analysis

Measured data on mechanical and physical properties of the composites were analyzed with analysis of variance (ANOVA) procedure using SAS software (Version 9.1; Statistical Analysis System Institute Inc., Cary, NC, USA). Duncan's Multiple Range tests were used to compare the difference among the mean values for the groups' properties at the level of 0.05.