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Experimental studies on utilization of coarse and finer fractions of recycled concrete aggregates in self compacting concrete mixes

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ABSTRACT

This experimental study deals with utilization of Coarse Recycled Concrete Aggregate (CRCA) and Fine Recycled Concrete Aggregates (FRCA) in Self compacting concrete (SCC) mixes. The concrete mix is designed for target strength of 40 MPa as per “Modified Nan-su Method”, with Fly Ash as mineral admixture. Four mixes are considered in the study viz., Control Mix (CM) with natural aggregates, 20% CRCA, 20% FRCA and both at 20% replacement levels. The slump flow and T500 time, V-funnel time, L-box height ratio, GTM stability test are conducted to evaluate the fresh properties of SCC mixes. The slump flow test result of the SCC mix containing 20% CRCA and FRCA, fails to satisfy the EFNARC (European Federation of National Associations Representing for Concrete) acceptance criteria marginally. However, results of T500 time, V-Funnel time, L-box height ratio, GTM screen stability test of all the four mixes are found to be within the specified limits. The tests on hardened properties are conducted to assess the cube compressive strength at 3, 7 and 28 days and split tensile strength of cylinders at 28 days. The hardened properties of SCC mixes containing recycled concrete aggregates (RCA) are found to be slightly higher than CM. Based on test results with respect to fresh and hardened properties and with focus on concrete waste utilization, SCC with 20% (CRCA+FRCA) is considered as the preferred mix combination. The durability tests such as sulphate and acid attack are conducted for this mix. The compressive strength is found to reduce by about 11% and 40%, after thirty days of immersion in $Na_2SO_4$and H_2SO_4 solutions respectively.

1. Introduction

Concrete waste can be processed to recover CRCA and FRCA. Review articles related to the use of CRCA in RAC mixes are published in the literature. Several experimental studies are pursued to gain a better insight about the physical, chemical, strength and durability aspects of CRCA as well as RAC. However, most of these studies are oriented towards normal grades of concrete. The utilization of FRCA has not been the subject of thorough studies, since it is believed that, their greater water absorption can jeopardize the final results. Currently, SCC is being increasingly used in monolithic building systems, wherein, both vertical elements (walls) and horizontal elements (Floors and Roof) are constructed using concrete only. Very few experimental studies are reported in the literature to ascertain the feasibility of CRCA and FRCA in SCC mixes. A brief review of experimental studies [1–10], which deal with utilization of either CRCA or FRCA or both, is presented in the next section.

2. Literature review

The cement content in SCC mixes [1–10], is found to be in the range of 285–500 kg/m^3 with water to binder ratio as 0.34–0.53 and 0.4–0.45 as the most preferred range. Different types of mineral additions such as Limestone powder (LP) [2–4,7,9], Fly ash (FA) [1,3,6,8,10], Rubble powder [3] and Silica fume [10] are used as fillers in varying quantities. The work reported by Kou and Poon [1], is with respect to the usage of CRCA at 100% and FRCA in the range 25–100%. The works reported in [2–10], deal with SCC mixes prepared either by replacing NCA by CRCA or NFA by FRCA in varying proportions.

2.1. Slump flow, segregation resistance and rheological properties

Kou and Poon [1] have observed the slump flow diameter and segregation ratio to increase with an increase in the FRCA content. Corinaldesi and Moriconi [3] have reported that, SCC mixes with 100% CRCA and rubble powder as mineral additions can have better

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flowability and segregation resistance properties. The fresh properties are found to decline with increase in CRCA content and higher dosage of super plasticizer is required to achieve the target fresh properties [5,7,8,10]. Hu et al. [6], have observed the viscosity of SCC mixes with FRCA and FA to be higher than without FA. Carro-Lópeza et al. [9] have found impaired performance in passing and filling ability after 45 min in SCC mixes with 50% and 100% of FRCA and to lose completely all the SCC characteristics at 90 min. However, the mix with 20% replacement is found to retain all the SCC characteristics.

2.2. Influence of CRCA volume fraction on strength

A slight reduction in compressive strength at 2, 7 and 28 days is observed by Grdic et al. [2] for CRCA replacement levels at 50% and 100%. Corinaldesi and Moriconi [3], have observed the compressive strength of SCC mixes with CRCA fraction even at 100% replacement level, to be almost same as that of control mix. The 7 and 28 days strength up to 50% CRCA content [5] are found to be marginally low, when compared with control mix. Pereira-de-Oliveira et al. [7], have reported only 3.3% of strength loss with 100% CRCA content. Tuyan et al. [8], have observed the compressive strength values to increase slightly with increasing CRCA content up to 40% and thereafter to decrease. The tensile splitting strength values are found to decrease slightly with increasing CRCA content. Tang et al. [10], have found the compressive strength to increase by 7% and 10% with CRCA at 25% and 50% replacement levels, respectively and thereafter to decrease. Similar trend is observed with respect to tensile splitting strength also.

2.3. Influence of FRCA volume Fraction on Strength

Kou and Poon [1], have observed increase in compressive strength in SCC mixes with FA for FRCA replacement level up to 50%. Corinaldesi and Moriconi [3] have noted that the compressive strength is reduced by 30% in SCC mixes with FRCA fraction at 100% replacement level. Hu et al. [6], have reported the 28 days cylinder strength to slightly increase with increase in FRCA content up to 75% in mixes with FA. Carro-Lópeza et al. [9] have found the 28 day strength of mix with 20% and 100% FRCA to be about 8% and 47% lesser than the mix without it.

2.4. Summary

CRCA and FRCA at lower replacement levels for their natural counter parts results in SCC mixes with minor changes in their properties both in fresh and hardened states. The higher levels of FRCA volume fraction in SCC mixes, results in significant reduction in fresh and hardened properties. FA can impart better properties to SCC mixes than other mineral additions. Based on test results, Carro-Lópeza et al. [9] have concluded that 20% replacement of NFA by FRCA is feasible for making SCC mixes.

3. Hypothesis and objectives of this study

The quantum of concrete waste generation is obviously much less than the concrete requirement in construction sector. The recycling of concrete waste results in the recovery of both CRCA and FRCA. Hence, their utilization in concrete mixes can be the preferred approach for handling concrete waste. Further, in view of research findings reported in literature, as summarized in Section 2.4, 20% replacement of NCA and NFA by CRCA and FRCA are considered as viable limits, even though higher replacement levels are technically possible. With this premise, this experimental study is pursued to assess the characteristics of SCC mixes with a target strength of 40 MPa using FA and 20% of CRCA or FRCA or both as possible replacements for NCA and NFA. Tests are conducted so as to assess the fresh and hardened properties of SCC mixes with the following objectives.

i. To establish a reference for comparison based on the test results of SCC-CM mix.
ii. To assess the influence of 20% CRCA, 20% FRCA and 20% (CRCA +FRCA) contents on the characteristics of SCC mixes.
iii. To know whether 20% (CRCA+FRCA), results in either cumulative or compensatory effects on the characteristics of SCC mix.
iv. To assess durability characteristics of preferred mix when exposed to acid and sulphate attacks.

4. Materials and methods

Concrete mixes are made by using NCA, NFA, CRCA and FRCA along with cement and FA as binders. Crushed stone is used as NCA and river sand < 4.75 mm as NFA. CRCA and FRCA are recycled from concrete waste generated from cube and cylinder specimens tested in the laboratory. The parent strength of concrete waste is around 30 MPa and is accumulated over a period of one year. The parent concrete is made of NCA and NFA. Basic tests are conducted to determine the physical properties of all these materials as well as the chemical properties of FRCA and FA. This section presents the properties of materials as well as the test procedures followed in this study.

4.1. Physical properties of cementitious materials

The physical properties of cementitious materials are determined as per IS 4031 [11] and IS 1727 [12] for cement and FA respectively. The results are based on two trials and are listed in Table 1.

4.2. Chemical composition of FRCA and Fly ash

The test results listed in Table 2 are based on the test reports of chemical analysis furnished by an ISO certified laboratory.

4.3. Physical properties of aggregates

The physical properties of aggregates are determined based on the procedures specified in IS 2386 Parts 1–4) [13]. The results are based on two trials. These are reported along with gradation curves in Table 3.

4.4. Mix design

The M40 grade SCC mix is designed as per "*Modified Nan-su method*" [5,14–16] by considering the properties of natural aggregates. FA is used as mineral admixtures along with chemical admixtures such as super-plasticizer (SP) and viscosity modifying agent (VMA). The mix proportion corresponds to 1:1.44:1.27, with water to binder ratio as 0.36. Coarse aggregates passing 12.5 mm and retained on 4.75 mm are used. Both NCA and CRCA are used in SSD condition. The NFA and FRCA are used in ambient dry condition. The details of mix constituents are given in Table 4.

Table 1
Physical Properties of Cementitious materials [11,12].

Sl. No.	Attributes	Cement	Fly ash
1	Type of cement	OPC 53 Grade	Class F
2	Specific gravity	3.07	2.17
3	Fineness (%)	5.53	–
4	Specific surface area (kg/m^2)	–	342
5	Standard consistency (%)	30.5	29
6	Initial setting time(min)	120	160
7	Final setting time (min)	310	360
8	28 Days compressive strength (MPa)	55.3	–