Construction and Building Materials 176 (2018) 323–332

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Durability properties of self-compacting concrete incorporating metakaolin and rice husk ash

Anhad Singh Gill *, Rafat Siddique

Department of Civil Engineering, Thapar Institute of Engineering & Technology (Deemed University), Patiala, India

HIGHLIGHTS

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

ARTICLE INFO

Article history:
Received 16 January 2018
Received in revised form 13 April 2018
Accepted 6 May 2018

Keywords:
Self-compacting concrete
Metakaolin
Rice husk ash
Compressive strength
Durability properties
Micro-structure

ABSTRACT

This paper put forward the durability and micro-structural properties of self- compacting concrete (SCC) made up of metakaolin (MK) and rice husk ash (RHA). For this purpose, metakaolin (MK) was used to replace cement by weight in three different proportions of 5, 10 and 15% and fine aggregates were replaced by rice husk ash (RHA) in proportion of 10%. A total of four mixes, including the control mix, were designed. Slump flow, L-box, U-box, and V-funnel tests were conducted in concrete's fresh state. Testing of specimen in hardened state was done at age of 7, 28, 90 and 365 days and was tested for compressive strength and durability properties such as water absorption, porosity, sulphate resistance and RCPT. Further SEM & XRD tests were also conducted. All the mixes passed all plastic stage tests of SCC. Furthermore hardened stage tests results were also positive. Durability properties showed significance improvement with the use of MK and RHA. Micro-structural analysis further confirmed the positive trend of results.

1. Introduction

Concrete is used almost in every construction work and that too from past so many years. It is one of the oldest construction material used in construction industry, and there is no doubt that its significance will continue as same. But to meet the modern day construction standards, timely modifications are necessary. One of such modification is the SCC. SCC is the need of modern day construction.

In today's modern world there are large quantities of waste products and by-products. It becomes very necessary to utilize these waste products in some useful and efficient ways. Some of these products can be used in the production of concrete and termed as 'mineral admixtures'. These are fillers that can react to form compounds having similar properties as of cement [1]. Metakaolin is one of the mineral admixtures which is available commercially since the mid-1990s and can be used in the production of concrete [2]. It is produced by process of thermal activation by heating kaolinite clay without production of CO_2 [3,4]. It is deprived of 14% hydroxyl water by heating betwixt of 700 and 900 °C, and converts into MK [5,6]. The production of MK can be done at lower temperatures as compared to cement, which leads to lower costs of MK production [4]. On the other hand RHA is a byproduct obtained from the paddy fields. When rice husk is properly burnt in the temperature range lower than 700 °C, it converts in RHA containing reactive amorphous silica content [7,8].

Many researchers in the past had tried to investigate the role of MK and RHA in concrete. The pozzolanic reaction of MK had been always the talking point of the researchers; and even many researchers stated that use of MK in concrete proves to be beneficial, as it can improve the hardened state properties of concrete. The use of MK can also be accounted for its environmental boon as well [9,10].

Poon et al. [9] scrutinized that the MK can accelerates the early age strength of concrete. They even stated that MK provides better

* Corresponding author.
E-mail address: raja_4342@yahoo.com (A.S. Gill).

https://doi.org/10.1016/j.conbuildmat.2018.05.054

strength in contrast to silica fume or fly ash. The reason for this enhancement can be linked to higher pozzolanic activity of MK and pore structure refinement. Poon et al. [11] commented on chloride ion penetration with the use of MK. Their results indicated that the addition of MK lowered the total charges passed by 87% when compared to concrete made without MK. Shekarchi et al. [10] used MK for their research work and studied the durability properties. They proclaimed that the use of MK improves the durability properties of concrete to a great extent. Madandoust and Mousavi [12] used MK for their experimental work in four different proportions. They replaced cement by MK in proportions of 5, 10, 15 and 20%. They discovered steep rise in early age compressive strength with addition of MK. At 14 days, compressive strength increased by 27%. Low water absorption was also resulted by use of MK. They tested different MK replacement levels from point of view of economic efficiency, fresh and hardened properties of concrete and detected that 10% is the optimum replacement level. Hassan et al. [13] used MK to replace cement for their work. They used MK in seven different proportions of 3, 5, 8, 11, 15, 20 and 25%. They affirm that with the increasing percentage of MK, compressive strength also followed the increasing pattern. The durability properties of SCC also showed positive results with the use of MK.

There have been several studies implemented on high strength SCC and fly ash SCC, but there are very few studies on RHA based SCC. Utilization of RHA in concrete can also be reckoned for its environmental advantages [14]. Also use of RHA in SCC can help in overall cost cutting of the project as stated by Memon et al. [15]. The RHA particles have high specific surface area due to their occurrence in cellular structure [16]. Due to which RHA can also be utilized as viscosity modifying agent for SCC [15]. This property of RHA can help in decreasing the segregation in SCC, which is very important property for SCC [17].

Ahmadi et al. [18] used different proportions of RHA for their work. The percentages of RHA were kept between 10 and 20% of weight of total cementitious material. They stated that the use of RHA fetched better results than the OPC based SCC. Durability performance of SCC was also positively affected. Safiuddin et al. [19] affirmed that the utilization of RHA in SCC certainly has positive effects on the durability properties. Their results indicated towards better resistance to corrosion, freeze thaw cycles and sulphate attack of concrete made with RHA as compared to concrete without RHA. Chopra et al. [20] used RHA in their work to replace cement. They used three different proportions of RHA between 10 and 20%. They spotted that the use of RHA had a positive impact on the compressive strength of SCC. They stated that there was about 33% addition in strength at 28 days with RHA content of 15%. In case of chloride ion penetration, mixes made with RHA performed exceptionally well, showing "low range" to "very low range" chloride penetration. Siddique et al. [21] reported that insertion of bacteria and RHA in concrete improved its strength as well as durability properties. They proclaimed that 10% replacement of RHA leads to best results in all properties.

It can be observed from the literature that the majority of the work had been done on RHA was RHA used as a replacement of cement. While the replacement of fine aggregates with RHA has very few researches. So the present paper is an effort in the same direction. As discussed in literature review, the high specific surface area of RHA helps in segregation resistance, which can otherwise be achieved by chemical viscosity modifying agent (VMA). The VMAs have very high cost, and there use in SCC can lead in the rise of overall cost of the project [22]. So the replacement of fine aggregates with RHA can help in cost cutting [23] as well as in enhancing the hardened properties of SCC.

2. Experimental program

2.1. Material used

2.1.1. Cement, aggregates and mineral admixtures

The ordinary Portland cement was used for this research. Cement was tested according to IS: 8112 [24] and found to be conforming the Indian standards. The cement does not had any knots and of grey with light greenish shade. Test results for cement are reported in Table 1. Chemical composition is given in Table 2.

The aggregates were acquired from Patiala (India). Aggregates were tested according to IS: 383-1970 [25] and found conforming to Indian standards. The various properties of aggregates are tabulated in Table 3.

Metakaolin was obtained from Faridabad (India). It is of off-white color. The test results of Metakaolin are stated in Table 3. EDS of Metakaolin was conducted and its results are given in Table 2. SEM analysis was also conducted for Metakaolin, which shows that Metakaolin particle is quite smaller than cement particle. SEM images of Metakaolin particle is shown in Fig. 1(a).

RHA was acquired from Ludhiana (India). It was of black color. The physical properties are given in Table 3. EDS analysis of RHA was conducted and its results are given in Table 2. RHA particle had irregular type of shape, which was evident from the images generated by SEM analysis. These images are shown in Fig. 1(b).

2.1.2. Admixture and Magnesium sulphate

Admixture used in this work was Conplast SP400 and was obtained from Chandigarh (India). It was of brown color and was obtained in liquid state. It was found conforming the Indian standards as per IS: 9103 (1999). The main aim of using the admixture was to reduce the water demand in the mix. Its specific gravity varied between 1.205 and 1.215 and ph at 27 °C is between 7.0 and 8.0. Magnesium sulphate was obtained from Patiala (India), in powder form. It was used by making solution of strength 5% by adding water and was used for sulphate resistance test.

2.2. Mixture proportionions

In total, four mixes were developed. One was the control mix (M1), and other three mixes (M2, M3 and M4) were prepared by partial replacement of cement with MK in proportions of 5%, 10% and 15% and fine aggregates were partially replaced by RHA in fixed proportion of 10%. The volume of coarse aggregates was fixed at 670 kg/m^{3}and w/b ratio of 0.44 was also maintained. An admixture, 1.5–2% by weight of total powder content was used. For control mix, cement used was 480 kg/m^3; and fine aggregates used were 900 kg/m^3. These were suitably replaced for other mixes. The mix designs are tabulated in Table 4.

For calculating the cost of concrete per cubic meter, the price of cement, fine aggregates (F.A.), coarse aggregates (C.A.), metakaolin (MK) and rice husk ash (RHA) were taken into consideration. The price of cement for control mix per cubic meter is Rs 3168

Table 1
Physical properties of cement.

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