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Research Paper

# Evaluating the Durability Properties of Self Compacting Concrete made with Recycled Concrete Aggregates

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ABSTRACT

This paper reports the durability properties of Self Compacting Concrete (SCC) made with Recycled Concrete Aggregates (RCA) as partial/full replacement of Natural Coarse Aggregates (NCA). The effect of RCA on fresh properties of SCCs was measured using slump flow test, V-funnel test, L-box test and J-ring test. Whereas the durability properties like such as initial surface absorption, water permeability, capillary suction and rapid chloride penetrability were investigated to study the effect of varying content of RCA on SCC. The compressive strength of different SCC mixes was also determined for reference. The results indicate that increasing the content of RCA in SCC leads to deterioration in durability related properties of SCC. The compressive strength has also been found to decrease with increasing RCA content. It has been seen that the reduction in the performance has been marginal up to 50% replacement level of RCA, but 100% replacement of RCA has been found to significantly affect the durability related properties and compressive strength.

## 1 Introduction

The judicious use of natural resources is first and foremost important factor for the sustainable development. In a search for alternative solutions, the use of Recycled Concrete Aggregates (RCA) to produce new concrete is becoming an obvious choice. Producing concrete using RCA has several advantages like the burden on non-renewable aggregates resources may be significantly decreased; the service life and capacity of landfills and waste management facilities can be extended. On the other hand, the carbon dioxide emissions and traffic congestion associated with the transport of virgin aggregates from remote sites can be reduced. The potential use of RCA in Self Compacting Concrete (SCC) not only has the aforesaid advantages moreover the problems like remote casting, confined and enclosed spaces, long cantilever access areas and dense reinforcement configurations can be easily worked out. Self-Compacting Concrete is highly flowable, non-

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segregating concrete that can spread into place, fill the formwork and encapsulate the reinforcement without any mechanical consolidation [1]. As the relative proportion of coarse aggregates in SCC is lower than that in Normally Vibrated Concrete (NVC), but it is still the major constituent of SCC and has a significant influence on its properties. The presence of residual mortar on RCA particle affects the physical and mechanical properties of RCA as it is relatively soft and porous.

In the literature, reported trends for properties like compressive strength [2,3], split tensile strength [4], drying shrinkage [5], water permeability [6], air permeability [7], resistance to chloride penetration [8], carbonation [9], ultrasonic pulse velocity [10], and freeze-thaw resistance [11] of NVC containing RCA indicate that the properties of concrete are influenced by the RCA content in concrete. In general, it is observed that the properties of concrete using RCA is inferior to those using Natural Aggregates (NA) which is due to the presence of numerous cracks and fissures and pores present inside the aggregate.

## 2 Research Significance

Though enough literature is available on the durability properties of NVC made with RCA, relatively little information is available on the durability properties of SCC made with RCA. Therefore, there is a need to quantify the effects of replacing Natural Coarse Aggregates (NCA) by RCA on the durability properties of SCC. In this investigation fresh, durability properties and compressive strength of SCC made with different replacement levels of RCA have been studied. Fresh properties of SCCs have been evaluated using slump flow test, V-funnel test, L-box test and J-ring test, whereas, durability properties such as Initial Surface Absorption, Water Permeability, Capillary Suction and Rapid Chloride Penetrability were investigated. The compressive strength of all the SCC mixes prepared in this investigation was also determined.

## 3 Experimental program

### *3.1 Materials*

Portland Cement (PC) was the principal binder in concrete and it was blended with class F FA. The replacement percentages of NCA with RCA were kept as 0%, 50% and 100%. The RCA were sieved and remixed to get the gradation comparable to NCA within the specified grading limits of IS 383:1970 [12].

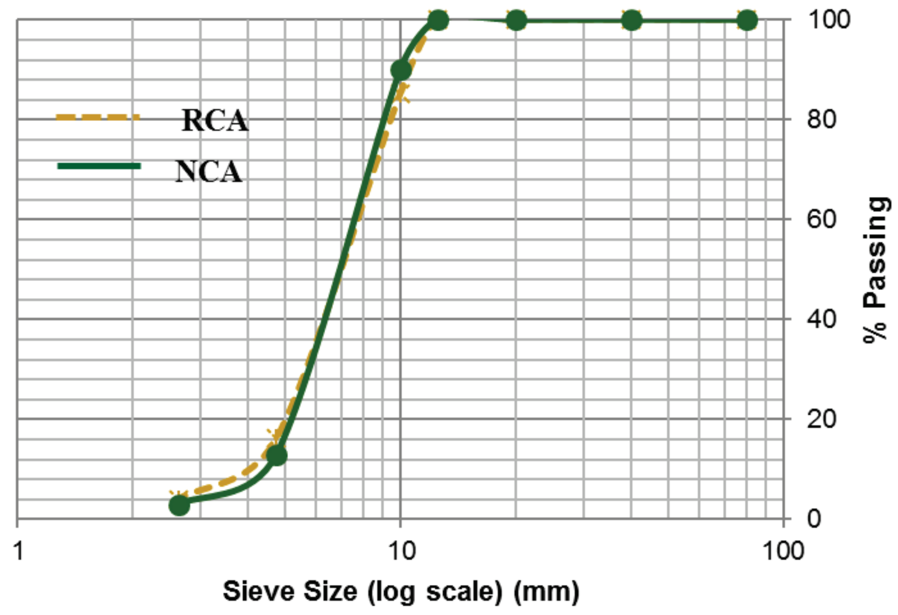


***Fig.-1: Grading curves for NCA and RCA used in this investigation***

The RCA were obtained by crushing of waste concrete specimens sourced from the Concrete Technology Laboratory of the author's Institute. The size fractions of the RCA particles obtained were so blended that the grading curves of both the RCA and NCA were comparable. The comparative representation of the grading curves of RCA and NCA is shown in Fig.-1. Crushed rock with fineness modulus of 6.13 was used as NCA in the SCC mixes. The fine aggregates were consisted of clean river sand with fineness modulus 2.64. Polycarboxylic ether based superplasticizer by weight of cement was used to ensure flowability of the SCC mixes while stability was sought to be controlled by the use of a viscosity modifying agent.

### *3.2 SCC mix proportions*

The basic mix proportions of the control SCC mix made with 100% NCA are given in Table-1. Both the NCA and RCA prior to mixing were first brought to the saturated surface-dry moisture state which was sought to be achieved by pre-soaking the aggregates for a period of 24 hours. The SCC mixes were prepared in the laboratory using a tilting type drum mixer and the workability results of all the SCC mixes along with mix designations and description are presented in Table-2. For the purpose of quality control and for measuring the durability properties of the SCC mixes the specimens which cast were: 100 mm sized cubes for Compressive Strength Tests, cylinders of 100 mm diameter and 200 mm height for Capillary Suction Tests (CST) and for Rapid Chloride Penetration Tests and 150 mm sized cubes for Water Permeability Tests and Initial Surface Absorption Tests. The specimens were demoulded 24 hours after casting following which they were moist cured for either 7 or 28 or 56 or 120 days depending upon the curing duration after which the relevant tests had to be carried out. Three nominally identical companion specimens were cast for each parameter under investigation and the reported test results are the averages of the results of the three companion specimens.

**Table 1 - Mix proportioning for SCC control mix**

| Mix ID. | Water (kg/ $m^3$) | PC (kg/ $m^3$) | FA (kg/ $m^3$) | Natural sand (kg/ $m^3$) | NCA (kg/ $m^3$) |
|---|---|---|---|---|---|
| C-R0 | 277 | 430 | 185 | 846 | 602 |

**Table 2 - Mix designation, description and workability test results for various SCC mixes**

| Mix ID. | Mix description | Slump flow | | V - funnel (s) | L-Box ($h_2/h_1$) | Whether conforms EFNARC guidelines |
|---|---|---|---|---|---|---|
| | | T50 (s) | D (mm) | | | |
| C-R0 | PC+FA+0%RCA | 2.5 | 720 | 6 | 0.95 | Yes |
| C-R50 | PC+FA+50% RCA | 2.8 | 700 | 7.1 | 0.92 | Yes |
| C-R100 | PC+FA+100% RCA | 3.2 | 690 | 7.5 | 0.82 | Yes |

### *3.3 Test methods*

#### *3.3.1 Compressive strength test*

Compressive strength tests were conducted under Compression Testing Machine in accordance with IS 516-1959 [13] at the curing ages of 7, 28, 56 and 120 days.

#### *3.3.2 Initial surface absorption test*

Initial Surface Absorption Test gives the rate of flow of water into concrete per unit area at a stated interval from the start of the test and at a constant applied head of water. Estimation of the flow volume is obtained by measurement of the length of flow along a capillary of known dimension. The Initial Surface Absorption (ISA) of the SCCs was found by testing the 150 mm sized cubes at the curing ages of 28, 56 and 120 days in accordance with BS 1881-208:1996 [14]. The specimens were oven-dried to constant weight prior to the test and left to cool to the laboratory temperature in a desiccator. The water contact area is defined by a plastic cell sealed onto the concrete surface of the test specimen and is not kept less than 5000 mm$^2$. Test setup is shown in Fig.-2 and the water is introduced into the cell via a connecting point and pressure is maintained at a head of 200 mm using a funnel. A second connection point to the cap leads to a horizontal capillary tube. At the start of the test, the connection to the reservoir is closed and the absorption is measured by observing the movement of the end of the water line in the capillary tube with an affixed scale at 10 minute interval. The ISA-10 (Initial Surface absorption at 10 min) was calculated as per the procedure laid down in the aforesaid Standard.

*Fig.-2: Test setup for the initial surface absorption test*

### *3.3.3 Water permeability test*

Water permeability test was performed in accordance with BS EN 12390-8:2000 [15] using specimens of size 150 mm × 150 mm × 150 mm at the curing ages of 28, 56 and 120 days. The specimens were kept under water pressure of 500 ± 50 kPa for 72 ± 2 hours. After the specified interval, the specimens were removed from the apparatus and split in two halves, perpendicularly to the face on which the water pressure was applied. As soon as the split face had dried to such an extent that the water penetration front could be clearly seen, the water front was marked on the specimen. The maximum depth of water penetration was recorded to the nearest millimetre. An example of a water penetration front is presented in Fig.-3.

### *3.3.4 Capillary suction test*

Capillary suction test is used to determine the rate of absorption (sorptivity) of water by hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water. In this investigation, the CST was conducted in accordance with ASTM C 1585 – 04 [16] at the curing ages of 28, 56 and 120 days. Discs of 100 mm diameter and 50 mm thickness were cut from the 100 mm × 200 mm cylinders and kept for oven drying till constant mass was achieved. The specimens were then allowed to cool to room temperature and kept in a desiccator till testing. The sides of the specimens were suitably sealed. The end of the specimen, which was not in contact with water was also sealed using a loosely attached plastic sheet. The mass of the specimen was recorded with a precision balance. As shown in Fig.-4, during the course of the tests the specimens were supported in such a way that the exposed end of each specimen was in touch with water. The mass of the specimens was recorded at suitable intervals as laid down in the Standard. The Initial Rate of Absorption (IRA) of water was calculated as per the procedure given in the Standard.

***Fig.-3: Water penetration front in one of the water permeability tests***

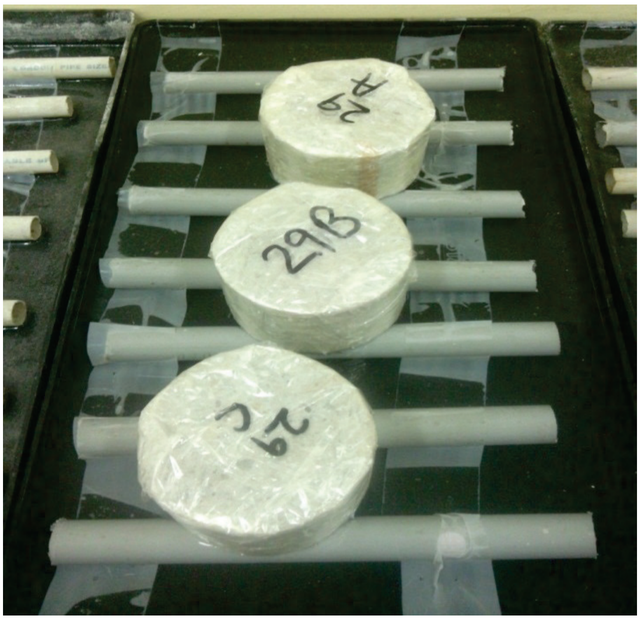


***Fig.-4: Test setup for the capillary suction test***

### *3.3.5 Rapid chloride penetrability test*

Rapid chloride penetrability of the SCC mixes was measured at the curing ages of 28, 56 and 120 days in accordance with ASTM C1202-94 [17] as shown in Fig.-5 using a 100 mm diameter and 50 mm thick concrete disc cut from the cylindrical specimen. The resistance of concrete against chloride ion penetration is represented by the total charge passed in coulombs during a test period of 6 hours.

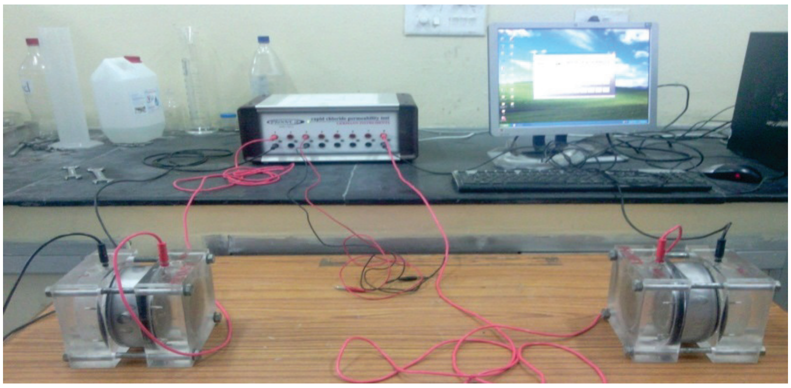

***Fig.-5: Test setup for the rapid chloride penetrability test***

# 4 Results and Discussion

## *4.1 Compressive strength*

The results of the compressive strength tests conducted on SCC mixes with partial and full replacement of NCA with RCA at curing periods of 7, 28, 56 and 120 days are shown in the Fig.-6. It can be observed that in general, the SCC mix show insignificant reduction in compressive strength up to 50% replacement of NCA with RCA. A marginal reduction of the order of 4.3%, 4.5%, 3.7%, 5.5% is observed for the concrete mix C-R50 with respect to the control mix C-R0 for curing periods of 7, 28, 56, and 120 days respectively.

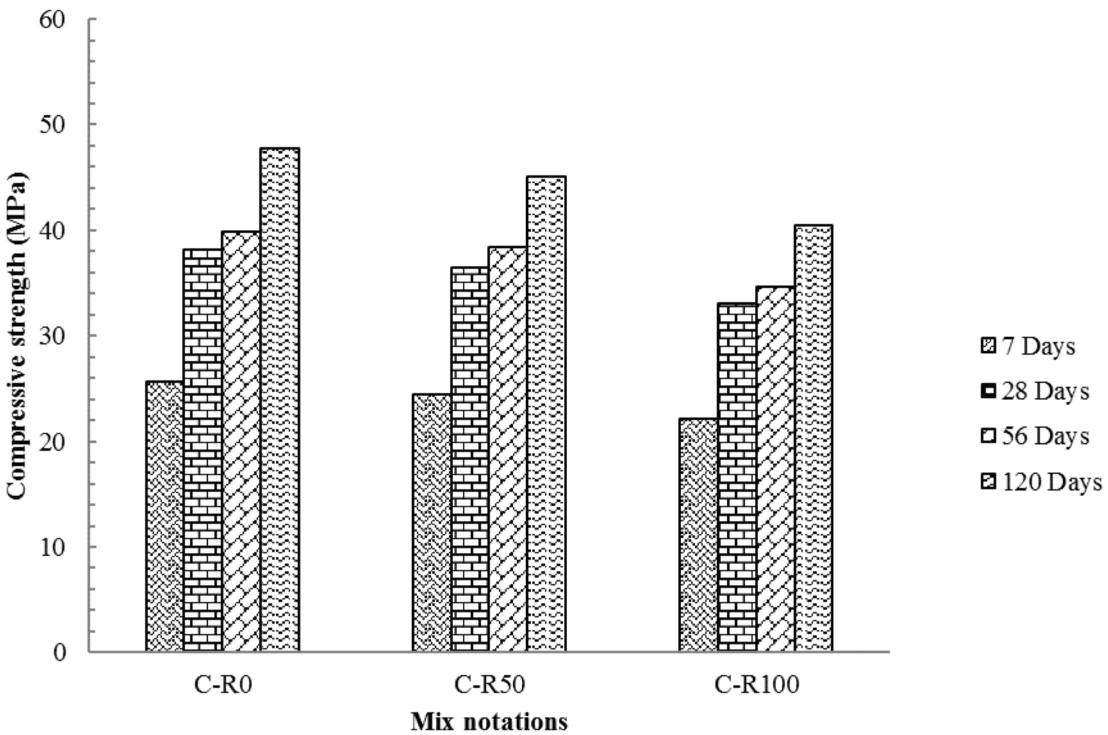


***Fig.-6: Compressive strength tests results for SCC mixes***

The reduction in strength becomes more evident for complete replacement of NCA with RCA. Reduction in the compressive strength of the order of 13.3%, 13.4%, 13.4% and 15.1% was observed for 7, 28, 56, and 120 days of curing respectively for the SCC mix C-R100 compared to the control mix C-R0 in which all the NCA have been replaced by RCA. This behaviour of loss in strength for SCC mix C-R100 can be mainly attributed to presence of the residual mortar in RCA which is responsible for the degradation of the mechanical properties of RCA itself.

### *4.2 Initial surface absorption*

The ISAT results for various SCC mixes tested in this investigation are shown in Fig.-7. It can be seen that ISA-10 values increase with the increase in the RCA content at all the curing ages tested in this investigation. For 50% replacement of NCA with RCA, there was an increase in the value of ISA-10 by the order of 12.6%, 13.8% and 14.5% at 28, 56 and 120 days of curing period respectively. This increase in the value of ISA-10 becomes significant for the 100% replacement of NCA with RCA. In this case, an increase of the order of 30%, 30.5% and 26.5% was observed for SCC mix C-R100 compared to mix C-R50 at curing periods of 28, 56 and 120 days respectively. Higher ISA-10 values indicate higher surface porosity which suggests that with increasing content of RCA the surface porosity of the SCC mix increases.

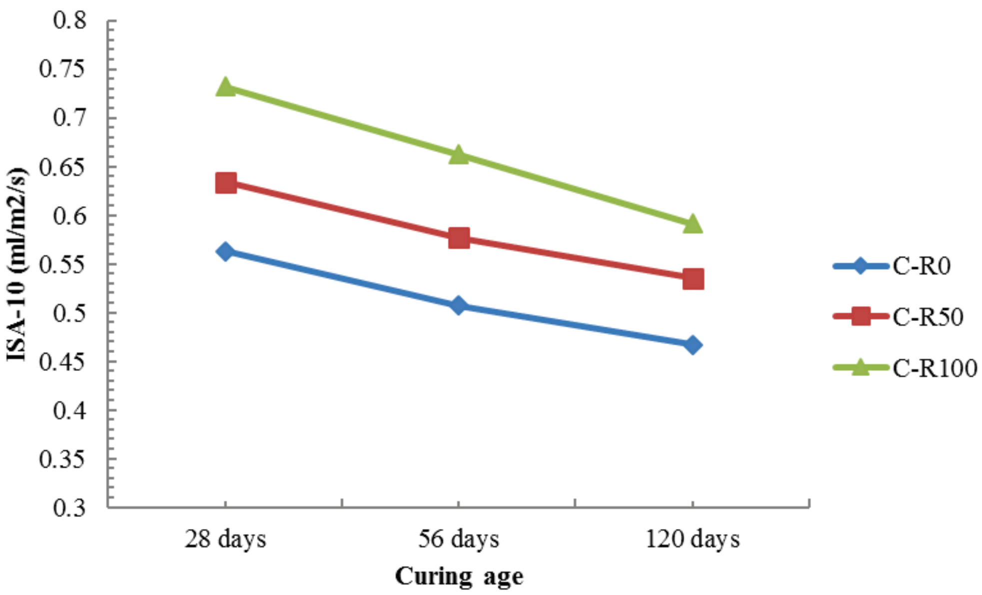


*Fig.-7: Initial surface absorption tests results for SCC mixes*

### *4.3 Water permeability*

Figure-8 shows the results of water penetration depths of different SCC mixes with partial and full replacement of NCA with RCA. It was observed that, there was increase in the depth of water penetration in the SCC mixes with the increase in the RCA content at all the curing ages tested. The SCC mix C-R50 made with 50% RCA shows an increase in the depth of water penetration by an amount of 7.4%, 8.3% and 20% at 28, 56 and 120 days respectively compared to the control mix C-R0. Furthermore, complete replacement of NA with RCA in SCC mix C-R100 shows a predominant rise in the water penetration depth by 29.6%, 20.8% and 33.3% at 28, 56 and 120 days respectively. Indeed, the presence of porous residual mortar on the surface of RCA is a major factor affecting the water penetration values in significant manner.

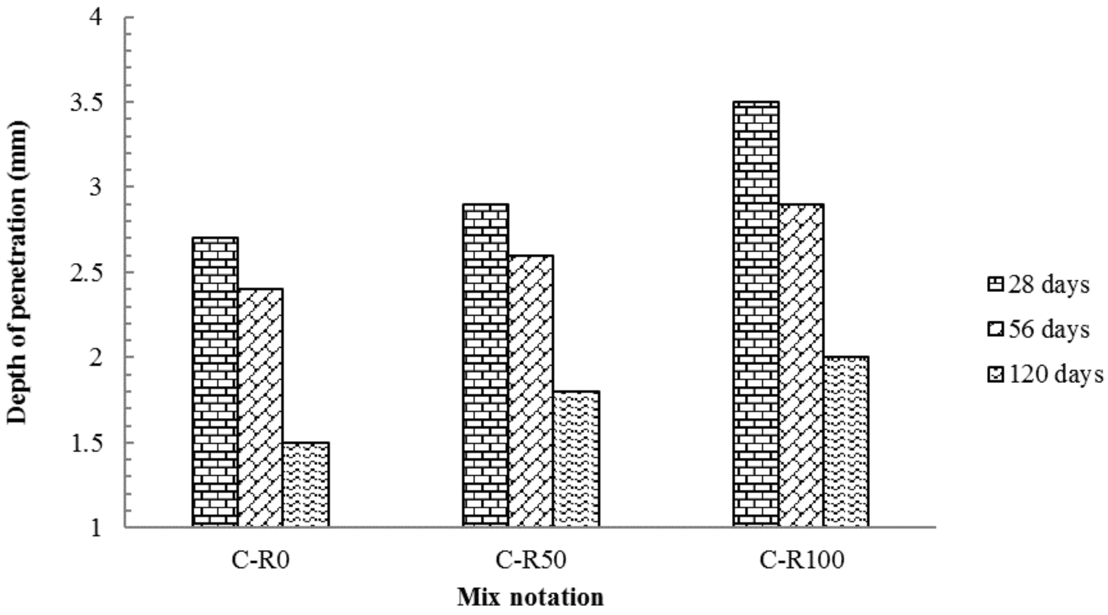


*Fig.-8: Water permeability tests results for SCC mixes*

### *4.4 Capillary suction*

The results of capillary suction test conducted on SCC mixes with partial and full replacement of NCA with RCA at 28, 56 and 120 days of curing are presented in Fig.-9. It can be observed from Fig.-9 that, there has been increase in the values of Initial Rate of Absorption (IRA) with the increase of RCA content in SCC mixes compared to control mix.

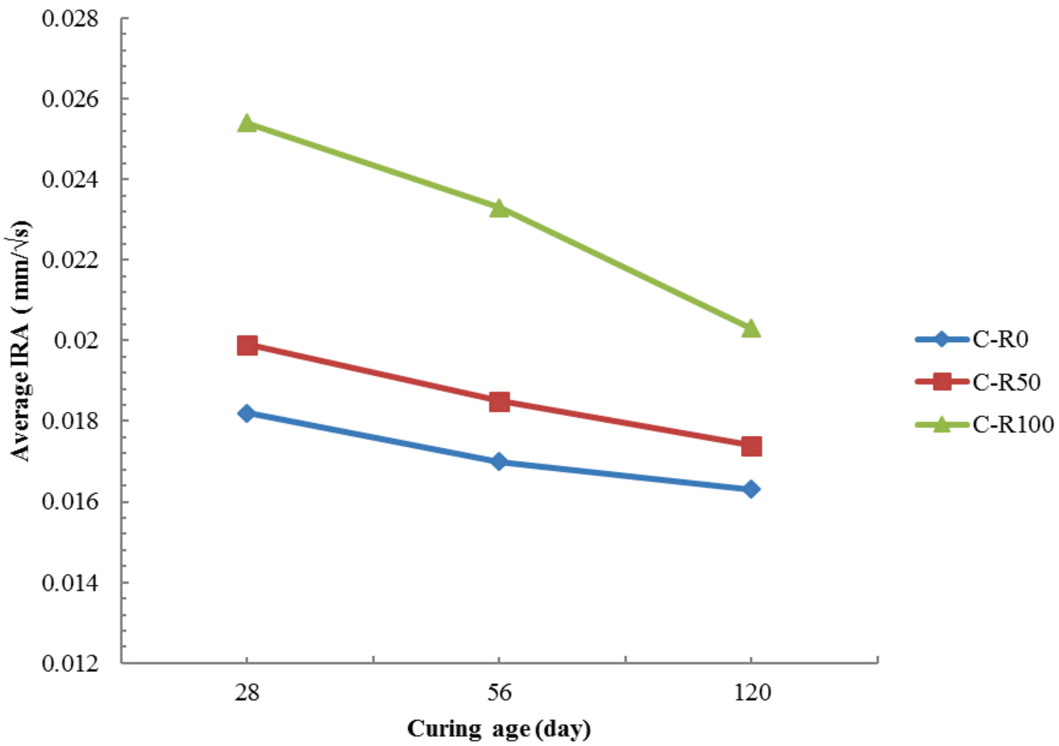


*Fig.-9: Capillary suction tests results for SCC mixes*

For example, at 50% replacement of NCA with RCA, the IRA marginally increases by the order of 9.34%, 8.82% and 6.75% at 28, 56 and 120 days of curing respectively compared to control SCC mix C-R0. The increase in IRA becomes more pronounced with full replacement of NCA with RCA, as there was an increase of 39.5%, 37% and 24.5% in the IRA values at 28, 56 and 120 days of curing respectively compared to the control SCC mix. This suggests that up to 50% replacement of NCA, the increase in absorption rate was marginal but during complete replacement IRA increases sharply.

### *4.5 Rapid Chloride Penetrability*

The results of resistance to chloride ion penetration of the various SCC mixes made with 50% and 100% RCA at 28, 56 and 120 days of curing are shown in Fig.-10. The results for control mix containing 0% RCA at different curing ages are also plotted for comparison. Figure-10 shows that the resistance to chloride ion penetration decreased with the increase in RCA content at all curing ages. From the results, it can be observed that incorporation of 50% RCA in SCC mix C-R50 shows an increase in the total charge passed by about 6.6%, 7.3% and 6.25% respectively after 28, 56, 120 days of curing. Similarly, the SCC mix C-R100 shows increment in the total charge passed relative to the control mix C-R0, which is of the order of 12.9%, 11.4% and 13.8% at 28, 56 and 120 days of curing. This increase in the charge penetration is related to the presence of high volume pores within the RCA mixes and this volume is expected to increase with an increase in the content of RCA. Again, the presence of cracks fissures in RCA can also be a possible reason for the SCC mixes C-R50 and C-R100 to diffuse chloride ions easily.

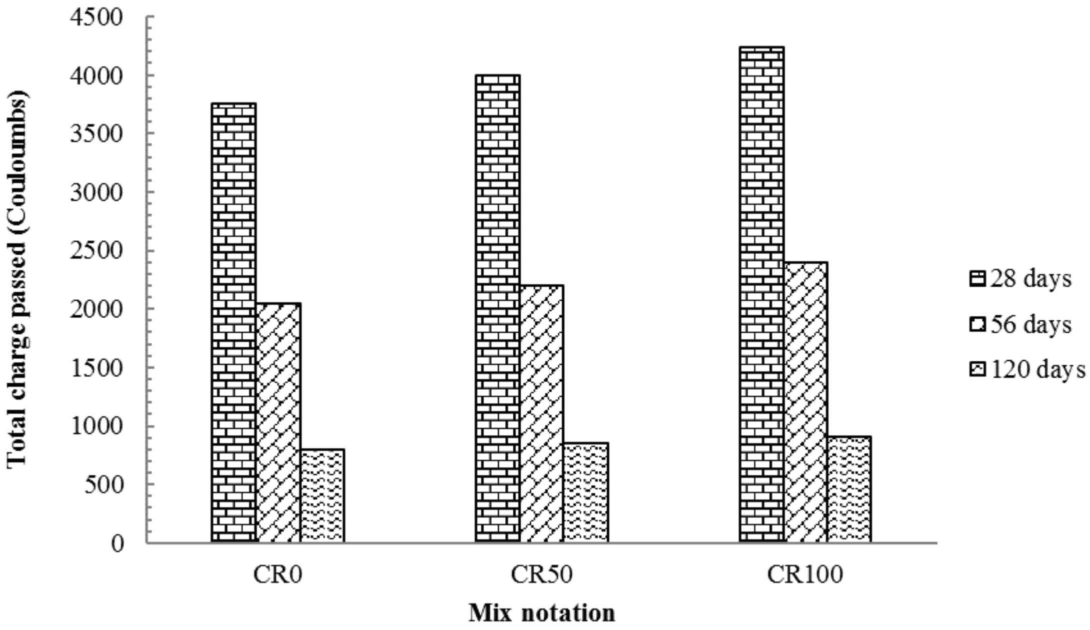


***Fig.-10: Rapid chloride penetration tests results for SCC mixes***

## 5 Conclusions

- Relative to the control SCC made with NCA, the 28-day compressive strength decreased by 13% when all the NCA were replaced with the RCA. The decrease in the compressive strength is insignificant for up to 50% replacement of NCA with RCA.

- Initial surface absorption of the control concrete increased with increase in the RCA content for all the curing ages, with changes of the order of 30% being observed when NCA were completely replaced with the RCA.

- Water penetration depths increased with increase in the content of RCA in the SCC mixes.

- Increase in initial rate of absorption of the SCC with 50% RCA was marginal but with complete replacement it becomes significant. As was about 40% higher IRA was observed for complete replacement of NCA with RCA as compared to that of the control SCC mix made with NCA only.

- Resistance to the chloride ion penetration was reduced with the increasing content of RCA in the SCC mixes at all the curing ages tested in this investigation.

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