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Mechanical performance of self-compacting concrete incorporating rice husk ash

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HIGHLIGHTS

- Rice husk ash (RHA) is used as cement replacement material.
- The effect of RHA on mechanical properties of self-compacting concrete (SCC) was investigated.
- Cement replacement by 5–10% RHA enhance the mechanical properties of SCC.
- Workability of SCC decreases considerably by adding RHA.

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ABSTRACT

Self-compacting concrete (SCC) is a highly-workable concrete that fills the formwork under its own weight without needing vibration. The application of byproducts or waste materials as cement substitutes in SCC can enhance its mechanical performance. Rice husk ash (RHA) is one of the highly reactive byproducts. The pozzolanic performance of RHA due to high silica content makes it a suitable supplementary cementitious material for being used in SCC.

In this paper, mechanical behavior of SCC was studied by 240 hardened concrete specimens with different variables i.e. partial replacement of cement with RHA (0%, 5%, 10%, 15% and 20%), concrete aged (3, 7, 28, 90, 180, and 270 days), and water to binder ratio (0.38, 0.44, 0.50, 0.56, 0.62, and 0.68). Fresh concrete properties were measured by V-funnel flow time, L-box, and slump flow diameter and time tests. Mechanical properties were determined in terms of compressive strength, modulus of elasticity, splitting tensile strength, and compressive stress-strain relationship tests. The test results showed that the workability of SCC containing RHA is decreased by increasing the RHA replacement ratio. On the contrary, compressive strength, modulus of elasticity, and splitting tensile strength increase with increasing the percentage of RHA up to 5% replacement.

1. Introduction

In the concrete industry, self-compacting concrete (SCC) has been recognized as one of the significant prosperities. SCC can simply be poured into the molds and go through obstacles by its own heaviness and without any vibration [1]. Strength and durability of SCC can be enhanced by incorporating supplementary cementitious materials (SCMs). SCMs are natural materials or industrial byproducts that display cementitious behaviors when accompanied by Portland cement and water. In addition, SCMs make concrete mixtures more economical, improve its strength, and reduce concrete's permeability [2]. Typical examples of SCMs are ground granulated blast furnace slag, silica fume, fly ash, and rice husk ash (RHA). RHA is a highly reactive pozzolanic material achieved by burning rice husks in a controlled manner at temperatures lower than 700 °C [3]. Since this product has high amorphous silica content, it can be utilized as SCMs. There have been a number of studies on the effects of using RHA as cement replacement material on the fresh and hardened properties of SCC.

The compressive strength of SSC specimens containing 10% and 20% RHA at two water to binder ratios of 0.35 and 0.40 up to the age of 180 days and comparing to normal concrete were investigated by Ahmadi et al. [4]. At ages after 60 days, SCC specimens containing RHA show positive results in terms of mechanical properties. Memon et al. [5,6] investigated the fresh properties of SCC mixes made with RHA (5% and 10%), and superplasticizer content ranging from 3.5% to 4.5%. Slump flow diameters for all the mixtures except for mix with 3.5% superplasticizer and 10% RHA complied with EFNARC specification [7]. Sadrmomtazi and

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Barzegar [8] examined the effect of nanosilica on the fresh and hardened state properties of SCC containing RHA. All the mixtures were prepared with a constant binder content of 450 kg/m^3 and a constant water to binder ratio of 0.43. The inclusion of nanosilica in SCC enhances the physical and mechanical properties and intensifies undesirable effect of RHA on concrete shrinkage. Safiuddin et al. [9] concluded that the addition of RHA improved compressive strength up to 56 days owing to micro-filling ability and pozzolanic activity of RHA particles. Excellent compressive strength and reduced porosity was achieved in SCC containing 15% RHA with lower water to binder ratio. The flowing ability of the mortars formulated from various SCCs containing RHA was scrutinized by Safiuddin et al. [10]. The mortar flow ability decreased with the higher RHA content and water to binder ratio, but increased with increment of high-range water reducer dosage.

Atan and Awang [11] studied the mechanical and rheological properties of SCC incorporating raw RHA, limestone powder, pulverized fuel ash, and silica fume. Test results revealed that 30% and 45% cement replacements using raw RHA combined with limestone powder exhibited comparable compressive strength and improved flexural strength. Sua-iam and Makul [12] investigated SCC mixtures containing RHA from electric power plants. Cement was partially substituted by RHA at replacement levels of 0%, 10%, 20%, and 40%. The mixtures were adjusted to maintain slump flow diameters of 60 ± 2.5 or 50 ± 2.5 cm. Unit weight was decreased by increasing the RHA fraction. Juma et al. [13] showed that the addition of RHA (0%, 2.5%, and 5%) and sugar cane baggase ash (0%, 2.5%, and 5%) alone or in blended mixtures increased compressive strength up to 28 days. Test results displayed that the compressive strength increased around 40%. Safiuddin et al. [14] also measured the properties of freshly mixed SCC incorporating RHA. RHA was substituted at 0%, 5%, 10%, 15%, 20%, 25%, and 30% for cement. The fresh state properties of concrete were significantly influenced by RHA content.

Sua-iam and Makul [15] also evaluated the properties of mixtures being comprised of ternary blends of Type I Portland cement, untreated RHA, and pulverized fuel ash. SCC mixtures formulated using ternary blends exhibited significant improvements in physical properties compared to the mixtures containing only RHA or pulverized fuel ash. Khadiry et al. [16] highlighted the initial results of a research project aimed at producing SCC containing shell lime powder and RHA as an additional cementing material. Rahman et al. [17] investigated the fresh and hardened state properties of SCC mixes incorporating RHA (0%, 20%, 30%, and 40%) obtained from uncontrolled burning. The results revealed that SCC mixes incorporating this type of RHA has a significant potential for being used when normal strength SCC is desired. Rukzon and Chindaprasirt [18] determined compressive strength, porosity, chloride penetration, and corrosion of SCC incorporating ground RHA at dosages of 0%, 20%, 30%, and 40%. The compressive strength ranged between 25.5 and 27 MPa and in comparison to control mix, all the mixes exhibited reduced compressive strength values.

Le et al. [19] reported the effect of macro-mesoporous RHA and silica fume on fresh properties and flowability of mortar formulated from SCC. The incorporation of RHA or silica fume increased superplasticizer saturation dosage and its adsorption, plastic viscosity and yield stress of mortar and decreased mini-slump flow. The effects of replacing cement content with RHA in SCC on fresh, mechanical, and durability properties at 7, 28 and 56 days were studied by Chopra et al. [20]. SCC mixes were designed with 0%, 10%, 15%, and 20% RHA as cement replacement. Compressive strength was in the range between 36.7 and 41.2 MPa at 28 days and 39.6–46.4 MPa at 56 days with constant water to binder ratio of 0.41. Le and Ludwig [21] investigated the effects of mineral admixtures and superplasticizer on self-compactability and compressive strength of SCC and mortar incorporating fly ash and RHA. After 56 days, compressive strength of SCC containing 20% fly ash and 20% RHA was about 130 MPa. In recent years, as mentioned in above, there are many studies in the literature about the compressive as well as splitting tensile strength of RHA based SCC. However, investigations in respect of mechanical properties specially, compressive stress-strain relationship and modulus of elasticity of SCC incorporating RHA with various water to binder ratios and different ages were too rare.

The current research is aimed at comprehensive investigation of the effects of RHA on mechanical performance and fresh properties of SCC. To fulfill the goal, three variables which are cement partial replacement with RHA, concrete age, and water to binder ratio were considered. To determine the fresh properties of SCC, V-funnel flow time, L-box, and slump flow diameter and time tests were performed. In addition, to investigate the mechanical performance of SCC, 240 hardened concrete specimens were made and compressive strength, modulus of elasticity, splitting tensile strength, and compressive stress-strain relationship were measured. Moreover, in order to assess the effects of RHA application, cement was partially substituted by RHA at levels of 0%, 5%, 10%, 15%, and 20%. Besides, for evaluating the influence of aging on mechanical properties of SCC, six different ages of 3, 7, 28, 90, 180, and 270 days containing two different RHA dosage levels of 0% and 10% were studied. Additionally, to explore the effect of water to binder ratio on SCC properties, six water to binder ratios of 0.38, 0.44, 0.50, 0.56, 0.62, and 0.68 containing two different RHA dosage levels of 0% and 10% were taken into account.

2. Experimental plan

2.1. Materials

Aggregate is composed of fine, coarse, and filler parts. Fine aggregate is washed river sand with a fineness modulus of 2.66, specific gravity of 2.58, and water absorption of 1.7%. Coarse aggregate with maximum nominal size of 12.5 mm possessed water absorption and specific gravity of 1.1% and 2.67, respectively. The gradation curves for the fine and coarse aggregates, as achieved through sieve analysis according to ASTM C33 [22], are provided in Fig. 1. Additionally, for enhancing viscosity of SCC mixtures, ultra-fine limestone powder which had a specific gravity of 2.66 and was produced by Negin factory (Neka, Iran), was utilized as filler part. Typical commercial Type I Portland cement provided by Firuz Kuh Cement Company (Tehran, Iran) was used. The Portland cement conforms to the requirements of specification mentioned in ASTM C150 [23]. The physical properties and chemical composition of the cement are tabulated in Table 1.

The required rice husks were provided from a northern province of Iran. RHA was obtained by burning at relatively high temperature in the range of 700 °C and the rate of heating was set to

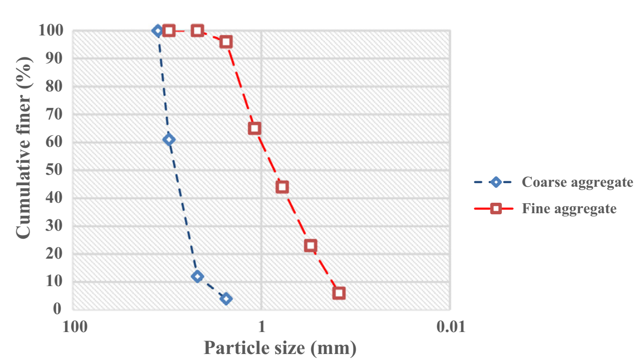

Fig. 1. Gradation curves of fine and coarse aggregates.