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Effect of rice husk ash and macro-synthetic fibre on the properties of self-compacting concrete

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HIGHLIGHTS

- RSM can provide statistically reliable results for the prediction of SCC designed mixtures.
- RHA had a nonlinear effect on slump flow more intensively in higher percentages.
- Incorporating RHA could reduce fibre defection in segregation and bleeding.
- There is a synergic effect between RHA and fibre on bridging macro-cracks in bending test.

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ABSTRACT

This study aimed to investigate the effects of rice husk ash (RHA) and macro-synthetic fibre on the consistency and mechanical properties of self-compacting concrete (SCC). Response surface methodology (RSM) was employed to study the effects of RHA (0–8%) and fibre (0–0.3%) on the consistency, compressive and flexural strength, and fracture energy of SCC. The results indicated that the presence of RHA in the SCC mix had a desirable influence on flowability and plastic viscosity and significantly reduced bleeding. Incorporating RHA also increased the compressive strength even in the early ages for some mixes. On the contrary, fibre caused bleeding and segregation and led to blockage, especially in higher percentages. According to the results, fibre caused fewer problems as the viscosity of paste increased. Furthermore, fibre reduced the compressive strength of mixes at 28 days and did not affect it in the long term at 90 days. Based on three-point bending test results on notched beam, fibre and RHA affect the flexural strength linearly and quadratically, respectively. In post-cracking extension, using fibres with 4% RHA exhibited a synergic effect on the more conceivably resistance against macro-cracks.

1. Introduction

Self-compacting concrete (SCC) can be placed and compacted under its own weight without any vibration using superplasticizers (SPs) and other additives. The most important requirements of SCC are high flowability, good passing ability and high resistance to segregation. Therefore, SCC eliminates vibration problems and makes use of a higher density of rebar in structural configurations with congested reinforcement where vibration is difficult to meet [1–3].

One of the main shortcomings of self-compacting concrete is its high cost of production due to the use of chemical additives, such as SPs, viscosity modifiers, and a high cement content. Since high cement content results in higher amounts of the hydration heat and shrinkage problems, supplementary cementitious materials (SCM) such as fly ash, silica fume, and limestone powder can be considered as partial cement replacement [4,5]. However, the high cost and limited available resources restrain their application in modern construction industry, especially in developing countries. These reasons motivate the investigation of other substitution materials with similar functions [6].

The world-wide production of rice in 2015 was about 742 million tons, which led to the production of approximately 148 million tons of rice husk [7]. Since rice husk is not an ideal feed for livestock and has no other application, efforts have been made to burn the husks at controlled temperature and atmosphere and use the produced ash so produced as a construction material. The characteristics of the produced ash varies according to burning conditions, the temperature of the geographic location and the final product fineness [8–11]. Nevertheless, the complete incineration of rice husk at temperatures lower than 800 °C produces ash which contains 90–96% silica in the amorphous form. When incorporated

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in cement, rice husk ash (RHA) can improve viscosity and segregation resistance and help achieve a greener and more economical SCC [6,12].

Previous studies [8,13–16] on effect of RHA on the fresh properties of SCC have demonstrated that the incorporation of RHA decreases the slump flow and increases slump flow time, yield stress, and plastic viscosity, primarily due to the higher reactivity and high surface area of RHA. Interestingly, when untreated RHA was incorporated as fine aggregate replacement (0–100%) in SCC, slump flow was decreased at higher than 60% of RHA usage. The higher slump flow at higher RHA percentages was due to the increased surface area of RHA which led to increased viscosity [17]. Besides, the compressive strength, splitting tensile strength and flexural strength of SCC increase with an increase in RHA content up to 15% due to its micro-filling and pozzolanic effects, which improve the microstructure and interfacial transition zone (ITZ) between the aggregate and the cement paste of SCC [8,18].

On the other hand, hardened SCC is still as brittle as conventional concrete and has a disadvantageous effect on the resistance to crack propagation. In order to improve the post-peak parameters of SCC, fibre-reinforced self-compacted concrete (SF-SCC) can be used which results in significant increases in compressive, tensile, and flexural strength and fracture energy [19,20].

2. Objectives

There are numerous studies on the mechanical properties of fibre-reinforced and incorporating RHA in SCC. Nevertheless, our understanding of what exactly constitutes of both fibre and RHA capable of producing maximum mechanical performance in SCC with respect to consistency remains quite limited. Accordingly, this research was conducted to study the effects of both RHA and fibre on the consistency, mechanical properties such as compressive and flexural strength, and post-cracking behavior of SSC using the response surface methodology to achieve the following goals:

- Studying the effects of macro-synthetic fibre, RHA and their interaction on the consistency of SCC.
- Presenting an SCC compressive strength prediction model at 28 and 90 days to evaluate the effects of these parameters, and find their interactions.
- Studying the performance of fibre in bending using the notched three-point bending test, investigating its effects on pre-cracking concrete behavior by finding the flexural strength, and comparing the post-cracking behavior of the fibre-reinforced SCC in the presence of different RHA contents through calculating the fracture energy.

3. Experimental design

3.1. Material

3.1.1. Aggregate

The physical properties of aggregates are listed in Table 1. The particle size distribution of aggregates with the nominal maximum aggregate size of 12.5 mm was used, in accordance with Iranian National method for concrete mix design, Fig. 1 [21].

Table 1
Aggregate properties.

Property	Value	Standard
Bulk specific gravity (g/cm^3)	2.59	ASTM C127
Absorption fine aggregate (%)	2.4	ASTM C127
Absorption coarse aggregate (%)	1.2	ASTM C127
Los Angeles abrasion loss (%)	11.3	ASTM C131
Two fractured faces (%)	93	ASTM D5821
Soundness	1.7	ASTM C88
Sand equivalent	70	ASTM D2419

3.1.2. Cement

Portland type I cement was used (ASTM C 150). The chemical and physical composition of this cement, as well as its mechanical properties are tabulated in Table 2.

3.1.3. RHA

Rice husk from Gilan fields was burned and decarbonized in an annealing furnace for 1 h at 660–750 °C, and then rapidly cooled with 5 °C water. The main problem regarding RHA ash production is melted particles which allow for the crystallization course and prevent the decarburization process [22]. Allowing RHA to burn in unblended conditions provides a situation for bottom layers of RHA to reach higher temperature and melt. Therefore, to ensure the non-melting mode, the rice husk was constantly stirred. Consequently, RHA was grinded by a grinding machine for 12 min and 69% of it passed through a 45-μm mesh.

The results of the XRF test are shown in Table 3. The comparison of Tables 2 and 3 reveal that the amounts of SiO2 and CaO were completely different from each other in RHA and cement: SiO2 contents were 91.94% and 19.98%, while CaO contents were 1.05% and 64.73% for RHA and cement, respectively. Moreover, the total amount of SiO_2, Al_2O_3, and Fe_2O (92.49%) demonstrate that RHA was a pozzolanic material in accordance with ASTMC618.

The low loss of ignition (LOI = 2.65) in RHA is a sign of the effective decarbonization of RHA. The percentage of de-carbonation has a direct effect on the specific surface of RHA, and its decrease leads to an increase in the surface area and pozzolanic effect of RHA [23]. X-ray diffraction pattern of RHA is shown in Fig. 2. The broad peak could be associated to amorphous silica. Therefore, it can be concluded that a significant portion of the silica contained in this material was in the amorphous phase.

The scanning electron microscopic (SEM) images of rice husk and RHA are illustrated in Fig. 3. Based on Fig. 3a, the shell surface of rice was uniform and has many outcrops and the transverse section of the rice husk is laminated (Fig. 3b). Between these sheets, there was a very porous layer of sugar and cellulose. Fig. 3c and d exhibit that RHA was composed of the particles less than 100 nm after grinding.

3.1.4. Superplasticizer

A superplasticizer of poly carboxylic acid (ASTM C494) with 1.05 g/cm^3 of specific gravity (at 20 °C) was employed to improve workability.

3.1.5. Fibre

The macro-synthetic fibre was utilized in this study. The geometric and mechanical properties of the macro-synthetic fibres are shown in Table 4 and Fig. 4.

3.2. Mix proportion

The absolute volume method was employed to calculate the component materials of SCC mixtures. All mixtures were designed with a constant water to cementitious ratio of 0.40, a constant paste volume of 380 L/m^3 (including air content of 2 vol%), constant coarse aggregate content of 629 (kg/m^3) and fine aggregate 950 (kg/m^3). The superplasticizer content was set on its saturation dosage. In mixing, sand and gravel, along with one-third of water were mixed, then the powdered and cementitious materials were added to the mixer. Finally the remaining water and superplasticizer were poured into the mixer. In order to achieve a uniform distribution, blending process was maintained at least for 3 min.

3.3. Response surface methodology

Response surface methodology (RSM) is a collection of mathematical and statistical techniques in order to find a logical approximation of the response function which is influenced by independent variables. This method is employed to fit an empirical relation between independent variables and the response of interest and optimize the results [24,25].

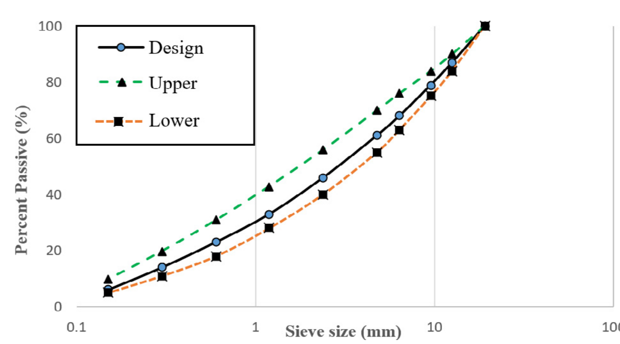

Fig. 1. Particle size distribution of the aggregate of SCC.