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Chloride and chemical resistance of self compacting concrete containing rice husk ash and metakaolin

V. Kannan [a,*], K. Ganesan [b]

[a] Department of Civil Engineering, National College of Engineering, Tirunelveli, Tamil Nadu, India
[b] Department of Civil Engineering, Sudharsan Engineering College, Sathiyamangalam, Pudukkottai, Tamil Nadu, India

HIGHLIGHTS

- Rice husk ash (RHA), metakaolin (MK) and their combination are used as cement replacement materials.
- The ternary systems of OPC, RHA and MK, enhance the mechanical properties of self compacting concrete.
- The RHA and RHA in combination with MK showed a considerable resistance against acid attack.
- Up to 30% the combination of RHA and MK as may be used as supplementary cement replacement materials.
- Strong interrelationship occurred between weight loss due to acid attack and Silica ratio of blended SCC.

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ABSTRACT

In this paper, the durability properties of self-compacting concrete (SCC) containing rice husk ash (RHA), metakaolin (MK) and a combination of MK and RHA (1:1 ratio) were evaluated and their relationships discussed. The durability properties of the various mixtures were studied. The results showed that SCC blended with RHA and a combination of RHA and MK showed a considerable improvement in durability than unblended SCC (100% OPC). However, the performance of SCC blended with MK was unsatisfactory in an acid environment. In addition, it was found that resistance to acid attack was directly related to the silica ratio (SR).

1. Introduction

Self-compacting concrete (SCC) was first developed in 1988 in Japan as a partial response to the gradual reduction of skilled labor in the construction industry. The concrete's qualities can be achieved without segregation and high deformability in three ways, which consist of limiting aggregate content, ensuring a low water-powder ratio and the use of superplasticizer [1]. Nowadays, SCC is gaining much popularity throughout the world because of some of its interesting structural properties [2]. However, it is not completely accepted due to higher cost as well as the lack of standard specifications and testing procedures. In most cases, it is treated only as a special concrete [3]. The reason for the increasing cost of SCC production is the use of higher powder content (cement), which can be reduced by the use of various mineral admixtures such as rice husk ash, fly ash, and metakaolin, etc. as partial replacement of the cement. The mineral admixtures additions also improve the structural properties of the SCC as well as reducing the CO_2 emission [4,5].

RHA is an agro-waste and used as it enhances the excellent properties of concrete; presently, it is well known as a cement-replacing pozzolanic material and there are also a number research projects being conducted on it. Usually, it can be obtained by burning rice husks at about 600–800 °C in a controlled manner, which causes the formation of amorphous silica with a high surface area [6]. Finely ground RHA is responsible for the high reactivity in cement and is used to reduce the porosity as well as the width of the inter-facial transition zone (ITZ) [7,8].

However, when the replacement level of RHA is increased (more than 10%), the high surface area decreases the workability of the SCC [9,10]; this property is unfavorable when it comes to generating the SCC. Therefore, to increase the workability and

* Corresponding author. Tel.: +91 4630 261481, mobile: +91 9787211014; fax: +91 4630 261108.
E-mail addresses: kannan_civil81@yahoo.in (V. Kannan), ganesanhari@yahoo.com (K. Ganesan).

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Table 1
Sieve analysis and physical properties of fine and coarse aggregate.

Sieve size (mm)	Fine aggregate (% of passing)	Coarse aggregate (% of passing)
20	100	100
12.5	100	90.1
10	100	10.4
4.75	99.9	0.00
2.36	99.1	0.00
1.18	83.1	0.00
0.60	58.3	0.00
0.30	10.0	0.00
0.15	0.70	0.00
Pan	0.00	0.00
Bulk density (kg/m^3)	1752	1640
Specific gravity (g/cm^3)	2.53	2.78
Water absorption (%)	2.01	0.36

quantity of the total cement replacement level of the SCC, the water-to-binder (W/B) ratio was increased with 2% superplasticizers (SP) and RHA was used with MK to make ternary blended SCC.

MK is an amorphous material that is obtained by dehydrating kaolin at a temperature of about 800 °C [11]. The high reactivity of MK with cement and its usability to accelerate the cement hydration differentiates it from other pozzolanic materials [12]. It also accelerates the initial setting time and improves the mechanical and transport properties, especially since it can also attain high compressive strength at an early age [13,14].

From the previous studies, concrete blended with RHA and MK shows better performance in strength and in some properties of durability. However, few studies have investigated the durability of SCC containing RHA and MK, especially in an acid environment [15]. Therefore, the objectives of this study were to investigate the performance of binary and ternary blended SCC containing RHA and MK in sulfuric and hydrochloric acid solutions. The effects of RHA, in combination with and without MK, on durability were determined experimentally. In addition, the relationships between the various durability properties were explored. Furthermore, the relationship between the silica ratio (SR) of the binder, $SiO_2/(Al_2O_3 + Fe_2O_3)$ and the resistance to acid attack on SCC was evaluated.

2. Materials and methods

2.1. Materials

Ordinary Portland cement (OPC) conforming to ASTM C 150 (Type1) was used. The sieve analysis of fine aggregate (FA) and coarse aggregate (CA) was carried out in accordance with the ASTM C136 standard provision. The results of the sieve analysis of FA and CA were tabulated in Table 1. The physical properties of FA and CA were also presented in Table 1. Commercially available MK was used for this study.

Boiled fired RHA residue was collected from a modern rice mill. The mill-fired husk residue ash was further burnt in a laboratory muffle furnace at a temperature of 650 °C over a period of one hour [11]. The burnt material was ground in a laboratory pulverizer with a disc diameter of 175 mm for 1 h to a mean particle size of 6.27 micron meters (μm) before it was used as a cement replacement material.

The physical and chemical analysis of OPC, RHA, and MK was carried out according to relevant Indian standard (IS) code provisions. Superplasticizers (SP) were used to increase the workability of SCC [16]. For this work, Sulphonated Napthalene Polymers based SP with the specific gravity of 1.220–1.225 was used as a high range water reducer (conforming to IS: 9103:1999 and ASTM-C-494 Type 'F' depending on the dosages used) to improve the performance of SCC.

2.2. Mix proportion and preparation of the specimens

The mix design, which was based on previous studies, was modified using EFNARC guidelines [17]. In general, self-compactability can be greatly affected by the material properties and the mix proportion. In the trail mix, the fine and coarse aggregate contents are fixed so that self-compactability can easily be achieved by adjusting the water powder ratio and the superplasticizer dosage only. From the trail mix, a suitable mix proportion was taken for further study. In this study, the ratio of fine and coarse aggregate was fixed at 1.1, with a W/B (W/(C + RHA or MK or RHA + MK) ratio of 0.55 and 2% of the superplasticizer; the only variable was RHA and MK to OPC.

The mix design was carried out to produce SCC without segregation and bleeding, with the target mean compressive strength of 38.5 N/mm^2 (as M30 graded normal vibrated concrete) at 28 days. For this study, a total of seventeen concrete mixtures (RHA, MK with a range of 0%, 5%, 10%···30%, and a combination of RHA and MK with a range of 10%, 20%, 30% and 40% with one normal SCC) were prepared, and all the mixtures satisfied the target mean strength. These mixes were designated as OPC (100%) and RHA5/MK5/RHA5 + MK5···RHA30/ MK30/RHA20 + MK20. The mix proportions are presented in Table 2.

During the production of SCC, the mixing order is very important to obtain homogeneity and uniformity in all mixtures [17–19]. Initially, the batching process is carried out and all the materials were separately placed on a nonporous plate. Mixing sequences consisting of FA and CA are mixed for 30 s in the laboratory mixing machine to achieve homogeneity, then about 50% of the mixing water is added to the mixer machine and mixing is continued for one more minute. Thereafter, the mixing process is stopped to allow the aggregates to absorb the water for one minute. Before adding the cement and admixtures (RHA or MK or RHA + MK), they are mixed in the dry state, then added to the mixing drum. Finally, the SP is poured in the remaining water and introduced to the mixture, and mixing is restarted for 5 min. The mixed concrete is assessed to check its fresh state properties and then placed in the required molds for curing.

For all mixes, three specimens of 100 mm^3 were cast for a compressive strength test; six specimens of 100 mm^3 were cast for acid attack tests (H_2SO_4 and HCl); nine cylindrical specimens with a diameter of 100 mm and height of 50 mm were cast for permeability-related property tests (WA, Sorptivity and chloride penetration). After casting, all of the specimens were left in their casts for 24 h and then they were unmolded and immersed in a water curing tank until they were required for testing.

2.3. Testing methods

To check the fresh state properties such as filling ability, viscosity, and passing ability of concrete, slump flow, V-funnel, and L-box tests were conducted according to European Federation of National Associations Representing the producers and applicators of specialist building products for Concrete (or EFNARC) specifications [17]. Mineralogical and mean particle size analyses of RHA and MK were carried out by X-ray diffraction (XRD). In addition, Scanning electron microscopic (SEM) with energy dispersive X-ray analysis (EDAX) were carried out to study the morphological behavior of concretes.

The compressive strength, permeability related tests (WA, Sorptivity and chloride penetration) and the acid attack tests were conducted after 28 days of water curing. The compressive strength tests were carried out according to IS 9013-1997.

Saturated water absorption values of RHA, MK and a combination of RHA and MK blended SCC specimens were measured according to ASTM C 642 and previous studies [20].

Three specimens were used for sorptivity measurement. Measurements of capillary sorption were carried out using specimens preconditioned in the hot air oven at about 50 °C until a constant weight was obtained. Then the concrete specimens were cooled down to room temperature. As shown in Fig. 1, the test specimens were exposed to the water on one face by placing them on a pan. The side faces of the specimens were coated with epoxy resin. The water level in the pan was maintained at about 5 mm above the base of the specimens during the experiment.

At suitable time intervals, each specimen was removed from the water, with excess water removed by damp paper towel, and then the specimen was weighed. It was then replaced in the water and the stopwatch started again. The gain of mass per unit area over the density of water is plotted versus the square root of the elapsed time. The slope of the line of best fit of these points was taken as the sorptivity value. The sorptivity values of RHA, MK and the combination of RHA and MK blended SCC specimens after 28 days of water curing were evaluated by the following expression (Eq. (1)):

$$\boldsymbol{i} = \boldsymbol{S}\, \boldsymbol{t}^{1/2} \tag{1}$$

where $\boldsymbol{i}$ is the cumulative water absorption per unit area of inflow surface (m3/m2), $\boldsymbol{S}$ is the sorptivity (m/s $^{1/2}$), and t is the time elapsed (s).

The chloride ion penetration in all SCC specimens was determined by a rapid chloride ion penetration test (RCPT). The resistance to chloride ion penetration in terms of total charge passed in coulombs of RHA, MK and the combination of RHA and MK blended SCC specimens was measured according to the ASTM C 1202 standard.

The acid resistance of the SCC specimens was assessed by immersing them into sulfuric acid (H_2SO_4) and hydrochloric acid (HCl) solutions. The specimens were tested after 28 days of curing and all the specimens were cleaned using a brush, in order to remove any loose material before testing. The initial weight was measured and then the specimens were immersed into either a 5% sulfuric acid (H_2SO_4) or 5% hydrochloric acid (HCl) solution. A separate plastic beaker was used for each specimen for identification purposes. The solutions were replaced at regular intervals (every week) to maintain a constant concentration throughout the test