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STRENGTH AND DURABILITY CHARACTERISTICS OF SELF COMPACTING CONCRETE (SCC) WITH RECYCLED AGGREGATE AND MANUFACTURED SAND

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Abstract.

The investigations on self compacting concrete (SCC) with recycled coarse aggregate and Manufactured sand (M-Sand) were performed in this current study. The SCC mixtures were produced with the recycled coarse aggregate of proportions of 0 to 100% with step increment of 25% with a ratio of water binder at 0.36. In addition, the mixtures were also prepared by mixing it with M-Sand. The feasibility of utilizing the recycled coarse aggregate in SCC was evaluated through strength and durability studies. The obtained results demonstrated that the SCC produced from these materials can be effectively recommended for their usages in concrete industries.

Keywords: M-Sand, mechanical properties, recycled coarse aggregate, self compacting concrete.

1. Introduction

Self compacting concrete (SCC) show superior rheological properties as compared to conventional concrete. These properties in SCC are generally achieved due to higher ratio of cement paste to aggregate. Accordingly, the SCC was developed to overcome the problems associated with the labor quality and the noise and dust problems as well. The mechanical characteristics such as tensile and compressive strength of concrete evaluated with recycled aggregate will be lower than the typical concrete. However, this can be overcome by using superplasticizer [1, 2]. The studies conducted on the fresh and hardened SCC using recycled coarse and fine aggregate confirmed that both the coarse as well as fine recycled aggregate can be effectively used for the production of SCC [3, 4]. Accordingly, in this study, an equal consistency was observed in SCC mixtures when it is prepared with the recycled coarse aggregate with 0, 50 and 100% proportions as a substitute for the natural coarse aggregate [5]. Regarding the fine aggregate, the manufacturing sand (commonly known as M-Sand) can be a suitable alternative for river sand in concrete. The incorporation of M-Sand contributes to increase in paste volume, which eventually helps for SCC for its improved properties. It means that as compared to the river sand, the M-Sand produces relatively high paste content, which is beneficial for SCC [6]. The utilization of recycled coarse aggregate of 0 to 40% proportions (with a step increment by 10%) in SCC as a substitute for the natural coarse aggregate showed relatively decreased mechanical strength as compared to those made with natural aggregate [7, 8]. On the other hand, it was reported that the utilization of fine and recycled coarse aggregate enhances the rheological and fresh properties of SCC [9]. Few authors [10, 11] have used the crushed red bricks and crushed ceramics materials as a replacement of coarse aggregate. However, the SCC made by M-Sand and fly ash contributed to raise of the strength characteristics of SCC [12].

From the above discussion, it is observed that only a very few studies were carried out with amalgamation of coarse and fine aggregate as suitable replacements in SCC. Hence, the current experimental study is focused on enhancing the strength characteristics and durability of SCC through the substitution of both coarse and fine aggregate, where these aggregate were substituted with recycled coarse aggregate and M-Sand, respectively at the proportions of 0, 25, 50, 75 and 100%.

2. Experiments and methods

2.1. Materials

In this current study, the conventional Portland cement grade 53 with specific gravity (SG) of 3.05 and fineness value of 310 m^2/kg, was used. Similarly, the Class F' fly ash was found to be as per the ASTM C 618 standard with a relative density of 2.13 and fineness value of 360 m^2/kg. The chemical ingredients of

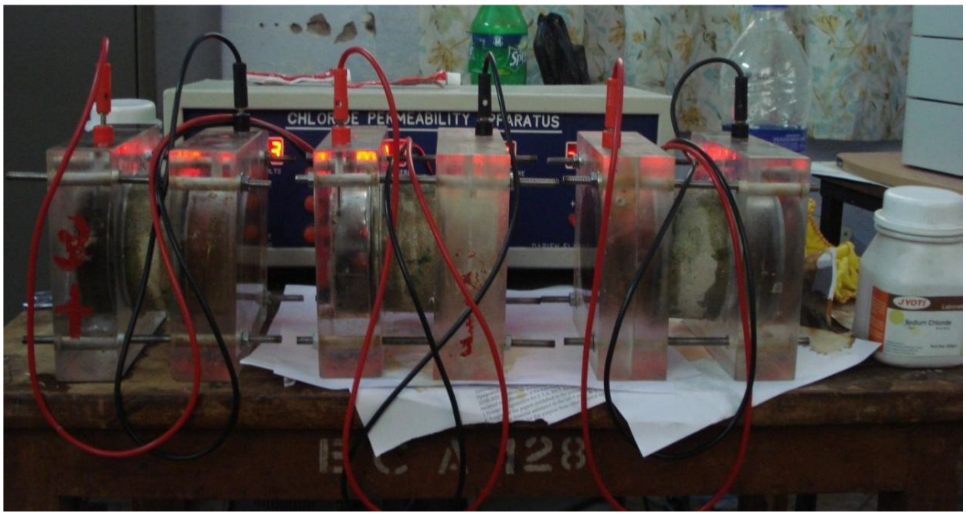

Figure 1. Photographic image of the experimental setup for rapid chloride permeability test.

the cementitious materials are tabulated in Table 1. Natural granite was used as a coarse aggregate with a max. size of 1.2 cm with SG around 2.66 and the water absorption value of 0.53. However, the Local demolished wastes were also used as the recycled aggregate, which was with a SG around 2.52 and water absorption value of 5.06. The Local river sand with SG around 2.58 and water absorption value of 0.95 was employed as the fine aggregate components. The SG and water absorption value of M-Sand used in the study are 2.46 and 1.20, respectively. A chemical based superplasticizer named Polycarbolic ether was also used to achieve a good workability.

Chemical present	Cement	Fly Ash
	Value (%)	
SiO_2	19.79	65.6
Al_2O_3	5.67	28.1
Fe_2O_3	4.68	2.9
CaO	61.81	0.95
MgO	0.84	1.55
SO_3	2.48	0.21
Chloride	0.003	
Lime Saturation Factor	0.92	

Table 1. Chemical compositions of SCC.

2.2. Mix Proportions

SCC mixtures at proportions of 0 to 100% replacements (with step increment by 25%) with the recycled aggregate and M-Sand were prepared, while keeping the ration of water binder (w b) constantly at 0.36. Throughout this work, cement and fly ash was taken to be 351 and 150 kg/m^3, respectively.

2.3. Test Methods

In this current work, the SCC prepared using the aggregate of recycled coarse and M-Sand was tested as per the EFNARC and IS guidelines [13].

2.3.1. Split tensile and Compressive strength test

The split tensile and compressive strength characteristics of various mixtures were evaluated on the test setup with capacity of 2000kN compression testing machine with a least count of 1kN.

2.3.2. Rapid Chloride Permeability Test (RCPT)

The RCP tests were conducted on the different concrete mixtures in order to investigate the developed concrete' ability to resist the penetration of chloride ions. For this purpose, the samples were cut into cylindrical specimens and subjected to impressed voltage of 60V between the anode and cathode using a DC power source as shown in Fig 1. The response current was monitored without any interruption for the period of 6 h at 30 min of interval time.

2.3.3. Acid resistance test

The resistance against the acid attack on SCC specimens was conducted in accordance with the ASTM C 267 01. After the process of moist curing for 28 days, the weight of each specimen has been taken and then the specimens were immersed in 3% hydrochloric (HCl) acid solution. During this test, the changes in weight as well as the compressive strength characteristics of specimens were evaluated after 28 days and 56 days of immersion of the specimens in 3% HCl acid solution.

3. Results and Discussion

3.1. Compressive strength analysis

3.1.1. Compressive characteristic strength of RCA in NCA (Natural coarse aggregate) concrete mix with 0% M-Sand

The compressive characteristic strength results of the developed various concrete mixtures are displayed in

S. No	Mix Type	Average Strength (MPa)									
		M0/Days		M25/Days		M50/Days		M75/Days		M100/Days	
		7	28	7	28	7	28	7	28	7	28
1	R0	29.77	42.66	28.88	41.77	28.1	40.44	27.42	40.00	27.07	39.11
2	R25	28.27	38.88	27.11	38.66	26.66	38.00	26.22	37.55	25.86	36.6
3	R50	26.76	36.24	25.55	35.92	25.33	35.57	24.88	35.14	24.44	34.52
4	R75	25.00	33.77	23.88	33.33	23.53	32.88	23.35	32.44	23.00	32.00
5	R100	23.77	31.58	22.66	31.11	22.00	30.44	21.55	30.11	21.33	29.77

R0 - First letter stands for RCA and the suffix number indicates the % used
M0 - First letter stands for M-Sand and the suffix number indicates the % used

Table 2. Estimated compressive strength of various concrete mixtures.

Table 2. From the obtained results, it can clearly be noticed that the increasing concentration of recycled aggregate concrete considerably decreases the effective compressive strength continuously, which is also well agreed with the literature reports. Further, it can also be noted that the compressive strength of 100% NCA is maximum and the compressive strength decreases with increasing recycled coarse aggregate at both 7 and 28 days. This might be due to the poor quality of the recycled aggregate as compared to the natural aggregate. The percentage decrease in the compressive strength for 7 days sample with reference to the basic mixture is found to be 7.45, 13.43, 19.38 and 22.37% for 25, 50, 75 and 100% replacement of recycled coarse, respectively. Similarly, the percentage decrease in the compressive strength for 28 days sample with reference to basic mix is estimated to be 8.86, 14.58, 20.83 and 23.62% for 25, 50, 75 and 100% replacement of recycled coarse, respectively.

3.1.2. Compressive strength of M-Sand substitution in Fine aggregate with 0% substitution of recycled coarse

The compressive investigation results of replacing the M-Sand in fine aggregate are given in Table 2. In this work, as aforementioned, the fine aggregate has been replaced by M-Sand at different percentages such as 0, 25, 50, 75 and 100% and the percentage amount of recycled aggregate was taken to be 0%. From the test results of the obtained compressive strength, it is noticed that the increasing substitution of M-Sand leads to a continuous decrement in the eventual compressive strength of the concrete mix. Accordingly, the strength property of 28 days immersed 100% M-Sand SCC is estimated to be 29.77 N/mm^2 and on the other hand, it can be seen that the compressive strength of cubes is decreasing with the increasing M-Sand substitution in fine aggregate. This may be because of the reason that the crushing process of M-Sand fundamentally affects its shape characteristic, where the grading of M-Sand and the proportion of micro fines may not be the same as fine aggregate. The percentage decrease in the compressive strength of 28 days immersed samples with respect to basic mix is estimated to be 2.08, 5.20, 8.86, 6.23 and 8.32% for 25, 50, 75 and 100% replacement of recycled coarse, respectively. Notably, this current study was essentially carried out to devise the possibility of replacing the 100% sand by M-Sand. Using M-Sand, the water demand may increase due to its high fines; however, the fines in M-Sand play role to increase in paste volume, which will be useful in the development of SCC with improved properties.

3.1.3. Compressive strength of recycled coarse aggregate concrete and substitution of M-Sand in fine aggregate

The compressive test results of the recycled coarse aggregate replaced in natural coarse aggregate and replacing M-Sand in fine aggregate are shown in Table 2. From the obtained results on compressive strength, it can be noticed that with increasing replacement of recycled aggregate and M-Sand, the effectual compressive strength is decreasing continuously in 7 and 28 days immersed samples. However, it is worth to mention that the researchers were widely used different waste materials other than the M-Sand in fine aggregate. The percentage decrease in the compressive strength for 7 days immersed samples with respect to reference mix was found to be 8.93, 14.91, 16.42 and 28.35% corresponding to 25, 50, 75 and 100% replacement of recycled coarse aggregate and M-Sand in fine aggregate. Similarly, the percentage decrease in the effective compressive strength for 28 days immersed samples with respect to reference mix was estimated to be 9.37, 15.61, 19.78 and 30.21% corresponding to 25, 50, 75 and 100% replacement of recycled coarse aggregate and M-Sand in fine aggregate. However, for the mixture having 100% of recycled aggregate and 100% of M-Sand, the compressive strength value was estimated to be 29.77 MPa, which is almost equal to M 25 grade concrete. Therefore, it is suitable and can possibly be recommended to utilize 100% recycled aggregate and M-Sand in producing the SCC with improved properties.

S. No	Mix Type	Average Strength (MPa)				
		M0	M25	M50	M75	M100
1	R0	3.65	3.61	3.56	3.44	3.4
2	R25	3.49	3.45	3.42	3.34	3.25
3	R50	3.38	3.36	3.33	3.27	3.15
4	R75	3.25	3.22	3.19	3.16	3.05
5	R100	3.19	3.16	3.13	3.05	2.94

Table 3. Estimated split tensile strength of the various concrete mixtures.

Mix	M0	M25	M50	M75	M100	Remarks ASTM C1202	
						Charge Passed (Coulomb)	Chloride Penetrability
R0	1155.00	1197.00	1246.00	1274.00	1316.00	> 4000	High
R25	1217.00	1259.00	1300.00	1318.31	1357.00	$2000 - 4000$	Moderate
R50	1273.00	1310.00	1350.12	1368.24	1404.00	$1000 - 2000$	Low
R75	1326.45	1370.00	1400.00	1419.54	1446.00	$100 - 1000$	Very Low
R100	1384.00	1420.00	1449.41	1470.90	1491.00	< 100	Negligible

Table 4. Estimated RCPT value of SCC mixtures after 56 days.

3.2. Split Tensile Strength

3.2.1. Split Tensile strength of RCA in NCA concrete mix with 0% M-Sand

From test results of split tensile strength, it can clearly be noticed that the increasing replacement of recycled aggregate continuously leads to the decrement in the split tensile strength as listed in Table 3. As per the literature reports, researchers typically observed a decrement in the strength when the % of recycled aggregate is increased. However, M. Seethapathi et al [12] encountered a kind of reverse trend and reported that the split tensile strength were increased with increasing percentage of the recycled aggregate. But there were no specific reasons mentioned for the observed reverse trend in their studies. In this present study, the mixture R0M0 was taken as a reference mix for all the mixtures. The split tensile strength value of the 28 days immersed 100% recycled coarse aggregate was found to be 3.19 N/mm^2. It was observed that the split tensile strength was noted to be decreasing with increasing recycled aggregate replacements in 28 days immersed samples. This could be ascribed to the low quality of recycled aggregate as compared to the natural coarse aggregate. The decrement % in the split tensile strength for 28 days immersed samples with respect to reference mix was estimated to be 4.58, 7.98, 12.30 and 14.42% for 25, 50, 75 and 100% replacement of recycled coarse, respectively.

3.2.2. Split tensile strength of M-Sand in Fine Aggregate with 0% Recycled Coarse Aggregate

The split tensile strength of M-Sand replaced in fine aggregate samples is displayed in Table 3. It can be noticed that the increasing replacing percentage of M-Sand, the split tensile strength is continuously decreasing. The split tensile potency of 28 days immersed 100% M-Sand in fine aggregate was estimated to be 2.81 N/mm^2. It can clearly be noticed that the split tensile is decreasing with increasing RCA replacement ratios in 28 days immersed samples. This could be due to the relative improved quality of M-Sand that varies with river sand. The percentage decrease in split tensile for 28 days immersed materials with respect to the reference mixture R0M0 is found to be 1.10, 2.52, 6.10 and 12.30 corresponding to 25, 50, 75 and 100% replacement of M-Sand in fine aggregate.

3.2.3. Split tensile strength of the Recycled coarse concrete and replacement of M-Sand in NCA and fine aggregate

The split tensile strength results of the recycled coarse aggregate replaced in the natural coarse and M-Sand replaced fine aggregate are presented Table 3. It can be noticed that the increasing replacing % of recycled coarse aggregate and fine aggregate by M-Sand continuously decreases the split tensile strength in 28 days immersed samples. Notably, no literature reports are available studying the replacement of RCA in NCA and M-Sand in fine aggregate. The percentage decrease in split tensile for 28 days immersed samples with respect to the reference mixture R0M0 is found to be 5.79, 9.60, 15.50 and 31.76% corresponding to 25, 50, 75 and 100% replacement of recycled coarse aggregate and M-Sand in fine aggregate samples. However, it is noteworthy that the mixture having 100% recycled aggregate and 100% M-Sand, the split tensile value was estimated to be 2.77 MPa. Therefore, it can possibly be recommended to utilize the 50% recycled aggregate and M-Sand in producing the SCC towards having the improved split tensile

Mix	M0		M25		M50		M75		M100	
	Before	After	Before	After	Before	After	Before	After	Before	After
R0	29.77	26.40	28.88	25.46	26.22	23.06	25.33	22.09	24.00	20.90
R25	27.74	24.17	26.94	23.46	24.94	21.65	24.00	20.80	22.67	19.62
R50	25.77	22.38	24.94	21.60	23.21	20.04	22.54	19.41	21.34	18.37
R75	24.00	20.75	23.21	20.04	21.67	18.70	20.93	18.02	19.94	17.10
R100	22.27	19.18	21.40	18.42	20.07	17.25	19.53	16.75	18.74	16.05

TABLE 5. Compressive strength of SCC mixtures after 56 days of acid immersion.

strength.

3.3. RAPID CHLORIDE PERMEABILITY TEST (RCPT)

Table 4 displays the rapid chloride (Cl) permeability characteristics of SCC mixtures after 56 days cured samples. From the Table 4, it can be noticed that the increasing percentage of recycled aggregate leads to the increment in the RCPT values of SCC mixtures. The permeability value of SCC mixture without any recycled coarse aggregate replacement was found to be 1155 and with 100% replacement, the value was increased to 1384. The decrease in permeability values could be attributed to the insufficient properties of the recycled coarse s as compared to the natural coarse aggregate. It could also be observed that with increasing replacements of M-Sand in fine aggregate, the permeability is also increasing in the samples. Accordingly, the permeability value of the mixture with 100% replacements of fine aggregate with M-Sand was estimated to be 1316. It is also observed that permeability is found to be increasing when the percentage of recycled coarse and M-Sand is replaced at a time in natural coarse aggregate and fine aggregate. The permeability value with 100% replacement of recycled coarse aggregate and M-Sand was found to be 1491.

4. CONCLUSIONS

From this current study and the obtained results, the following conclusions could be arrived;

- From the obtained results of the present investigation, it can be recommended that the recycled coarse aggregate and M-Sand can be effectively used in developing SCC with relatively improved properties.
- The compressive strength of SCC is decreasing with increasing % replacements of recycled coarse aggregate in natural coarse aggregate and M-Sand in fine aggregate. The compressive strength of the mixture having 100% recycled aggregate and 100% M-Sand was estimated to be 29.77 MPa, which is almost equal to M 25 grade concrete's strength
- The split tensile strength of SCC is decreasing with increasing percentage replacement of recycled coarse aggregate in natural coarse aggregate and M-Sand in fine aggregate. The split tensile strength of the mixture having 100% recycled aggregate and 100% M-Sand was estimated to be 2.77 MPa.
- Permeability values are found to be increasing as the replacement of recycled coarse aggregate and M-Sand in natural coarse aggregate and fine aggregate are increasing.
- When immersed in HCl, the compressive properties of SCC were decreasing when the replacements of recycled coarse aggregate and M-Sand in natural coarse aggregate and fine aggregate are increasing.
- From the strength properties observed in this study, the SCC can be effectively produced with recycled coarse aggregate replacement as well as M-Sand replacement.

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