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Strength and Durability Properties of Eco-SCC Using Recycled Aggregate from Building Demolished Waste (BDW)

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Abstract—*The main problems faced by concrete construction industries are material scarcity and compaction of concrete. During the last decade, rapid progress has been made in the green concrete technology through introduction of self compacting concrete (SCC) as well as use of recycled aggregate in concrete amongst others. The application of recycled aggregate in SCC provides benefits from the perspective of sustainability and environmental protection. In the present study use of recycled aggregate in Self Compacting Concrete is studied and a comparison was made with SCC made with natural aggregate. The parameters of the study include grade of concrete, type of aggregate, age of curing. Sorptivity, acid attack, rapid chloride permeability (RCPT), compressive strength, split tensile and flexural strength tests are carried for determining durability and mechanical properties of Self Compacting Concrete made with natural aggregates and recycled aggregates. It is observed that SCC with recycled aggregates (Eco-SCC) gave on par results with SCC made using natural aggregates.*

Keywords: *Recycled Aggregate; compressive strength; acid attack; RCPT*

1. INTRODUCTION

Reuse of aggregates from demolished concrete structures was introduced into practice many years ago, and from the beginning it has been considered in main two environmental aspects: solving the increasing waste storage problem and protection of limited natural sources of aggregates. Sustainable development was defined as "development that meets the needs and aspirations of the present without compromising the ability of future generations to meet their own needs"[1].Shortage of natural aggregate in urban environments and increasing distance between the sources of quality natural aggregate and construction sites compelled in substituting natural aggregate by recycled material. On the other hand, large quantities of old concrete often occur in urban environments, whose removal and disposal presents an environmental problem. Since the use of recycled concrete aggregate helps to reduce both of these important environmental issues, it is becoming a more desirable building material. To achieve sustainable development in concrete, along with materials the type of concrete is also to be modified. One of the forward steps in progressing towards sustainability is use of self compacting concrete in place of ordinary concrete. Self Compacting Concrete (SCC) is considered as a concrete which can be placed and compacted under its self-weight with little or no vibration effort, and which is at the same time cohesive enough to be handled without segregation or bleeding. In recent years, SCC has gained wide use for placement in congested reinforced concrete structures with difficult casting conditions. For such applications, the fresh concrete must possess high fluidity and good cohesiveness. From the last two decades, many researchers [2-5] have studied the performance of SCC for the fresh and mechanical properties with different admixtures like fly ash, GGBS and micro silica etc.

2. RESEARCH SIGNIFICANCE

Due to the large depletion of natural resources, there arises a dire necessity to look for alternate resources. Sustainability of natural resources is hence a prime factor. It is felt there replacement of natural coarse and fine aggregates with recycled coarse and fines in SCC and thereby examining the fresh properties along with the strength and durability results of recycled aggregate can ensure sustainable Eco-SCC. In the present work aggregates from building demolished waste (BDW) are attempted.

3. EXPERIMENTAL WORK

The experimental programme consists of developing recycled and natural aggregate SCC mix proportions, for both A-Mix and B-Mix based on Nan Su specifications. The mix proportions obtained were tested for the fresh properties as per EFNARC guidelines [6] and hardened properties in accordance with IS: 516:1956 [7]. After confirming the results of these two mixes of concrete viz. Mix-A and Mix-B, for both recycled and natural aggregates durability tests on each of them were performed.

3.1 Materials Used

a) Cement: Cement used in the project was 53 Grade Ordinary Portland cement confirming to IS: 12269:2013 [8]. The specific gravity of cement was 3.14 and specific surface area of 225 m^2/g having initial and final setting time of 45 min and 560 min respectively.

b) Recycled Fine Aggregate: The recycled fine aggregate were obtained by crushing the left out tested concrete specimens in concrete technology laboratory. The specific gravity was 2.27, while the bulk density of sand was 1.26 gram/c.c. Fineness modulus 2.87 and water absorption was 8.5%. The Recycled fine aggregate was conforming to Zone-2 according to IS: 383:1970 [9].

c) Natural Fine Aggregate: The fine aggregate was conforming to Zone-2 according to IS: 383:1970 [9]. The fine aggregate used was obtained from a nearby river source. The specific gravity was 2.65, while the bulk density of sand was 1.45 gram/c.c.

d) Recycled Coarse Aggregate: Recycled Coarse aggregates of 20 mm size were used. The recycled coarse aggregate was obtained by crushing the left out tested concrete specimens in concrete technology laboratory having 20mm nominal size according to IS: 383:1970 [9]. The specific gravity was 2.55, Fineness modulus was 7.15 and water absorption was5.68 while the bulk density was 1.28 gram/c.c.

e) Natural Coarse Aggregate: Crushed granite was used as coarse aggregate. The coarse aggregate was obtained from a local crushing unit having 20mm nominal size, well graded aggregate according to IS: 383:1970 [9]. The specific gravity was 2.8, while the bulk density was 1.5 gram/c.c.

f) Fly Ash: The fly ash used in the experiments was from Ramagundam thermal power station (NTPC) was sieved by 90 micron sieve and confirmed to IS 3812:1981 [10]. The specific gravity was 2.17. The fly ash had a silica content of 63.99%, silica+ alumina +iron oxide content of 92.7%, Calcium oxide of 1.71% , Magnesium oxide of 1.0%, Sulphuric anhydride of 0.73% , water and soluble salts of 0.04%, pH value of 10 and a loss on ignition of 2.12.

g) Water: Potable water was used in the experimental work for both mixing and curing companion specimens.

h) Micro silica: It is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. The specific gravity of silica fume is generally in the range of 2.2 to 2.3. It typically ranges from 15,000 to 30,000 m^2/ kg. To get better results, the dosage of micro silica is 8% of weight of cement.

i) Super plasticizer: High range water reducing admixture confirming to ASTM C494 [11] commonly called as super plasticizers was used for improving the flow or workability. In the present investigation, water-reducing admixture CHRYSO FLUID OPTIMA P-77 (poly carboxylic ether based) obtained from Chryso Chemicals, India was used.

3.2 Mix Design

Nan Su method of simple mix design for SCC was used to get trial mixes and then mixes were confirmed as per EFNARC specifications [6]. The quantities for two mixes A, B per m^3 of concrete is as given in Table 1.

Table 1: Mix Proportions of SCC for Mixes A and B

Material	Quantity in Kg/m3	
	MixA	**Mix B**
Cement	500	360
Recycled Fine Aggregate	800	860
Recycled Coarse Aggregate	775	788
Water	194	188
Fly ash	110	250
Micro Silica	40	-

3.3 Casting

The standards moulds were fitted such that there are no gaps between the plates of the moulds.. A pan mixer of having 100 Kg capacity was used for mixing concrete. After 24hrs of a casting, the moulds were kept under curing for the required number of days before testing.

3.4 Curing

After the completion of casting all the specimens were kept to maintain the ambient conditions viz. temperature of 27±2 C and 90% relative humidity for 24hours**.** The specimens were removed from the mould and kept in water for specific curing time.

4. TESTS ON RECYCLED AND NATURAL SCC

4.1 Tests on Fresh Properties

The mix design which is selected finally is mainly based on their relationship with the key properties of SCC Viz: filling ability, passing ability, and resistance to segregation. Various Fresh properties tests- slump flow, L-box, J-ring, and V-funnel tests were carried out on Self Compacting Concrete of both the mixes for recycled and natural SCC. The fresh property test results of Mix-A and Mix-B for recycled and natural aggregates SCC are shown in Table 2. It is observed that Mix-A and Mix-B for recycled and natural aggregates SCC satisfy EFNARC specifications [6].

4.2 Tests on Hardened Properties

After satisfying the fresh properties of SCC, the hardened properties of these two mixes of self compacting concrete (Mix-A and Mix-B) of both types of aggregates are determined. For each test i.e. compressive strength, split strength and flexural strength test, a total of 18 specimens are cast and tested. The testing procedure adopted for each specific test is as per IS 516-1956 (7).

Table 2: Fresh properties of RSCC and NSCC

Properties	EFNARC Range	Designation	R SCC	N SCC
Slump flow (mm)	650-850	MIX-A	700	700
		MIX-B	665	670
T 50 (sec)	2-05	MIX-A	2	3.69
		MIX-B	3.27	2.4
J-Ring (mm)	0-10	MIX-A	5	5
		MIX-B	8	8
L-Box	0.8-1.0	MIX-A	0.94	0.94
		MIX-B	0.87	0.87
V-Funnel (Sec)	6-12	MIX-A	6	11.5
		MIX-B	6.19	9.77
V 5min (sec)	6-15	MIX-A	7	17
		MIX-B	7.44	10.6

4.3 Tests on Durability Properties

4.3.1 Sorptivity Test

The sorptivity tests were carried out on RSCC and NSCC for both mixes with size of 150 x 150 x 150 mm. The preparation of samples also included water impermeability of their lateral faces, reducing the effect of water evaporation. The test started weighing the samples and afterwards they are placed in a recipient in contact with a level of water capable to submerge them about 5 mm. After a predefined period of time, the samples are removed from the recipient and they are weighted. The procedure was repeated, consecutively, at various times such as 10min, 20min. 30min, 1hr, 2hr, 3hr and 6hrs (12).

Because of a small initial surface tension and buoyancy effects, the relationship between cumulative water absorption (kg/m^2) and square root of exposure time ($t^{0.5}$) shows deviation from linearity during first few minutes. Thus, for the calculation of sorptivity coefficient, the section of curves for the above exposure period of 10min to 6 hours and linear curves were plotted. The sorptivity coefficient (S) was taken by using the following expression obtained from equation of curve line:

$i = S\sqrt{t} + C$ .... Eq. (1)

Where, i = cumulative water absorption per unit surface area in “mm”

$i = \frac{\Delta W}{A * D}$

Where ΔW = the amount of water adsorbed in (g); A = the cross-section of specimen that was in contact with water (mm^2); D = density of water; S = the sorptivity coefficient of the specimen (m/min$^{0.5}$); C= constant

4.3.2 Acid Attack

The chemical resistance of the concrete was studied through chemical attack by immersing them in an acid solution. Being alkaline in nature concrete is susceptible to acid attack. The components of cement products were broken down and leave the weak reaction materials on form of loose materials on the concrete surface. After 28days curing period the specimens of each batch were taken and their surfaces were cleaned with a soft nylon brush to remove weak reaction products and loose materials from the specimen. The initial mass, body diagonal dimensions values were measured. 2specimens of each batch of concrete were immersed in 5% HCl.

The mass, diagonal dimensions values are measured at 3, 7, 14, 21, 28 days of immersion. Compressive strength is measured after 28days of immersion before testing; each specimen is removed from the baths, brushed with a soft nylon brush and rinsed in tap water. This process removes loose surface material from the specimens. Mass change, reduction in compressive strengths values and diagonal dimensions are observed. The results of acid attack were presented in 3 factors namely, acid strength loss factor, acid attack factor and acid mass loss factor. Acid attack and mass loss factors related to the change in diagonal dimension and mass with time.

In the present work, the “Acid Strength Loss Factor (ASLF)” is derived from Eq. (2).

ASLF = (Loss in strength due to immersion in acid/ Strength at 28 days) x 100 .... Eq(2)

The extent of deterioration at each corner of the struck face and the opposite face is measured in terms of the acid diagonals (in mm) for each of two cubes and the “Acid Attack Factor” (AAF) per face is calculated as per Eq. (3).

AAF = (Loss of acid diagonal after immersion)/ (Acid diagonal before immersion) x100 .... Eq. (3)

To evaluate acid mass loss factor (AMLF), initial mass of each specimen was taken as a reference value. Change in mass was observed with age of immersion in acid. The difference between mass at a particular age and reference value will give the change in mass.

AMLF= (Loss of mass after immersion)/(original mass of specimen before immersion) x 100...Eq (4)

5. RESULTS AND DISCUSSIONS

5.1 Compressive Strength (CS)

Compressive strength test was carried on all mixes of all types of concrete using same quantity of cement and its variation with the age of concrete is plotted. It can be observed from Fig. 1 that the difference in compressive strengths of SCC with natural aggregates and SCC with recycled aggregates for the same type of mixes was less which later increases and become nearly constant at 28 days. It can be inferred that, for the same mix and same quantity of cement, results of compressive strengths for SCC with recycled aggregates is on par with that of SCC with natural aggregates. The lesser value can be accounted in the case of former due to slightly inferior quality of aggregates.

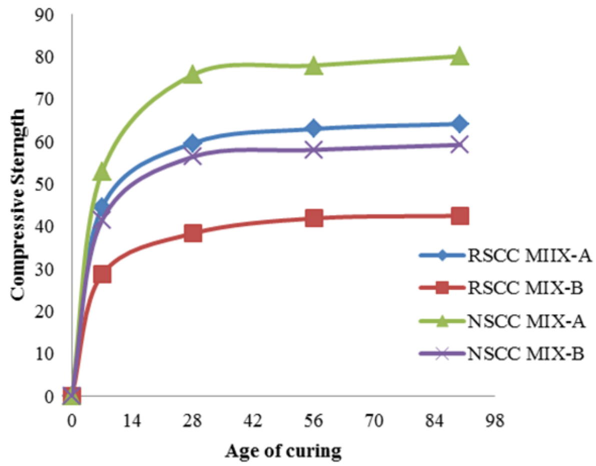

Fig. 1: CS of RSCC and NSCC

5.2 Split Tensile Strength (STS)

Split tensile strength test was conducted all type of concretes and results are tabulated. Variation of split tensile strength test with compressive strengths of respective type of concrete is also plotted. It can be observed from Fig. 2 that that slope for SCC with natural aggregates is slightly more as compared to that of SCC with recycled aggregates which show that increase in split tensile strength for SCC with natural aggregate is more than that of SCC with recycled aggregates. So the results for split tensile strength for both type of concrete are comparable.

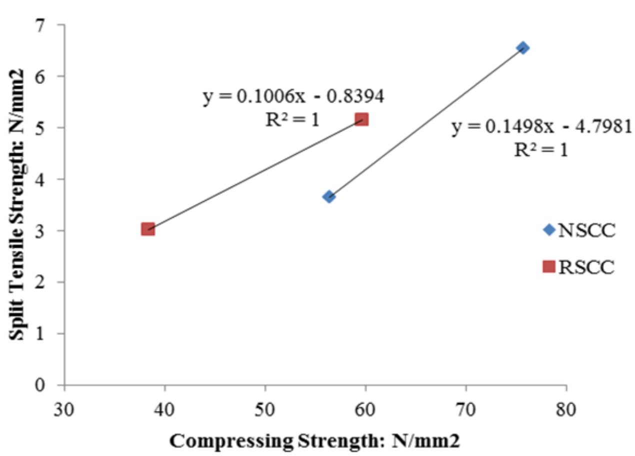

Fig. 2: STS VS CS of recycled, natural SCC

5.3 Flexural Strength (FS)

Flexural strength test was conducted all type of concretes and results are tabulated. Variation of flexural strength test with square root of compressive strengths of respective type of concrete is also plotted to determine how many times of square root of compressive strength is the flexural strength for a particular type of concrete . It can be observed from Fig. 3 that that slope for SCC with natural aggregates is slightly more as compared to that of SCC with recycled aggregates which show that increase in flexural strength for SCC with natural aggregate is more than that of SCC with recycled aggregates. So the results for split tensile strength for both type of concrete are comparable.

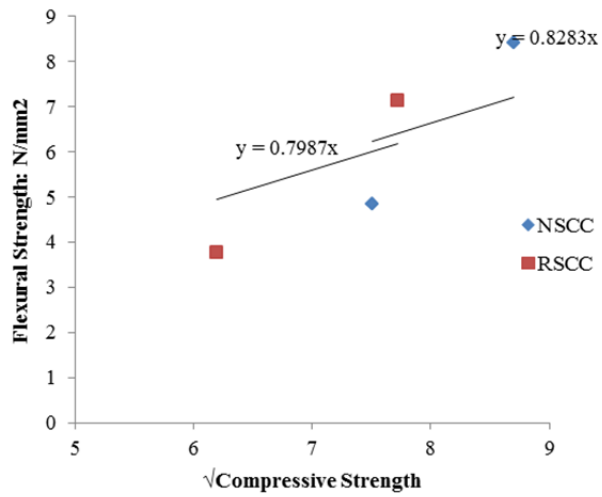

Fig. 3: FS VS √CS of Recycled, Natural SCC

5.4 Sorptivity Test

The absorption and transmission of water by capillary action called as ‘‘Sorptivity” is found based on Hall’s work [12]. This test indirectly indicates the amount of voids present in the concrete and the results are obtained by water retention test. The concrete specimens with more water retention capacity show less water absorption. A higher value of sorptivity coefficient indirectly indicates the presence of more voids. From the Figs 4 -6, Sorptivity is observed to be more for SCC with recycled aggregates as compared to that of SCC with natural aggregates this could be accounted because of slightly lower quality of aggregates.

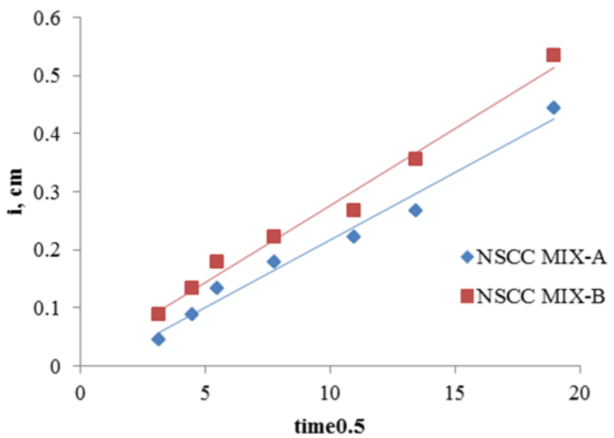

Fig. 4: i Vs √time of Natural SCC.

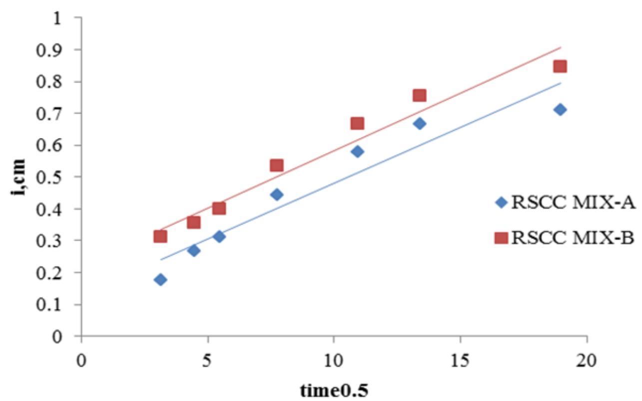

Fig. 5: i Vs √time of Recycled SCC

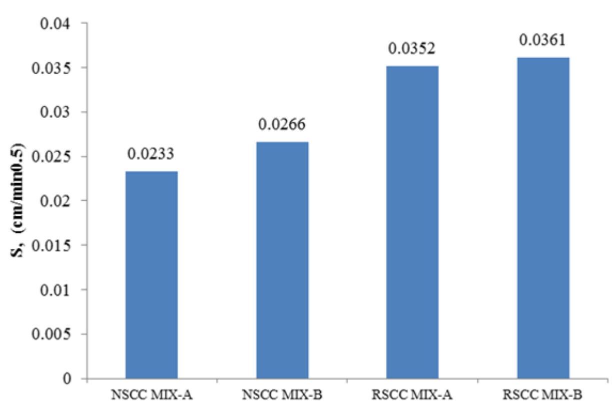

Fig. 6: Sorptivity Coefficient Vs Recycled and Natural SCC

6.5 Acid Attack

The resistance of concrete to chemical attack can be understood by subjecting cubes to undergo acid attack by immersing them in HCl solution. The loss in mass, strength and geometry can be determined using Acid Mass Loss Factor, Acid Strength Loss Factor and Acid Attacking Factor.

It can be observed that in case of 5%HCl, from Figs 7-9, Acid attacking, Acid mass loss and Acid strength loss factors for SCC with natural aggregates is less as that of SCC with recycled aggregates.

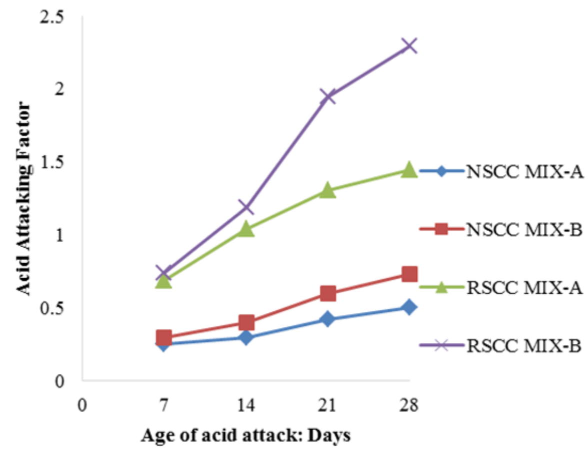

Fig. 7: AAF Vs Age of Acid attack

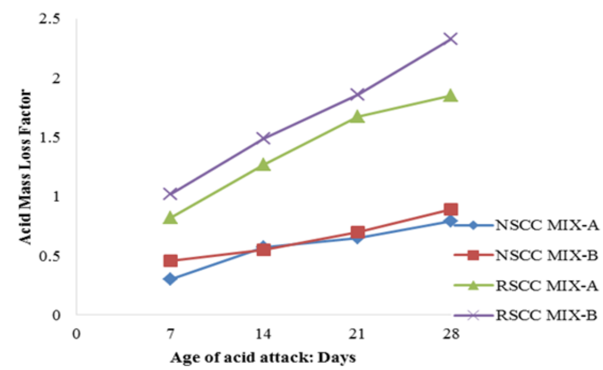

Fig. 8: AMLF Vs Age of acid attack

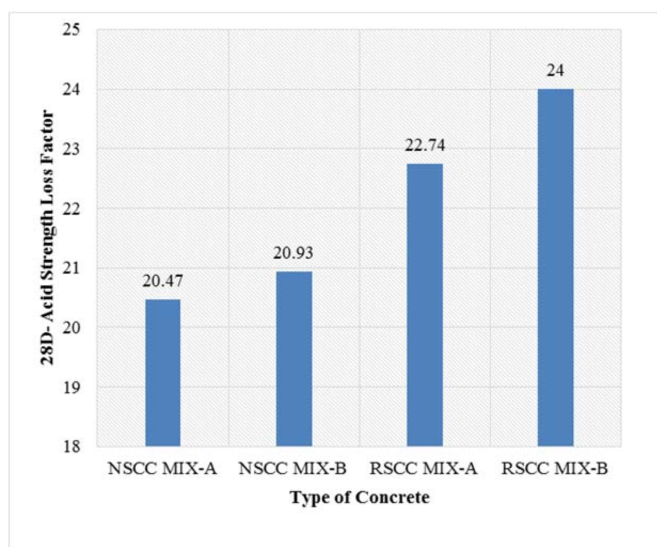

Fig. 9: 28 DAYS ASLF Vs Type of concrete

6. CONCLUSION

From the detailed experimental study, the following conclusions are drawn:

1. In Self Compacting Concrete, with 100% replacement for natural aggregates, Recycled-SCC achieved sufficient fresh properties with slight change in water reducing admixture.
2. The compressive strengths are slightly less in RSCC specimens than NSCC specimens. For A-mix, the increase in compressive strength is 26.96% for NSCC compared to RSCC, whereas, in mix B, the increase in strength is 46.99% for NSCC compared to RSCC.
3. The relationships between Compressive strength and Split Tensile strength are proposed for NSCC and RSCC mixes. The relationships are given as Split Tensile strength = (0.149) x Compressive strength for NSCC and Split Tensile strength = (0.101) x Compressive strength for RSCC.
4. The relationships between Compressive strength and Flexural strength are proposed for NSCC and RSCC mixes. The relationships are given as Flexural strength = (0.828) x √Compressive strength for NSCC and Flexural strength = (0.789) x √Compressive strength for RSCC.
5. The sorptivity coefficient values are moderately higher for RSCC than NSCC which indicates the presence of more voids in RSCC.
6. The durability factors are high for RSCC specimens than NSCC specimens and low grade concretes it is quite higher than high grades.
7. Overall it can be stated that Recycled coarse and fine aggregates obtained from construction demolished waste can be an effective alternative for natural aggregates. Recycled aggregates are well suited for Eco-SCC.

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