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Durability of self-compacting concrete made with Recycled Concrete Aggregates and mineral admixtures

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HIGHLIGHTS

- The durability properties of SCC made with RCA have been investigated.
- The use of RCA deteriorates the properties of SCC mixes.
- The use of MK and SF compensate the loss due to swap of coarse NA with RCA.

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ABSTRACT

Durability performance of Self-Compacting Concrete (SCC) made with Recycled Concrete Aggregates (RCA) as partial or full replacement of Natural Coarse Aggregates (NCA) and with selected mineral admixtures as partial replacement of Portland Cement (PC) is reported. The replacement levels of NCA with RCA were kept at 0%, 50% and 100%. The workability properties of various SCC mixes were assessed using slump flow test, V-funnel test, L-box test and J-ring test. Durability performance of the SCC mixes was investigated using rapid chloride penetrability test, initial surface absorption test, water penetration test, and capillary suction test. Addition of Silica Fume (SF) or Metakaolin (MK) at 10% by weight of PC was able to compensate for the loss of durability properties when 50% of the NCA were substituted with RCA, with MK being more effective than SF. For 100% replacement of NCA with RCA, the aforesaid pozzolans were not effective in fully compensating for the loss of durability properties on account of substitution of NCA with RCA.

1. Introduction

According to ACI [1], Self-Compacting Concrete (SCC) is highly flowable, non-segregating concrete that can spread into place, fill the formwork and encapsulate the reinforcement without any mechanical consolidation. In many ways, SCC has been the most significant development in concrete technology in the recent past and it has had a profound impact on concrete placement in particular and on construction processes in general. Although the relative proportion of aggregates in SCC is lower than that in Normally Vibrated Concrete (NVC), this material is still the major constituent of SCC and has a significant influence on fresh and hardened properties. The use of coarse Recycled Concrete Aggregates (RCA) obtained from processing of construction and demolition waste as a substitute for Natural Coarse Aggregates (NCA) is being encouraged to reduce the environmental impact of concrete construction. However, due to presence of the relatively soft and porous residual mortar on a typical RCA particle, the physical and mechanical properties of these aggregates may be inferior to those of NCA. This may raise concerns about the strength and durability properties of concrete made with RCA. This situation is likely to get compounded in the case of SCCs since the use of RCA will impact the fresh properties also which in turn are fundamental to the performance of such concretes.

Although the mechanical and durability properties of NVC made with RCA have been extensively studied, relatively few investigations have concentrated on the durability properties of SCC made with RCA. In the literature, reported trends in the durability properties like water permeability [2,3], air permeability [2,4], resistance to chloride penetration [5,6], carbonation [7,8], sulphate

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attack [9,10], ultrasonic pulse velocity [6,11], and freeze-thaw resistance [12,13] of NVC containing RCA indicate that for improvement in durability, the microstructure of concrete should be improved. One way of achieving this objective is to incorporate mineral admixtures like Fly Ash (FA), Metakaolin (MK), Silica Fume (SF), Nano Silica (NS), Ground Granulated Blast Furnace Slag (GGBS) etc. in the concrete. These mineral admixtures can play the role of micro-fillers which in turn will increase the compactness and decreases the porosity of concrete [14,15]. By extending this hypothesis to SCC made with RCA, it is reckoned that by adding suitable mineral admixtures, deterioration in the durability properties of SCCs because of the use of RCA can be reduced, if not fully compensated. The different authors have reported different results as far as influence of MK and SF on the strength and durability properties of NVC is concerned. In some of the investigations, MK modified concretes have been shown to perform either better or comparable to SF modified concretes [16–21]. However, there are some investigations wherein SF has been shown to perform better than MK [22–26].

2. Research significance

A brief review of literature as presented in the preceding section indicates that lot of research work has been done to examine the strength and durability properties of NVC made with different replacement levels of NCA with RCA. However, the information on the durability properties of SCC made with RCA is scanty. As in case of NVC, the performance of SCC in terms of strength and durability is expected to deteriorate with the replacement of NCA with RCA, there is need to quantify the same. Therefore, this investigation was undertaken with the objective to examine the durability and compressive strength of SCC made with RCA. Durability properties of SCC made with RCA and Portland Cement (PC) (70% PC + 30% FA) have been studied by replacing 10% by weight of the blended cement in the concrete mixes with either SF or MK. Towards characterization, fresh properties of the SCCs have been evaluated using slump flow test, V-funnel test, L-box test and J-ring test. Durability properties of the SCCs were investigated with the help of the following tests: Rapid Chloride Penetrability Test (RCPT), Initial Surface Absorption Test (ISAT), Water Penetration Test and Capillary Suction Test (CST). The effect of RCA replacement level and the use of MK and SF on the durability properties of SCC are reported and relevant recommendations have been made with respect to the relative efficacy of MK and SF in compensating for the deterioration of durability properties due to use of RCA in SCCs.

3. Experimental programme

3.1. Materials

Portland Cement was the principal binder in all the SCC mixes and it was blended with class F FA. The control SCC used in this investigation was made using blended PC (total cementitious content = 70% PC + 30% FA), coarse sand and NCA. In the next stage, due to addition of SF or MK, the total cementitious content of the control SCC was modified to: 70% PC + 20% FA + 10% SF or MK. The particle size distribution of various PC, FA, MK and as determined by Laser Particle Sizer is shown in Fig. 1. Self-compacting concretes mixes containing RCA were obtained by replacing NCA with RCA at 0%, 50% and 100%.

The physical and chemical properties of the PC are presented in Tables 1 and 1a respectively. The physical and chemical properties of the FA, SF and the MK are reported in Table 2. The aggregates consisted of coarse sand (fineness modulus = 2.64), available crushed rock (fineness modulus = 6.13) used as NCA. The properties of NCA and RCA used in the study are tabulated in Table 3. The RCA used in the investigation obtained by crushing waste concrete specimens sourced from the Concrete Technology Laboratory

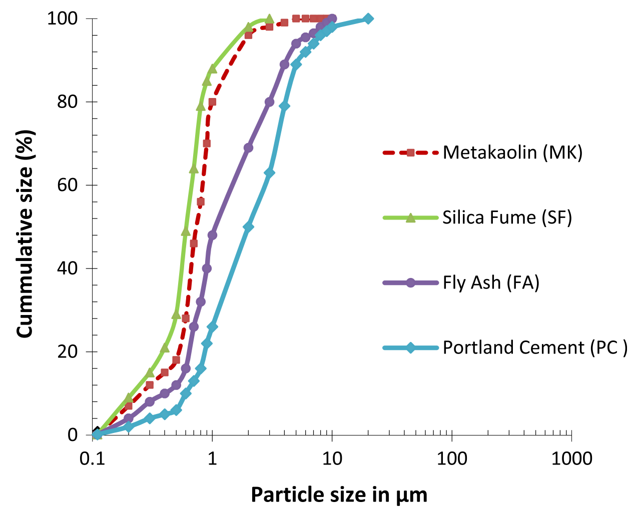

Fig. 1. Particle size distributions of PC, FA, MK and SF.

Table 1
Physical properties of the Portland cement.

Property	Portland Cement (PC)
Soundness	1 mm
Specific gravity	3.15
Normal consistency	30%
Setting time	
(i) Initial	115
(ii) Final	275

Table 1a
Chemical composition of PC.

S.No.	Test parameter	Test value (%)
1	Calcium oxide (CaO)	61.30%
2	Magnesium oxide (MgO)	2.60%
3	Silica (SiO_2)	20.10%
4	Aluminum oxide (Al_2O_3)	6.80%
5	Ferrous oxide (Fe_2O_3)	4.30%
6	Silicon trioxide (SO_3)	1.30%
7	Ratio of lime to silica, alumina and iron oxide	0.90%
8	Ratio of alumina to iron oxide	1.58%
9	Insoluble residue	1.10%
10	Magnesia	2.60%
11	Total sulphur content	1.30%
12	Total loss on ignition	1.20%
13	Total alkali	0.49%
14	Chloride content	0.08%

Table 2
Physical and chemical properties of the fly ash, silica fume and metakaolin.

Composition	Fly ash (FA)	Silica fume (SF)	Metakaolin (MK)
SiO_2	56.50%	85–97%	52.10%
Al_2O_3	17.70%	–	41%
Fe_2O_3	11%	–	4.32%
CaO	3.20%	<1%	0.39%
Loss of ignition	1.20%	4%	<1%
Physical Property			
Specific gravity	2.38	2.20	2.60