

ДРЕВЕСНОВОЛОКНИСТЫЕ УКРЕПЛЕННЫЕ ЦЕМЕНТОМ ПЛИТЫ НА ОСНОВЕ РИСОВЫХ СТЕБЛЕЙ И ЗОЛЫ РИСОВОЙ ШЕЛУХИ

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В статье рассмотрена возможность создания древесных композитов, а именно древесноволокнистых плит с укреплением цементом при трех дозировках вяжущего 10, 25 и 40 % по весу. Зола рисовой шелухи добавлялась как альтернатива цементу в дозировке 0, 10 и 20 % по весу. В общей сложности было проведено 9 испытаний по три доски в каждом, при этом доски соответствовали стандарту (DIN / EN 634 part1, 2) по размеру и физико-механическим свойствам, таким как сопротивление изгибу. Различное соотношение массы волокон с массой цемента влекло за собой различные физико-механические свойства досок, лучшие результаты получены при соотношении цемент-волокна как 25 к 75 %. 20 %-ные добавки золы рисовой шелухи, хотя и приводят к некоторому снижению прочности ДВП, тем не менее, могут быть рекомендованы для использования.

Ключевые слова: древесноволокнистая плита, зола рисовой шелухи, сопротивление изгибу, внутренние связи

1. Introduction

Wood fiber is a unique reinforcing material that offers numerous advantages. Wood fiber-cement composites occupy a special place in this development of fiber reinforced cement, because of non-hazardous, high filling levels possible, low energy consumption, and wide variety of fibers available throughout the world (Yadollahi et al., 2013). On the other side, faced with an increasing worldwide shortage of wood resources, there has been a strong trend to produce fiber-cement products using industrial wastes, non-wood plant materials and agro-waste fibers (Ashori et al., 2012). Many previous researches have obtained valuable results to use the industrial wastes in various forms of concrete production (Turgut et al., 2007). For instance, the use of waste rubber, glass powder and paper waste sludge in concrete mix has received remarkable attention over the past years.

Among the possible alternatives, the development of composites using agro-waste fibers is currently at the center of attention (Ashori et al., 2011; Jarabo et al., 2012; Torkaman et al., 2014). Millions of tons of crop waste materials are produced from agricultural and industrial processes every year. Features of these

agro-waste resources such as high tenacity, low bulk density and high transportation costs make them difficult to use them as filler or pozzolanic materials, with the exception of rice waste (Jarabo et al., 2012). The global annual production of rice paddies is about 700 million tons. Thus, about 140 million tons of rice husk are disposed as waste (Van et al., 2014). This waste is dumped or burned in the outdoor causing soil, water and air pollution issues in rice producing countries like Iran (Torkaman et al., 2014). Rice husk is an agricultural residue obtained from the outer covering of rice grains during milling process. The main chemical composition of rice husk is silicon dioxide (SiO_2), and the highest amount of amorphous silica is achieved when rice husk ash is burned between 500 and 700 °C (Nair et al., 2008). The rice husk ash (RHA) which is produced by burning of rice husk has a high content of amorphous silica (Wansom et al., 2009).

Many research studies have been conducted to investigate the effect of the rice stalk fiber (RSF) and RHA on the properties of cement mortar. There is, however, a remarkable lack of knowledge on the use of RSF and RHA admixtures in the reinforced fiber-cement. With the purpose of contributing to building up this knowledge, the work described in this

Mixture proportions of blended materials
Пропорции смеси из смешанных материалов

Treatment		MHF (wt %)	RHA (wt %)	Cement (wt %)	Treatment		MHF (wt %)	RHA (wt %)	Cement (wt %)
Group	Code				Group	Code			
A	1	10	0	90	B	1	10	0	90
A	2	10	10	80	B	2	10	10	80
A	3	10	20	70	B	3	10	20	70
A	4	25	0	75	B	4	25	0	75
A	5	25	10	65	B	5	25	10	65
A	6	25	20	55	B	6	25	20	55
A	7	40	0	60	B	7	40	0	60
A	8	40	10	50	B	8	40	10	50
A	9	40	20	40	B	9	40	20	40

paper was aimed to study how the variations in RSF (as reinforcement) and RHA (as cement replacement) admixtures can influence on some selected mechanical and physical properties of the blended fiber-cement composites. Moreover, the results were compared with the addition of mixture of hardwood fibers (MHF) as a conventional fibrous material.

2. Materials and methods

2.1. Materials

RSF and MHF used in this investigation were generated from the chemical and mechanical pulping processes, respectively. Both fibrous materials were obtained from the northern part of Iran.

The ground rice husk was burned in suspension at a temperature of 700 °C for 2 h 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.

The binding agent employed was commercial grade of ASTM type I Portland cement, a product of Hegmatan Cement Co. Iran.

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 6.3, 5.5 mg/L sulfate content and have a hardness of 3.7.

2.2. Mixing and fabrication of samples

In this work, two groups of mix designs, namely A and B, were made. Each group had 9 various treatments containing RSF and MHF with three levels of fibrous material and RHA. Formulation of the mixes and abbreviation used for the respective mixes prepared are given in Table. As it can be seen, 18 different types of mixtures were prepared in the laboratory trials. All specimens were made with 1.00:0.50 weight ratio for cement-to-water. Other parameters such as CaCl_2 content (0.5 wt %), press time (10 min), press pressure (80 kg/cm²), thickness (16 mm), and target density (1.2 g/cm³) were held constant. For each treatment (formulation), three boards were fabricated.

In the mixing process, raw materials using the mixture proportions given in Table were placed in a mixer and blended for 5 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 5 min. Consequently, the blended mortars were immediately fed into the steel moulds (420×270 mm²). The mixture was evenly distributed and flattened by hand. Afterward, the resulting assemblage was cold-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.

2.3. Mechanical and physical characterization

The series of tests were carried out according to DIN/EN 634 to determine the mechanical and physical properties of the samples.

2.3.1. Mechanical properties

Conditioned boards were sawn into test samples for modulus of rupture (MOR) modulus of elasticity (MOE) according to DIN/EN 610 and internal bonding (IB) strength using DIN/EN 319. 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.

2.3.2. Physical properties

Physical properties in terms of water absorption (WA) and thickness swelling (TS) were evaluated using DIN/EN 317. The specimens for WA and TS ($50 \times 50 \text{ mm}^2$) 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.

3. Results and discussion

3.1. Mechanical properties

The average values of the mechanical properties in terms of MOR, MOE and IB are presented in Fig. 1. Mechanical properties generally improved with increase in fibrous material and increased with addition of RHA. The bending strength of the fiber-cement specimens enhanced with an increase in the fiber content and the maximum values were obtained at fiber loading of 25 % by weight. However, a further increase in RSF or MHF content showed a reduction in the mechanical properties (Fig 1a). The decrease in strength at higher fiber content may be due to the inefficient utilization of particles attributed to the formation

of ‘clumps’ and increase in the porosity of the composite. It also results in the reduction in fiber-matrix interfacial area and hence lower strength properties than the expected. In addition, samples made with MHF exhibited inferior mechanical properties compared to the RSF. For example, the maximum values of the MOR and MOE for MHF were 8.1 MPa and 3.3 GPa, respectively, while the values for RSF (A_4 sample) were 8.6 MPa and 3.6 GPa, respectively. This is probably due to the chemical and morphological properties of used fibrous materials. In addition, pulping process can influence on the mechanical properties of fibers.

Both MOR and MOE properties of the boards were improved when RHA was increased from 0 % to 10 %. This may be due to the fact that the compatibility of the RHA with cement was improved considerably. The strength properties of the boards were found to be a maximum when fibrous material and RHA was 25 wt % and 10 wt %, respectively.

Based on the results, IB values ranged from 0.33 to 1.95 MPa. The values of IB were well above the requirements set forth by ISO standard (0.45 MPa). Like MOR and MOE, boards made with RSF showed higher IB than those made from MHF (Fig. 1b). The possible reason for this kind of behavior may be the high compatibility of RSF furnish which caused better bonding. The IB strength of the boards was found to be a maximum when fiber content was 25 wt %. At this concentration, probably maximum reinforcing effect can be achieved with optimum volume of cement matrix. Further addition of fibrous material increases volume of particles and reduces volume of matrix causing lower bond strength. Also, as the fiber content in the mix is increased, a greater number of fiber-to-fiber bonds are formed. The increase in fiber-to-fiber bonds reduces the interfacial area of contact between the fiber and the cement matrix, and hence diminishes the potential of a given wood to be able to bond with the matrix. Aggarwal et al. (2008) reported that the failure of the boards is due to failure of fiber-to-fiber bond or fiber-to-matrix bond. At lower percentage of wood, it is predominantly fiber-to-fiber bond failure

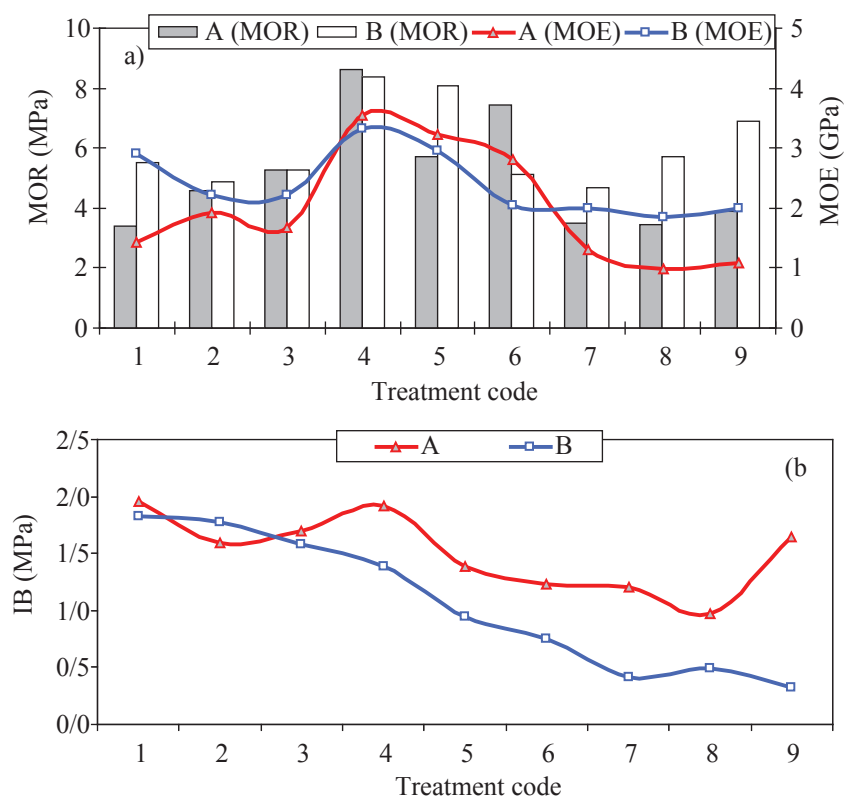


Fig. 1. Effect of fiber types and RHA contents on MOR, MOE (a) and IB (b)
Рис. 1. Влияние типа волокон и содержание RHA по MOE, MOE (a) и IB (б)

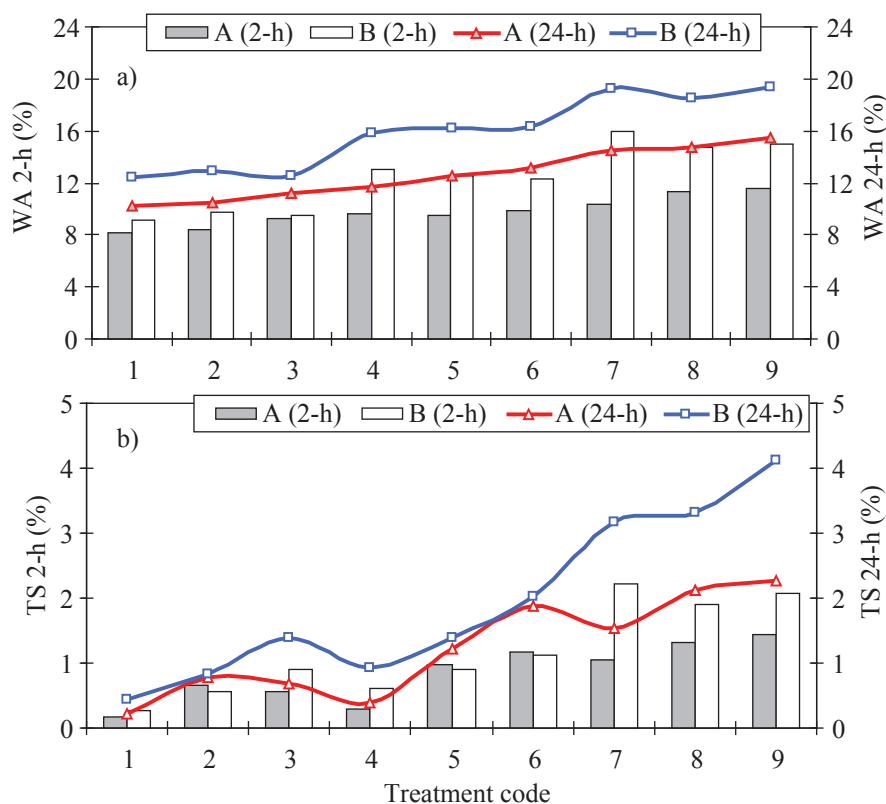


Fig. 2. Effect of fiber types and RHA contents on water absorption (a) and thickness swelling (b)
Рис. 2. Влияние типа волокон и содержание RHA на водопоглощение (a) и Разбухание по толщине (б)

and at higher percentage it is due to fiber to matrix bond failure, i.e., fibers pull out from the matrix.

3.2. *Physical properties*

One of the most important properties to be evaluated for fiber-cement composites is water absorption, since it can affect on the mechanical properties and also dimensional stability. The effect on the WA of the samples at different weight percentages of fibrous materials in the composites are shown in Fig 2a. Results indicate that as the amount of fibrous material (RSF and MHF) increases, the water absorption of the samples increases moderately. A₁ and B₁ showed the lowest values of water absorption among the studied boards. As Fig. 2a present, a significant difference in water absorption was observed for the 9 types of samples after 2– and 24-h of immersion. Based on the results, water absorption values varied from 8.2 to 14.9 % for 2-h and from 10.2 to 19.6 % for 24-h. In case of constant fibrous material in all blends, the different water absorptions among all manufactured samples can be attributed to the role of RSF and MHF. In addition, the rate of water uptake significantly correlated with the percentage weight of fibrous material; lower loadings in samples exhibited lower rate of absorption. Weight gain upon exposure to water increased as the percentage of MHF increased for all boards tested. This could be possible due to the hydrogen bonding of the water molecules to the free hydroxyl groups present in the cellulosic cell wall of fibrous materials and the diffusion of water molecules into the fiber-cement interface. From chemical view, this result could be explained by the highly different chemical composition of MHF compared to RSF. Because MHF contains higher hydrophobic content (lignin and extractives) and lower hydrophilic content (cellulose and hemicelluloses), it would be expected to show lower water uptake compared to RSF. The other possible reason could be attributed to low bulk density of fibrous materials which cause more void space in the composite (Tabarsa and Ashori, 2011).

After addition of 20 wt % RHA to A9 composite, an increase ratio of 11.5 % and 7 %

in water absorption after 2– and 24-h of water soaking, respectively, was observed. In addition, it was observed that RHA filled composites generally absorbed slightly more water at 2– and 24-h, respectively.

The TS is an important property that represents the stability performance of the composite. The TS of the samples increases with the WA and thus has similar trend to the WA regarding the impacts of fiber to cement ratio. As expected, the TS increased sharply with increasing fibrous material loadings in the composites – a trend that is true for intervals of 2– and 24-h (Fig 2b). In other words, a further increase in fiber content showed a reduction in the dimensional stability of samples. Moreover, boards made with MHF exhibited inferior dimensional stability compared to the RSF. For example, the maximum values of TS were 2.2 % and 4.1 % for 2– and 24-h, respectively, while the values for RSF were 1.4 % and 2.2 %, respectively. As mentioned earlier this is probably due to several reasons in terms of chemical compositions and fiber morphology.

4. **Conclusions**

In recent years, an increasing high interest has been drawn to the potential use of agricultural waste as raw material to produce structural reinforcement fibers for building materials, due to environmental and economical aspects. Rice is one the most produced cereal in terms of quantity in world, what entails the generation of large quantities of waste. Despite this fact, only a few research works concerned with the use of RSF and RHA admixture in the production of fiber-cement composites have been published and there is a complete lack of data on the characterization of these composites.

The main objective of this work was to study the feasibility of using fibers obtained from rice stalk as reinforcement and RHA as Pozzolan material in the production of fiber-cement composites. The effects of these fibers on the mechanical and physical properties of the final product were investigated. The strength properties of the boards were found to be a maximum when fibrous material was 25 wt %. The WA and TS values of specimens increased

with an increase in the fibrous content and the maximum values were obtained at treatment of B₉. By addition of RHA, WA and TS of the samples slightly increased, confirming that free water available in the paste matrix remains the primary source of open pores. In general, the results confirmed the high potential of the RSF as a source of fibers for the manufacture of a fiber-cement capable of meeting the requirements of demanding applications.

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FIBER REINFORCED CEMENT BOARDS MADE FROM RICE STALK FIBER AND RICE HUSK ASH

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This work presents a parametric experimental study which investigates the potential use of rice stalk fiber (RSF) as reinforcement and rice husk ash (RHA) as cement replacement for producing a lightweight fiber-cement composite. Three levels of fibrous materials, namely 10, 25 and 40 wt % were mixed with 0, 10 and 20 wt % of RHA. The effects of above-mentioned variable parameters on the mechanical properties of the samples, i.e., modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond (IB), and the physical properties of those, i.e., water absorption (WA) and thickness swelling (TS), were studied. The results showed that the effect of high level replacement of RSF with RHA does not exhibit a sudden brittle fracture even beyond the failure loads which indicates high energy absorption capacity. Based on the findings in this work, the WA and TS of the composites increased with increasing amount of the RSF content in the samples from 10 wt% to 40 wt %. On the other hand, MOR and MOE of the boards were enhanced with the increased percentage of RSF. Boards having 25 wt % RSF showed the highest internal bond (IB) strength. However, the addition of RSF and RHA reduced the IB strength. Moreover, boards made with RSF had superior properties compared to the mixture of hardwood fibers.

Keywords: Fiber-cement composite; Mechanical properties; Rice stalk fiber; Rice husk ash.