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Recycled Aggregate Self Compacting Concrete

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Abstract - An experimental investigation was conducted on self compacting concrete with different percentages of coarse recycled concrete aggregate. The main objective was to study suitability and effect of coarse recycled aggregate in new generation concretes. In the recent years the demand for construction materials has grown tremendously, so has the amount of construction and demolition waste, putting huge pressure on the environment. This has encouraged the use of recycled aggregate in concrete which not only allows for a more efficient life cycle of natural resources but also contributes to environmental protection leading to sustainable development. In this study coarse recycled aggregate (RCA) are used in the production of self compacting concrete (SCC) in varying percentage replacements of natural coarse aggregate (NCA) from 0% to 100% with increment of 20%. The various test performed were compressive strength, split tension test, water absorption, acid attack and chloride ingress. It is observed that up to 40% recycled aggregate can be effectively used in the production of SCC without any significant reduction in strength and durability.
Keywords: recycled aggregate, self compacting, strength, permeability.

I. INTRODUCTION

Recently, there has been an increasing trend toward the use of sustainable materials. Sustainability helps the environment by reducing the consumption of non-renewable natural resources. Concrete the second most consumed material in the world after water uses a significant amount of non-renewable resources. As a result, numerous researchers have investigated the use of recycled materials in the production of concrete such as fly ash [1,2] and recycled aggregate [3-7]. In the recent time due to significant increase in population and urbanization large amount of waste from construction and demolition are generated. Therefore majority of the developed/ developing countries are facing the problem of handling and disposal of such construction and demolition wastes. Considering this aspect, there has been a growing emphasis on the utilization of waste materials and byproducts in construction activities. Use of waste materials not only helps in getting them utilized but also has numerous indirect benefits such as savings in energy and protection of environment.

Over the last decades, large amount of experimental works have been carried out to investigate the material properties [8–14] and durability [15–16] of recycled aggregate concrete (RAC). Accordingly, significant progress has been gained by applying recycled aggregates into construction materials in the form of RAC members [17]. Compared with natural aggregates, recycled aggregates usually have greater porosity and water absorption, lower density, and lower strength than normal aggregate [18–21]. As a result, RAC structural components invariably experience inferior physical and mechanical properties compared to normal aggregate concrete (NAC), such as low mechanical performance and poor durability behavior [22–23]. For concrete made with 100% recycled aggregates, the compressive strength of RAC was reportedly decreased by 9–40% [24-25]. It is generally accepted that the lower elastic modulus of RAC is attributed to a lower modulus of elasticity of recycled aggregate, and the lower strength of RAC is mainly due to the weaker mortar as well as the weaker interfacial transition zone (ITZ) between the old mortar and new mortar [26]. Irrespective of all the inferior properties of recycled aggregate, many researchers are of the opinion that recycled aggregate are a good alternative to natural coarse aggregate in concrete considering its environmental and economical benefit apart from reducing load on natural resources in construction industry.

II. RESEARCH SIGNIFICANCE

Utilization of recycled aggregate in new concrete production has been increasing gradually due to the environmental and economic considerations. However, information on the quality of recycled aggregate concrete is still scarce. This study attempts to examine the influence of recycled aggregate on strength, permeability, acid attack, chloride penetration, and alkalinity of self compacting concrete. This research is an attempt to provide very useful information for the practical use of recycled aggregate in advance concrete production.

III. MATERIALS

An ordinary Portland cement (Grade 53) conforming to IS12269:1987 [27] was used in all compositions. Its specific gravity, specific surface area and 28 days compressive strength were 3.18, 380 m^2/kg, and 56.5 MPa respectively. In order to increase the powder content in SCC silica fume obtained from Elkem Company of grade 920D having specific gravity 2.3 was used. Locally available river sand was used as fine aggregate. The grading of sand satisfied the IS383:1970. The natural aggregate used was crushed basalt of maximum size 12 mm, obtained from nearby stone quarry. The recycled aggregate of 12 mm maximum size used in the investigation was obtained from the demolished cubes tested in concrete technology lab of civil engineering department of B.N. College of Engineering. All the aggregates were immersed in water up to 24 hours and surface dried before use to compensate the effect of initial higher water absorption of recycled aggregates. The aggregate were tested as per IS 383-1970. Table 1 reports the results of various physical properties of aggregates. The superplasticizer used was a polycarboxylic-ether polymer based admixture, commercially branded as Auramix 400 obtained from Fosroc chemicals.

Table 1 Physical properties of aggregates

Characteristics	Natural Coarse Aggregate	Recycled Coarse Aggregate	Fine Aggregate
Specific Gravity	2.65	2.19	2.60
Bulk Density, kg/m^3	1614	1356	1690
Water Absorption, %	1.31	5.64	0.84
Fineness Modulus	6.2	5.96	2.36
Impact Value, %	9.88	17.36	--

IV. MIXTURE DESIGN

For the purpose of the experiment six types of concrete mixes were made. In each mix natural coarse aggregate was replaced by recycled coarse aggregate in the ratio of 0%, 20 %, 40%, 60%, 80% and 100% by volume. The preliminary mix design was carried out using method prescribed by Nan-Su et al, 2001 [28] for target strength of 20 MPa. After the initial mix design, the trial mixes were prepared and tested for the fresh properties of SCC as per EFNARC guidelines [29]. The quantity of components required for making 1 m^3 of concrete was constant, with the exception of small variations in the quantity of superplasticizer for the purpose of achieving equal consistency for all the mixes and due to slightly higher water absorption by the recycled aggregate. To counteract the effect of higher water absorption of recycled aggregate, all the aggregates were immersed in water for 24 hours and surface dried before use. The composition of designed mixtures has been shown in table 2.

Table 2. Details of mixes for 1m^3 concrete

Mix Type	Cement, Kg	Coarse Aggregate, Kg		Fine Aggregate, Kg	Silica Fume, Kg	Water Kg	Dose of SP, Kg
		Normal	Recycled				
R0	270	893	0	936	128	179	3.2
R20	270	714	148	936	128	179	3.2
R40	270	536	296	936	128	179	3.2
R60	270	357	443	936	128	179	3.2
R80	270	179	591	936	128	179	3.9
R100	270	0	740	936	128	179	3.9

V. TEST METHODS

The entire test program was divided in three parts i) Fresh state properties ii) Strength investigations and iii) Durability Investigations.

5.1 Fresh State Properties

Self compacting concrete is characterized by its flowing ability, passing ability, filling ability and segregation resistance. For any concrete to be characterized as self compacting it should possess the above mentioned characteristics. In this experiment the following test methods as suggested by EFNARC were used. Slump-flow test for flowability, V funnel and T_{500} for viscosity and L-box test for testing passing ability. The segregation resistance was observed visually during slump flow test. Table 3 gives the recommended values by EFNARC of SCC for structural purpose for different tests.

Table 3. Typical ranges of values for different tests for SCC

Sr. No.	Method	Unit	Typical range of values	
			Minimum	Maximum
1	Slump Flow	mm	550	800
2	T_{500} slump flow	Sec	2	5
3	V-Funnel	Sec	6	12
4	L-box	(h2/h1)	0.8	1.0

5.2 Strength Investigations

The hardened concrete was tested for 3, 7, 28 and 90 days compressive strength and 28 days tensile strength as per relevant IS codes. For Compressive strength test 72 numbers of 100 mm size cube specimens were cast, whereas for tensile strength test 18 cylinder specimens of 150 mm diameter and 300 mm height were cast.

5.3 Durability Investigations

The durability of a concrete structure is closely associated to the permeability of the surface layer, the one that should limit the ingress of substances (CO_2, chloride, sulphate, water, oxygen, alkalis, acids, etc.) that can initiate or propagate possible deleterious actions. For durability characteristics, several tests are used to evaluate the performance of the concrete in different aggressive environments. The durability properties such as permeable voids, water absorption, chloride attack, acid attack and alkalinity were investigated.

5.3.1 Permeable Voids and Water absorption

In the present investigation the percentage of water absorption and percentage of permeable voids were determined as per the procedure given in ASTM 642-82 [30]. The absorption and permeable voids were determined on 100 mm cubes for each mix. Saturated surface dry specimens were kept in a hot air oven at 105^0 C till a constant weight was attained. The ratio of the difference between the mass of saturated surface dry specimen and the mass of the oven dried specimen at 105^0 C to the volume of the specimen (1000 ml) gives the permeable voids in percentage as given below:

$$\text{Permeable Voids} = [(W1 - W2) / V] \times 100$$

Where, W1 = weight of surface dried saturated specimen after 28 days immersion period. W2 = weight of oven dried specimen in air and V= volume of specimen.

The oven dried cubes after attaining constant weight, were then immersed in water and the weight gain was measured at regular intervals until a constant weight was reached.

5.3.2 Acid attack

The chemical resistance of the concrete was studied through acid attack by immersing cubes in 5% Sulphuric acid solution. The pH of the solution was maintained for entire test duration. After 28 days of curing the specimens were taken out from water and immersed in acid solution. After 28 and 90 days immersion period the specimen were removed from the acid and loss in weight and compressive strength were measured.

5.3.3 Chloride Ingress

Chloride attack is one of the most important aspects for consideration when we deal with the durability of concrete. Chloride attack is particularly important because it primarily causes corrosion of reinforcement. For this test cubic specimen of 100 mm sides was immersed in 5% Sodium Chloride solution. The solution was replaced at regular intervals to maintain constant concentration throughout the test period. After the 28 and 90 days of immersion period the specimen was fractured. The fractured surface was sprayed with 0.1N Silver Nitrate aqueous solution, and the chloride penetration depth was indicated by the white precipitation resulting from the formation of silver chloride.

VI. RESULTS AND DISCUSSIONS

6.1 Fresh State Properties

Results obtained by fresh concrete testing are displayed in Table 4. Slump flow test used to examine flowability property of SCC. All mixes exhibit slump flow in the range of 620-720 mm which is the considered as good slump for civil engineering usage and practice. The T_{500} slump flow is the time for which concrete reaches the diameter of 500 mm and it was measured during execution of slump flow test. It represents the viscosity of mixture. All the mixes recorded the T_{500} time between 2.15 to 3.11 seconds. As per EFNARC specification V-funnel time ranging from 6 to 12 seconds is considered adequate. The test results of V-funnel test for all mixes meet the requirement of flow time which is an indication of good filling ability even with congested reinforcement. The L-box test examined another key property – passing ability. All the mixes meet the criterion that the ration of heights of concrete at the ends of L-box is no less than 0.80. L-box ratio for all mixes were recorded above 0.87. All the mixes showed horizontal slump flow without any bleeding at the periphery which indicates good deformability and segregation resistance.

Table 4. Fresh state properties of SCC

Mix Type	Slump Flow, mm	T_{500} Slump Flow, sec	V-Funnel, sec	L Box, H1/H2
R0	720	2.15	6.08	0.97
R20	670	2.82	6.18	0.92
R40	655	2.63	6.29	0.92
R60	650	2.78	6.72	0.90
R80	685	2.43	6.18	0.87
R100	620	3.11	7.22	0.90

6.2 STRENGTH INVESTIGATIONS

The results of the strength investigations for all the mixes were tabulated in table 5.

Table 5 Compressive strength results

Mix Type	Compressive Strength				Tensile Strength
	3 days, MPa	7 days, MPa	28 days, MPa	90 days, MPa	28 days, MPa
R0	11.16	19.40	26.78	35.33	3.96
R20	10.71	18.90	25.91	32.87	3.68
R40	10.70	18.63	25.14	32.12	3.39
R60	10.20	18.54	24.15	28.40	3.11
R80	10.68	17.98	22.88	26.26	3.11
R100	10.50	17.60	22.08	25.25	2.90

6.2.1 Compressive Strength

The compressive strength results of all the mixes were tabulated in table 5 and shown in figure 2. It is observed that in all the mixes the target strength is achieved. The result reveals that as the percentage of recycled aggregate increases the compressive strength of the SCC decreases. This variation is similar to the results reported by other researchers [31-32]. The inverse relationship between the RCA and compressive strength is due to the poor quality of the adhered mortar which has undergone the crushing process and created the zones of weakness in the concrete. The compressive strength result also revealed that, up to 60% replacement of NCA by RCA, the loss in 28 days compressive strength is found to be 9.82% only. From the figure it is observed that all the mixes have attained almost same compressive strength in 7 days. However mix containing higher amount of RCA fails to maintain the rate of gain of strength at later days. This is attributed to the presence of partially hydrated adhered mortar in the recycled aggregate which contributed for high early strength in RCA mixes.

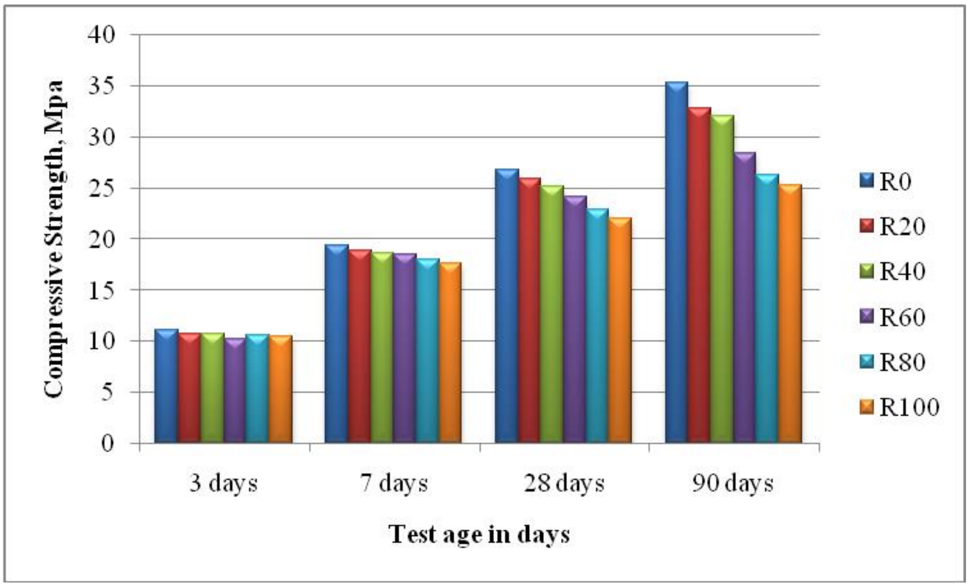

Figure 2: Compressive strength of mixes

6.2.2 Tensile Strength

The results of the split tensile strength of all the mixes are listed in table 5. The result has shown the same trend as that of compressive strength. As the percentage of recycled aggregate increases the tensile strength decreases. This reduction of strength is again significant in the mixes having high amount of recycled aggregates. Visual inspection of fractured surface showed that most failures in recycled concrete mixes occurred were interfacial bond failure and aggregate failure which is on expected line as suggested by researchers [33-34]

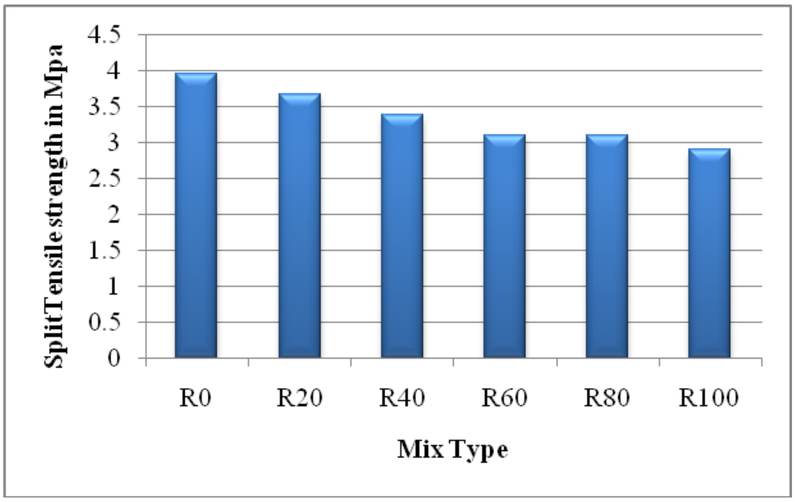

Figure 3: Tensile strength of mixes

6.3 Durability investigations

6.3.1 Water Absorption

Water absorption is the indicator of permeability of concrete. From the results it is clear that water absorption is directly proportional to percentage of recycled aggregate. As the recycled aggregate increases the water absorption increases linearly, which is obviously the result of higher initial water absorption of recycled coarse aggregate. The percent increase in water absorption with increasing RCA were recorded as 4.53%, 12.62%, 14.00%, 20.11% and 26.82% respectively compared to mix containing no recycled aggregate. However the initial water absorption of RCA was 4.3 times (330%) higher than that of NCA.

Table 6 Results of permeability tests

Mix Type	% Water Absorption
R0	5.07
R20	5.3
R40	5.71
R60	5.78
R80	6.09
R100	6.43

6.3.2 Resistance to Acid Attack

The acid resistance test was conducted by immersing the specimens in sulphuric acid solution and measuring the loss in weight and compressive strength of the specimens. From the results it is found that the loss in weight of mixes increases as the replacement of NCA with RCA increases. The mix containing highest amount of coarse recycled aggregate was undergone maximum weight loss of 2.10% and 4.64% respectively at 30 and 90 days immersion period. The loss in compressive strength also shows increasing trend with increase in RCA. However up to 40 % replacement level the loss in compressive strength was just below 10% whereas it increases significantly after that and reaches the maximum value of 20.51%. The loss in compressive strength and weight is attributed to the fact that Portland cement being highly alkaline is not resistant to attack by strong acids. Hence in mixes having high RCA content, the adhered mortar contributed to high alkalinity which ultimately resulted in reduced resistance to attack by acids.

Table 7 Results of Acid Attack

Mix Type	30 days		90 days	
	% Loss in Weight	% Loss in Compressive Strength	% Loss in Weight	% Loss in Compressive Strength
R0	0.86	2.01	1.75	7.69
R20	0.95	2.43	2.44	8.14
R40	1.12	3.07	2.72	9.50
R60	1.51	3.65	3.58	12.84
R80	1.61	4.40	3.98	16.95
R100	2.10	4.68	4.64	20.51

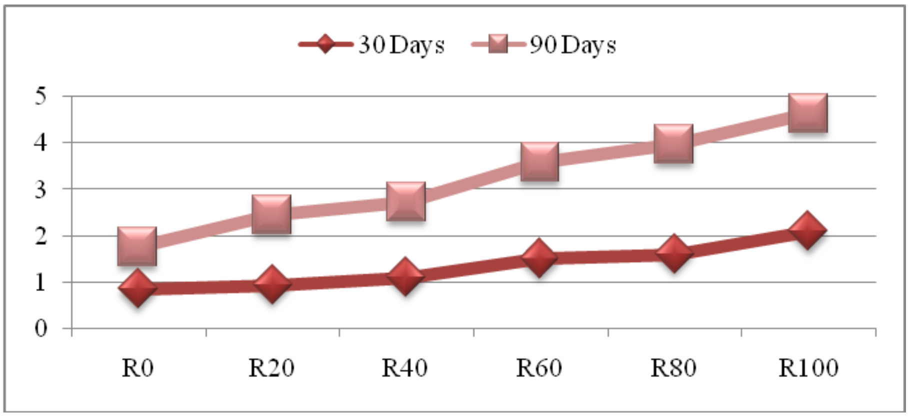

Figure 4.0 % Loss in mass in acid

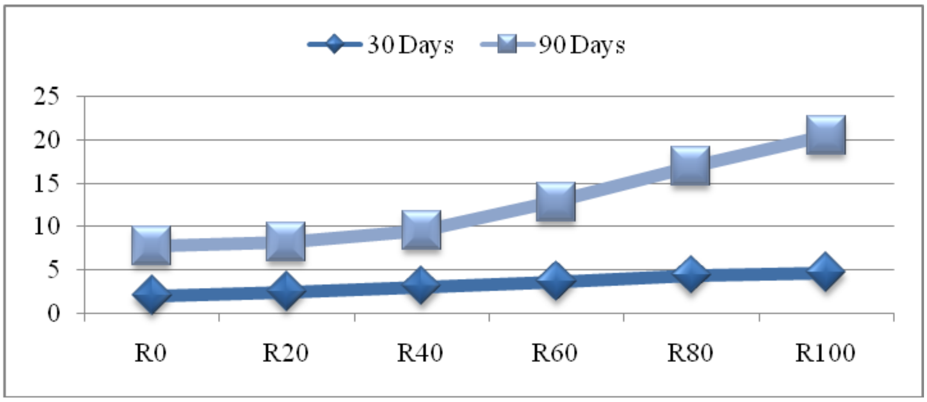

Figure 5.0 % Loss in compressive strength

6.3.3 Chloride Ingress

Table 8 shows the chloride penetration depths of concretes immersed in 5% sodium chloride solution at 30 and 90 days. The result indicates that chloride penetration depths of SCC increases with increasing RCA. The increase in porosity and capillary pores in recycled aggregate causing chloride ions to penetrate easier into concrete. The maximum depth of chloride ingress was recorded as 28.60 mm for mix R80 at 90 days.

Table 8. Chloride ingress depth

Mix Type	Depth of Chloride ingress in mm	
	30 days	90 days
R0	6.15	11.25
R20	10.25	17.70
R40	13.10	19.60
R60	15.80	26.00
R80	19.70	28.60
R100	20.20	27.25

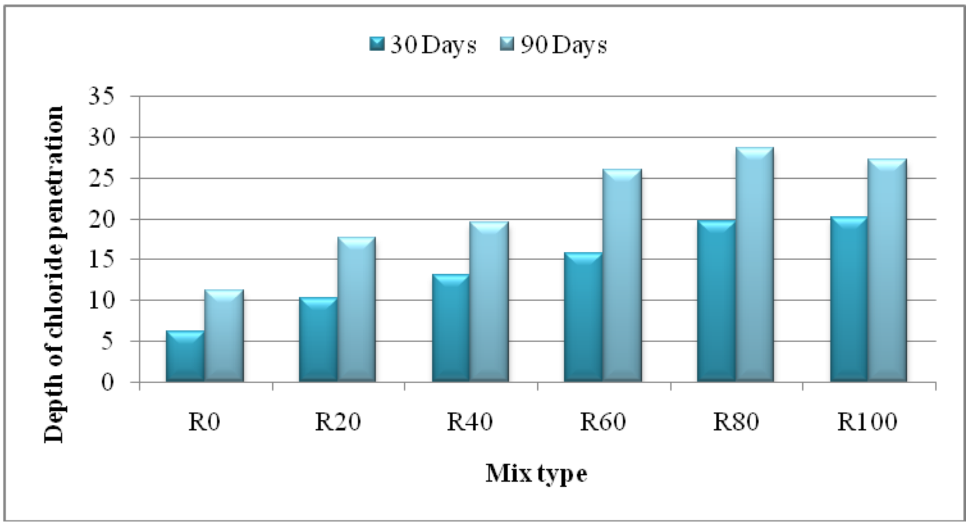

Figure 6.0 Results of chloride ingress

VII. CONCLUSION

Under the conditions of this research, the following conclusions can be made.

1. There is a significant potential for growth of recycled aggregate as an appropriate and green solution for sustainable development in construction industry.
2. Self compacting concrete made with recycled aggregates have achieved the target strength in all the mixes and also satisfied the fresh state properties required for SCC as per EFNARC specification.
3. The strength investigation shows that, in all the mixes compressive and tensile strength has inverse relationship with percentage of recycled coarse aggregate. This is a consequence of adhered mortar attached to recycled aggregate contributing for weaker interfacial transition zone.
4. It was observed that the mixes containing recycled aggregate gains quick early strength due to presence of partially hydrated cement adhered to aggregate which accelerates the hydration process.
5. All the mixes having recycled aggregates have higher permeability values, which is a consequence of high initial water absorption of RCA.
6. Concrete mixes up to 40% RCA have shown good resistance to acid attack and chloride penetration.

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