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EXPERIMENTAL INVESTIGATION ON DURABILITY PROPERTIES OF RECYCLED AGGREGATES CONCRETE

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Abstract - *Recycled aggregate was made by crushing the waste concrete of laboratory test cubes and precast concrete columns. Concrete made entirely with natural aggregate (NAC) as a control concrete Regardless of the replacement ratio, recycled aggregate concrete (RAC) had a satisfactory performance. However, for this to be fulfilled, it is necessary to use quality recycled concrete coarse aggregate and to follow the specific rules for design and production of this new concrete type.The properties of RCA of hardened concrete, such as compressive strength, tensile splitting strength, density and water absorption tests are conducted with replacement of 0% - 50%. Increasing the RCA content significantly improves the tensile splitting strength of the concrete according to the compressive strength. The ratios between the tensile splitting strength to the compressive strength are greater in the RCA concretes incorporating SF. An inverse relationship between the density and the water absorption ratio is observed in RCA concretes and this relation is more significant in higher amounts of RCA contents.*

1. INTRODUCTION

Every year, more than 165 million tones of natural aggregates are used in different civil and industrial constructions. Meanwhile, approximately 109 million tones of construction and demolition residues are generated in the UK; around 60 million tones of this are derived from concrete. The resources such as coarse aggregates, sands and cements will be at a disadvantaged position, as these resources are not able to cope with the high demand in the construction industry. Therefore, utilizing the recycled aggregate may be one of the significant efforts in achieving a sustainable construction.

As Recycled Aggregate (RA) begin to be acknowledged and accepted as a viable alternative to Natural Aggregates (NA), it is important to understand how Recycled Concrete Aggregate (RAC) performs compared with conventional concrete. A correct mix design and the introduction of differently shaped aggregates and different super plasticizers can influence structural concrete's performance and provide it with strengths similar to the corresponding natural aggregates concrete (NAC), or even a possible enhancement, making it a feasible solution for the construction industry.

1.1. Types of Recycled Aggregates

Recycled Aggregate are of 8 types:-

- RCA (Recycled Concrete Aggregate)
- RCM (Recycled Concrete & Masonry)
- RA (Reclaimed Aggregate)
- RAP (Reclaimed Asphalt Pavement)
- RAA (Reclaimed Asphalt Aggregate)
- Glass Cullet
- Scrap Tires
- Used Foundry Sand

1.2. Recycled Concrete Aggregate

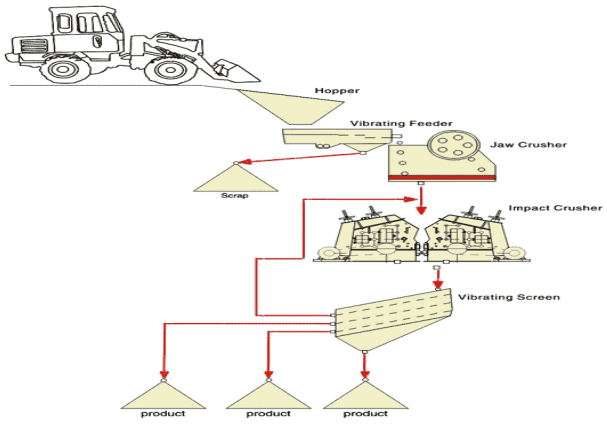
Recycled aggregate must confirm to certain standard for optimum engineering use; clean, hard, strong, durable particles free of absorbed chemical, coating of clay and fine materials in amounts that could affect hydration and bound of the cement paste. For this project, it does not include recycled glass aggregate, recycled plastic, tiles, clayware, brick etc.

1.3 Production process of Recycled Aggregates

The production of coarse recycled aggregates involves two basic processes and the same is shown in Fig 1.1 and Fig 1.2

- Primary crushing using a jaw crusher
- A primary and secondary crushing, the later with an impact crusher.

Mobile recycling plant



Production process of recycled aggregates

1.4. Properties and Characteristics of Recycled Aggregate

A concrete pavement's strength and performance is very dependent on the aggregates used to produce the concrete. Recycled concrete aggregates are different in many ways from virgin aggregates as shown in Table

Table 1.1. Comparison of typical virgin aggregate and recycled aggregate (RA) properties (source M. Snyder unpublished report).

Property	Virgin Aggregate	RA
Shape and Texture	Well rounded, smooth (gravels) to angular and rough (crushed rock).	Angular with Rough surface.
Absorption Capacity	0.8 – 3.7 percent	3.7 – 8.7 percent
Specific Gravity	2.4 – 2.9	2.1 – 2.4
L. A. Abrasion Test Mass Loss	15 – 30 percent	20 – 45 percent
Sodium Sulfate Soundness Test Mass Loss	7 – 21 percent	18 – 59 percent
Magnesium Sulfate Soundness Mass Loss	4 – 7 percent	1 – 9 percent
Chloride Content	0 – 1.2 kg/m3	0.6 – 7.1 kg/m3

1.5. Applications of Recycled Aggregates

Here are the some applications of recycled aggregates:

Low grade applications

- Saves Land fill space.
- Base filling material.
- Sub-base filling material.
- In leveling roads.
- In temporary constructions.

High grade applications

- As a coarse aggregate in structural elements.
- Recycled asphalt mixes.
- Larger pieces of crushed concrete can be used as erosion control

2. EXPERIMENTAL WORK

The properties of materials used in concrete are determined in laboratory as per relevant code of practice. Different materials used in the present study were cement, natural coarse aggregate, recycled concrete aggregates of 10mm and 20mm, fine aggregate, silica fume, and water. The materials in general, conformed to the specifications laid down in the relevant Indian Standard Codes. The materials used were having the following characteristics.

2.1 Compressive strength test

By definition, the ultimate compressive strength of a material is the value of uniaxial compressive stress reached when the material fails completely. The compressive strength is usually obtained experimentally by means of a compressive test. The apparatus used for this experiment is the same as the used in a tensile test.A compression test determines behaviour of materials under crushing loads. The specimen is compressed and deformation on various loads is recorded. Compressive stress and strain are calculated and plotted as a stress-strain diagram which is used to determine elastic limit.

The test was conducted on cubes of size 100mm×100mm×100 mm. Specimens were taken out from curing tank the age of 7,28,60 and 90 days. Surface was then allowed to drip down. Specimens were then tested on 200 tones capacity compression testing machine (CTM). The position of cube while testing was right angles to that of casting position. Axis of specimens was carefully aligned with the centre of thrust of the spherically seed plus.

2.2. Split tensile strength

Concrete cubes of size 100 mm × 100 mm × 100 mm were cast with incorporating copper slag as partial replacement of sand and cement. During casting, the cubes were mechanically vibrated using a table vibrator. After 24 hours, the specimens were demoulded and subjected to curing for 7, 14, 28, 56 and 90 days in portable water. After curing, the

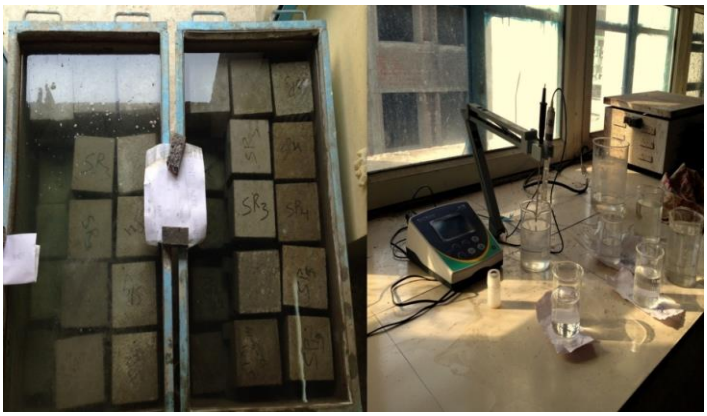
specimens were tested for split tensile strength using compression testing machine of 200 tonnes capacity. The ultimate load was taken and the average split tensile strength was calculated.

2.3 Capillary suction test (CSAT)

This test method 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. The exposed surface of the specimen is immersed in water and water ingress of unsaturated concrete dominated by capillary suction during initial contact with water. This test is done as per ASTM standards C 1585-04 standards test method for measurement of rate of adsorption of water by hydraulic-cement concretes.

2.4. Acid resistance test

Concrete cubes of size 150mm x 150mm were cast and stored in a place at a temperature of 32°C for 24 hours and then the specimens were water cured for 56 days. After 56 days curing, the specimens are taken out and allowed to dry for one day. Initial weights of the cubes were taken. For acid resistance test, 1% dilute Sulphuric acid (H_2SO_4) by volume of the water with pH value of about 2 was maintained. After that cubes were immersed in the above said acid water for a period of 30 days and the setup is shown in Fig 3.7. The specimens were taken out from the Acid solution at 30 days, and final weights of the dry cubes were taken



2.5 Alkalinity resistance test

Concrete cubes of size 150mm x 150mm was cast and stored in a place at a temperature of 32°C for 24 hours and then the specimens were water cured for 56 days. After 56 days curing, the specimens are taken out and allowed to dry for one day. Initial weights of the cubes were taken. For alkaline attack, 5% sodium hydroxide (NaOH) by volume of the water with pH value of about 10-12 was maintained. After that cubes were immersed in the above said alkaline water for a period of 30 days. The specimens were taken out from the Acid solution at 30 days, and final weights of the dry cubes were taken.

3. RESULTS AND DISCUSSIONS

Quantities of materials for mix of concrete (percentage)

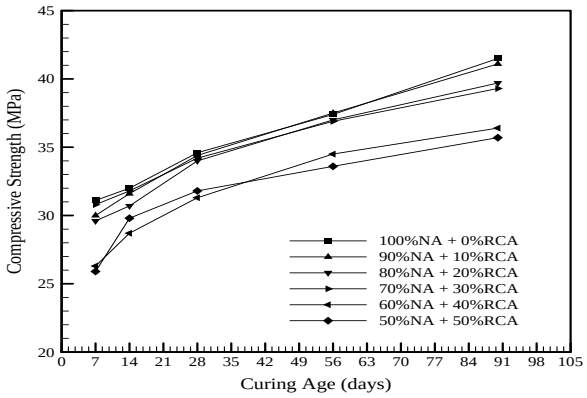
Mixes	Opc	S.F	Cag (20mm)	Cag (10mm)	RCA (20mm)	RCA (10mm)
M1	90%	10%	50%	50%	0%	0%
M2	90%	10%	45%	45%	5%	5%
M3	90%	10%	40%	40%	10%	10%
M4	90%	10%	35%	35%	15%	15%
M5	90%	10%	30%	30%	20%	20%
M6	90%	10%	25%	25%	25%	25%

Slump values for different concrete mixes:

Mix description	Slump (mm)
M1 0%RA +100%NA + 10% SF	113
M2 10%RA +90%NA + 10%SF	108
M3 20%RA +80%NA + 10%SF	100
M4 30%RA +70%NA + 10%SF	98
M5 40%RA +60%NA + 10%SF	95
M6 50%RA +50%NA + 10%SF	90

Compressive strength results

Cubes of sizes 100 x 100 x 100 mm were casted for strength testing. These cubes were cured for 7, 14, 28, 56 and 90 days and tested in Compression testing machine having a capacity of 200 T. The specimens were allowed to dry in sunlight for 1 day and are placed centrally in testing machine and load was applied continuously, uniformly and without any shock.



Mix Name	Mix Description	Compressive Strength (MPa)				
		7 days	14 Days	28 Days	56 Days	90 days
M1	0%RA+100%NA	31.1	32.0	34.6	37.4	41.5
M2	10%RA+90%NA	30.0	31.6	34.4	37.5	41.0
M3	20%RA+80%NA	29.6	30.7	34.0	37.0	39.7
M4	30%RA+70%NA	30.8	31.8	34.2	36.9	39.3
M5	40%RA+60%NA	26.3	28.7	31.3	33.2	36.4
M6	50%RA+50%NA	25.9	29.8	31.8	32.6	35.7

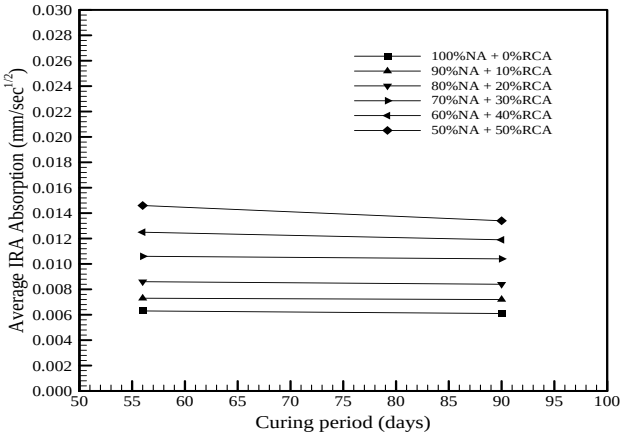
From the above test results and the graphical variation as shown in Fig 4.1, it was observed that the compressive strength results of the M2, M3 and M4 are comparable with the mix M1. This shows that the compressive strength of recycled aggregate concrete with up to 30% replacement of natural aggregates with recycled aggregates gives the same values as compared to the normal aggregates concrete or conventional concrete.

Split Tensile Strength results

Mix Name	Mix Description	Split Tensile Strength (MPa)				
		7 days	14 Days	28 Days	56 Days	90 days
M1	0%RA+100%NA	3.70	3.96	4.16	4.45	4.99
M2	10%RA+90%NA	3.76	4.01	4.22	4.37	4.91
M3	20%RA+80%NA	3.67	3.98	4.23	4.32	4.83
M4	30%RA+70%NA	3.65	4.01	4.13	4.27	4.74
M5	40%RA+60%NA	3.19	3.71	3.96	4.21	4.64
M6	50%RA+50%NA	2.91	3.59	3.78	3.94	4.47

Capillary Suction (Sorptivity) Test Results

Sl No.	Mix Identity	Average IRA (mm/Sec$^{1/2}$)	
		56 days	90 days
1	100%NA + 0%RCA	0.0063	0.0060
2	90%NA + 10%RCA	0.0073	0.0072
3	80%NA + 20%RCA	0.0086	0.0084
4	70%NA + 30%RCA	0.0106	0.0104
5	60%NA + 40%RCA	0.0125	0.0119
6	50%NA + 50%RCA	0.0186	0.0174



Acid Resistance Test results

For acid resistance, 1% dilute sulphuric acid (H_2SO_4) by volume of the water with pH value of 2 was maintained. Cubes were immersed in acid for a period of 28 days. The action of acids on hardened concrete is the conversion of ferrous compounds into the ferrous salts of the attacking acid.

4. CONCLUSIONS

1. The higher water absorption capacity of recycled aggregates has great influence on the water added to the mix, which can affect concrete's workability

2. It is possible to gain the same compression and split tensile strength as conventional concrete up to 30% replacement of natural aggregate with recycled ones. But from the overall study, both the compression and split tensile strength values are decreasing with the increase in replacement levels of recycled aggregates

3. The increase of recycled aggregates content beyond 30% has negative effect on compressive strength of recycled aggregates concrete. The reduction in compressive strength after 28 days is about 10% when 50% recycled aggregates are used.

4. Split Tensile results also show down trend like compressive strength beyond 30% replacement of recycled aggregates.

5. The pores filling capacity of silica fume enhances the both mechanical and durability properties of recycled aggregates concrete. The use of silica fume as a partial

replacement of cement decrease the water absorption of recycled aggregate concrete.

6. From the initial surface absorption test (ISAT), the recycled aggregate concrete is absorbing more water in the initial stages. The increase in absorption capacity at 10 min after 56 days is about 35% from 0% to 50% replacement of RCA in the mix.

7. The capillary suction test (CSAT) test results clearly confirm that the recycled aggregate concrete is having high porosity and the absorption increases with increase in the recycled content in the mix. So, water absorption value is directly proportional to the level of the RCA replacement.

8. The concrete containing recycled aggregates was found to be low resistant against H_2SO_4 solution than the control concrete with 0% recycled aggregates. The maximum weight loss recorded was 5.35% by weight of cube.

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