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Strength and micro-structural properties of self-compacting concrete containing metakaolin and rice husk ash

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HIGHLIGHTS

- Strength and micro-structural properties of SCC with MK and RHA are presented.
- RHA & MK improves the strength properties of SCC.
- RHA & MK improves the micro-structure of SCC.

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ABSTRACT

This paper presents strength and micro-structural properties of self-compacting concrete (SCC) containing Metakaolin (MK) and Rice Husk Ash (RHA). For this purpose, SCC mixes were prepared where cement was replaced by weight in three proportions of 5, 10 and 15% by metakaolin; and fine aggregates were replaced by RHA in percentage of 10, 20 and 30. In total sixteen mixes were prepared. First was control mix, next three mixes were prepared with 5, 10, 15% MK as replacement of cement, next three mixes were prepared with 10, 20, 30% RHA as replacement of fine aggregates and additional nine mixes were prepared with various combinations of MK & RHA. The fresh properties tests were conducted for slump flow, L-box, U-box, and V-funnel. Tests for compressive strength, splitting tensile strength and micro-structural analysis (SEM & XRD) were conducted up to 365 days.

The experimental results indicate that SCC mixes produced with MK, RHA & in combination of MK & RHA satisfies norms of EFNARC. The compressive strength and splitting tensile strength results were also positive. Mixes produced with MK and RHA showed gain in compressive strength at all the ages. Micro-structural analysis confirmed the strength development pattern of SCC mixes made with MK, RHA and in combination of both.

1. Introduction

Construction industry these days is using many construction materials, but cement is one material which is used from ages. It is used time and time again in construction industry; and it is likely to be used in future also. However, this construction material must meet the challenges of other modern construction materials in order to sustain in the construction market. An important step in this regard is the evolution of self-compacting concrete.

On the other hand, mineral admixtures are fillers that can form the compounds having similar properties to cement [1]. One of such mineral admixtures is Metakaolin. It is an unreal pozzolana formed by heating kaolinite clay at definite temperature. It is deprived of 14% hydroxyl water by heating betwixt of 700 and 900 °C, and converts into MK [2,3]. The pozzolanic reaction of MK had been always of keen interest for the researchers; and many researchers concluded that this helps in refining the binder capillary porosity which results into betterment of the mechanical and durability properties. RHA is a byproduct obtained from the paddy fields. When rice husk is perfectly burnt at temperatures beneath 700 °C, it gives rise to RHA, which contains reactive amorphous silica content [4,5].

Many researchers tried to investigate the role of MK and RHA in concrete in the past. The use of MK can also be accounted for its environmental boon as well as favourable effects on various properties of concrete [6,7]. Poon et al. [8] contemplated that at initial ages the strength growth is relatively high when MK is used as in contrast to silica fume or fly ash. The reason for this betterment of early age strength was associated to the higher pozzolanic activity of MK and pore structure refinement. Hassan et al. [9] used MK in

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seven different proportions of 3, 5, 8, 11, 15, 20 and 25% to replace cement; and established that there is gain in compressive strength of SCC as percentage of MK increases from 0 to 25%. Madandoust and Mousavi [10] used MK to replace cement in proportions of 5, 10, 15 and 20%. They observed that comprisal of MK in concrete notably embellish the compressive strength of SCC in a period of the first 14 days, up to 27%. They also stated that 10% replacement of cement by MK gives the best results and hence can be considered as most advantageous percentage. Shekarchi et al. [11] contemplated that use of MK improves the strength properties. Kim et al. [12] used Korean MK in concrete and advocated that 10% substitution of MK is most ideal replacement. Similar positive results for mechanical properties of concrete with the use of MK were also stated by Badogiannis et al. [13].

RHA can better the various properties of concrete if processed and used properly, [14–18]. Utilization of RHA in concrete can also be reckoned for its environmental advantages [19]. Khan et al. [20] used RHA as a replacement of cement and stated that rice husk ash concrete have better properties as compared to conventional concrete. Also, it helps in minimizing the cost and improving the environment burden.

Ahmadi et al. [21] used RHA in proportions of 10 to 20% of weight of total cementitious material, and observed that the SCC made with use of RHA showed better results in contrast to SCC without RHA. Memon et al. [22] carried out research on SCC containing rice husk ash and stated that SCC made with RHA helps in decreasing the overall cost. Rahman et al. [23] prepared self-compacting concrete replacing cement and fine aggregates with RHA in proportions of 0, 20, 30 and 40%. Test results revealed that there is decline in compressive strength of mixes with the rise in the RHA level, but at the age of 3 and 7 days it is more than control mix. Chopra et al. [24] replaced cement by RHA in proportions of 10, 15 and 20%. They observed an addition in compressive strength at all ages when replacement level of RHA is kept at 15%. There was addition of about 25% strength at 7-day, 33% at 28-day and 36% at 56-day. Siddique et al. [25] reported that insertion of bacteria and RHA in concrete improved its strength as well as durability properties. They also reported that best results were achieved at 10% RHA. Safiuddin et al. [26] also reported positive results with use of RHA in self-compacting concrete.

Majority of researchers have replaced cement with RHA; and there is very few work available on RHA as a replacement for fine aggregates. Also, segregation should be avoided, which can be achieved by adding a VMA or by maximizing the fine particles. VMAs lead to increase in overall cost as they are very expensive [27]. The other method is by maximizing the fine particles, such as RHA, which can be done without increasing the cost [28]. RHA is available in very large quantities. By replacing the RHA with fine aggregates, author had tried to decrease the overall cost of the concrete.

2. Material and method used

2.1. Material used

2.1.1. Cement

The OPC, conforming to the Indian standards was used in this work. The cement does not had any knots and of grey with light greenish shade. Various tests as per IS: 8112 (1989) [29] were conducted. The results are given in Table 1. Chemical compositions of the cement, analyzed by EDS, are tabulated in Table 2.

2.1.2. Metakaolin

Metakaolin, used in this work, was of off-white color. EDS analysis of metakaolin was conducted and results are given in Table 2.

Table 1
Physical properties of cement.

Property	Results
Color	Grey with a light greenish shade
Consistency (%)	34
Initial setting time (minutes)	38
Final setting time (minutes)	550
Specific gravity	3.2
Expansion (mm) (Le–Chatler's) (mm)	6
Silt Content (%)	4

Table 2
Chemical properties of cement, metakaolin and rice husk ash.

Composition (%)	Cement	Metakaolin	Rice husk ash
Silicon dioxide (SiO_2)	21.96	51.10	93.50
Aluminum Oxide (Al_2O_3)	5.05	43.80	0.55
Ferric oxide (Fe_2O_3)	3.96	1.60	0.23
Magnesium oxide (MgO)	1.56	0.30	0.31
Calcium oxide (CaO)	63.45	0.20	1.11
Sodium oxide (Na_2O)	0.36	0.10	0.10
Potassium oxide (K_2O)	0.64	0.20	1.40
Sulphur trioxide (SO_3)	1.62	0.05	0.07

SEM analysis of metakaolin was done at 20000× magnification. It shows that metakaolin particle is quite small as compared to cement and RHA particle. It is shown in Fig. 1(a). Specific gravity of metakaolin was 2.65 and its particle size was less than 1 μm.

2.1.3. Rice husk ash

RHA, used for this work, was of black color. EDS analysis was used to identify the chemical properties and results are tabulated in Table 2. SEM analysis of RHA, done at 1000× magnification, revealed that RHA particle was of irregular shape. It is quite evident from Fig. 1(b). The particle size of RHA was less than 20 μm.

2.1.4. Fine and coarse aggregates

The sand and coarse aggregates used for this work were obtained from Patiala (Punjab). Tests were performed for specific gravity, sieve analysis/grading curve, and water absorption as per Indian standard specifications [30]. The results are tabulated in Table 3. The fineness modulus for fine aggregates was determined from grading curve. The fineness modulus of fine aggregates was 2.65. When fine aggregates was replaced by 10% RHA, the value of fineness modulus was 2.45, at 20% RHA replacement level, the value of fineness modulus come to be 2.08 and at 30% RHA replacement level, fineness modulus was 1.81.

2.1.5. Admixture

Admixture used in this work was Conplast SP400, which was of brown color. The liquid state of the admixture was used, which helped in reducing the water demand. It satisfies the IS: 9103 (1999) specifications. Conplast SP400 is based on Sulphonated Naphthalene Polymers. Its specific gravity ranges from 1.205 to 1.215; and pH at 27 °C remains between 7.0 and 8.0.

2.1.6. Magnesium sulphate

Magnesium sulphate was used in the sulphate resistance test for concrete. It is used in the form of solution of strength 5%. It was procured in powder form; and a solution of strength 5% was prepared by adding it into the water. The powder was white in color.