EXPERIMENTAL INVESTIGATIONS OF COARSE AGGREGATE RECYCLED CONCRETE

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ABSTRACT**: - *In*** India, a huge quantity of construction and demolition wastes is produced every year. These waste materials need a large place to dump and hence the disposal of wastes has become a problem. And the continuous use of natural resources for making conventional concrete leads to the reduction in their availability and results in the increase of the cost of the coarse aggregate and fine aggregate. The possible use of recycling demolition waste as coarse aggregate in the construction industry is thus increasing importance. In addition to the environmental benefits in reducing the demand of land for disposing the waste, the recycling of demolition wastes can also help to conserve the natural resources. When recycled coarse aggregate is used in structural concrete, the assessment of physical, mechanical and durable characteristics of recycled coarse aggregate is very important. The physical and mechanical properties of concrete with the recycled coarse aggregate (RCA) are to be evaluated to assess its application as structural concrete. The present work is directed towards the evaluation of concrete using full replacement of natural coarse aggregate (NCA) with RCA. The experimental results of mechanical and durability properties are also evaluated and compared with NCA concrete. Recycled coarse aggregate used in the concrete preparation was obtained from the tested laboratory concrete specimens. Tests were carried out to obtain the mechanical properties of RCA such as compressive strength and durability of concrete using rapid chloride permeability test (RCPT). The main problem with RCA concrete is high percentage of water absorption. RCA has high compressive strength comparable to the natural coarse aggregate concrete. This is mainly due to high amount of attached mortar on the surface of the recycled coarse aggregate and highly angular nature of RCA leads to poor quality of coarse aggregate. In RCPT, the chloride penetrating rate is “Moderate” for all grades of concrete with NCA and “High” for all grades of concrete using RCA. Based on the results of the experimental investigation, the RCA can be recommended as structural concrete in limited applications due to its high percentage of water absorption property of RCA.

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1. INTRODUCTION -

One of the major challenges of the present society is the protection of environment. Some of the important elements in this respect are the reduction in the consumption of energy, natural materials and extensive use of waste materials [1-5]. Nowadays these are getting considerable attention under sustainable development. The use of recycled coarse aggregate from the construction and demolition wastes is showing prospective application in construction as an alternative to the natural aggregate. It conserves natural resources and reduces the space required for the landfill disposal [6].

India is presently generating construction and demolition (C &D) waste of 23.75 million tons annually and these figures are likely to double in the next 7 years. C&D waste, specifically concrete, has been seen as a resource in developed countries. Works on recycling have emphasized that if old concrete has to be used in second generation concrete, the product should adhere to the required compressive strength. Literature reveals that compressive strength primarily depends upon adhered mortar, water

absorption, size of aggregate, strength of parent concrete, age of curing and ratio of replacement, interfacial transition zone, moisture state, impurities present and controlled environmental condition[7].

The recycling and reuse of construction and demolition wastes seems to be a feasible solution in new constructions after the natural disasters or demolition of old structures. Due to shortage of aggregate and increasing transportation costs, there is continued pressure to use recycled materials in the construction industry as these materials can provide cost effective and environmentally friendly alternatives to the natural aggregate.

2. EXPERIMENTAL STUDY-

The objective of the present research work is to get the characteristics of the recycled coarse aggregate concrete for structural applications. Then properties of recycled coarse aggregate concrete are to be compared with the natural coarse aggregate concrete. The present investigation is focused on the compressive strength and durability characteristics of RCA concrete. The full replacement of natural coarse aggregate with RCA is investigated. Three grades of concrete M 20, M 25 and M 30 are adopted in the present investigation.

MATERIALS

The materials used in the experimental investigation are:

1. 43 grade ordinary Portland cement (OPC)
2. Fine aggregate
3. Coarse aggregate (Recycled and natural aggregate)
4. Potable water.

Cement

43 grade Ordinary Portland Cement was used in the experimental investigation. Tests are carried out in accordance with procedures described in IS 4031:1968[8]. The properties of cement are within the permissible limits as per IS 8112:1989[9]. The properties are shown in Table 1.

Table 1: Physical Properties of 43 Grade Ordinary Portland Cement

Property	Results
Specific gravity	3.15
Normal consistency	30%
Setting time (min) a)initial b)final	 65 155
Compressive strength(MPa) a)3 day b)7 day c)28 day	 24.5 34.2 44.1

Fine Aggregate-

The sand used throughout the experimental work was obtained from the river Swarnamukhi near Tirupati, Chittoor district, Andhra Pradesh. The fine aggregate falls under the Zone II as per IS 383-1970[10].

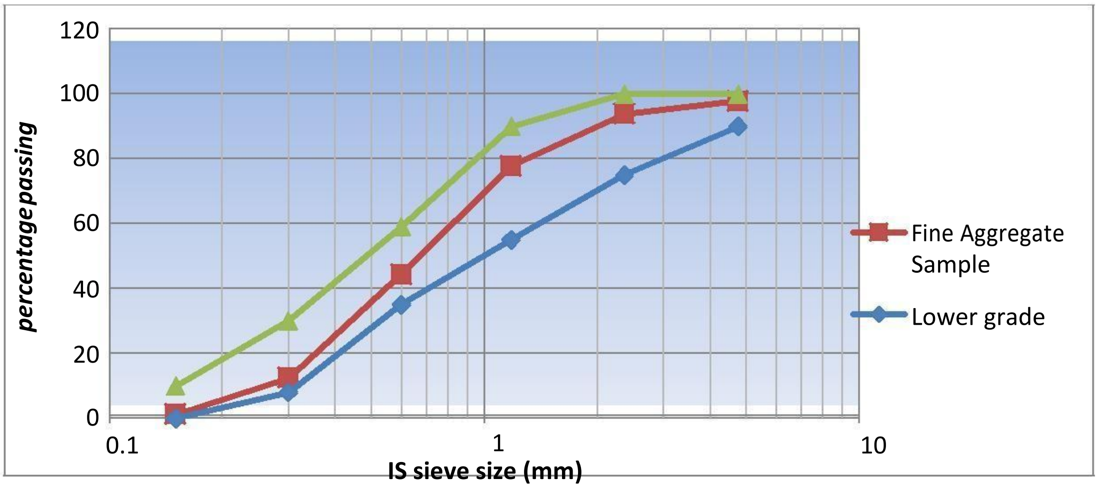

Figure 1: Grading Curve of Fine Aggregate

Water

Potable water available in the laboratory was used for mixing and curing.

Coarse Aggregate

The coarse aggregate used for the experimental work is both natural and recycled aggregate. In this study, graded 20 mm and 10 mm crushed granite coarse aggregate was used as the natural coarse aggregate.

Table 2: Properties of Fine Aggregate and Coarse Aggregate

Type		Specific Gravity		Water Absorption (%)	
		10 mm	**20 mm**	**10 mm**	**20 mm**
Coarse Aggregate	Natural	2.6	2.6	0.4	0
	Recycled	2.45	2.51	0.82	0.9
Fine Aggregate		2.53		0.4	

Figure 2: Grading Curves of Natural and Recycled Coarse Aggregate

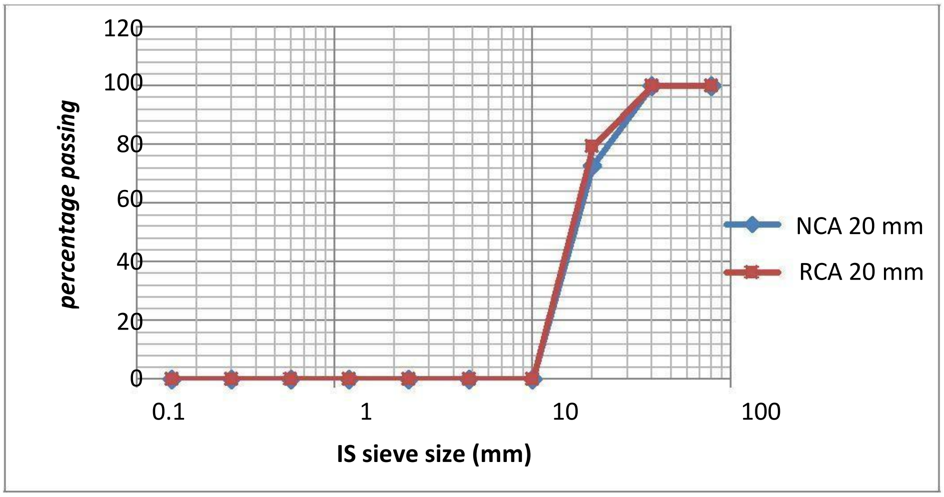

Figure 3: Grading Curves of Natural and Recycled Coarse Aggregate

III. CONCRETE MIX DESIGN

The mix design of recycled coarse aggregate concrete is not different from that of conventional concrete and the same mix design procedure given in IS 10262:2000 [11] was adopted. But an additional quantity of water is to be used to account the higher percentage of water absorption of RCA.

The concrete specimens are prepared with natural aggregate and fully recycled aggregate for three grades of concrete M 20, M 25 and M 30 and the mix proportions are shown in table 3.

Table 3: Concrete Mix Proportions for Different Grades

	Grade of Concrete	Mix Proportions	w/c ratio	Slump (mm)
Natural Coarse Aggregate Concrete	M 20	1:1.87:3.78	0.55	30
	M 25	1:1.71:3.62	0.50	25
	M 30	1:1.50:3.29	0.45	30
Recycled Coarse Aggregate Concrete	M 20	1:1.87:3.55	0.55	30
	M 25	1:1.71:3.46	0.50	25
	M 30	1:1.50:3.21	0.45	30

IV. EXPERIMENTAL INVESTIGATION

Compressive Strength

Compression test is the most common test to be conducted on hardened concrete, because most of the properties of concrete are qualitatively related to its compressive strength. The compression test was carried out as per IS 516:1959[12] using compression testing machine.

A total of 72 concrete cubes of size 150 mm x 150mm x 150 mm (36 with NCA and 36 with RCA) and 72 cylinders of size 150 mm x 300 mm (36 with NCA, and 36 with RCA) were tested for compressive strength at different curing periods 3, 7, 28 and 90 days. The average value of three specimens was taken as the compressive strength of the concrete.

The results of compressive strength of natural coarse aggregate and recycled coarse aggregate of concrete cubes and cylinders are tabulated and graphs are provided. Compressive strength of NCA and RCA cubes for different grades (M 20, M 25and M 30) at 3, 7, 28 and 90 days of curing are shown in Table 4 and figures 4-6.

Table 4: Average Compressive Strength (N/Mm^2) of Tested Cubes for Different Grades at Different Periods of Curing

Aggregate	Grade of Concrete	Days of Curing			
		3 days	7 days	28 days	90 days
Natural Coarse Aggregate Concrete	M 20	13.36	16.23	36.6	42.37
	M25	17.03	20.3	38.3	44.44
	M30	18.84	22.97	44.60	47.85
Recycled Coarse Aggregate Concrete	M 20	14.18	20.78	37.33	44.15
	M25	15.41	22.07	40.73	46.37
	M30	18.52	27.70	45.63	49.47

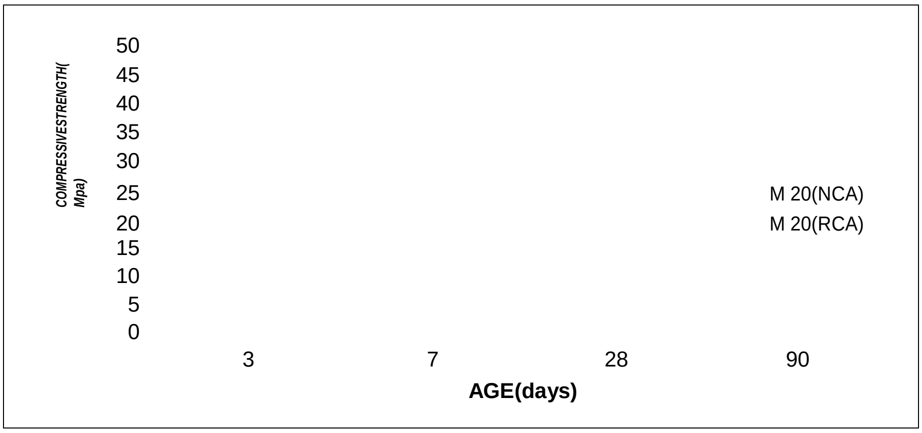

Figure 4: Variation of Compressive Strength of M 20 Grade Concrete with Curing Period

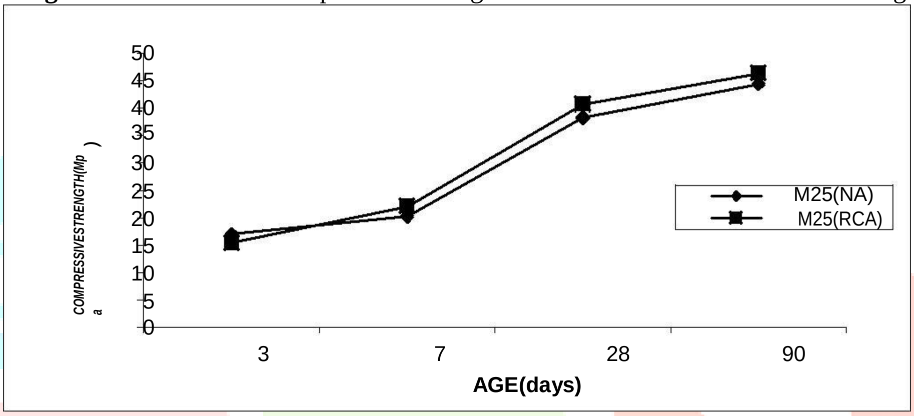

Figure 5: Variation of Compressive Strength of M 25 Grade Concrete with Curing Period

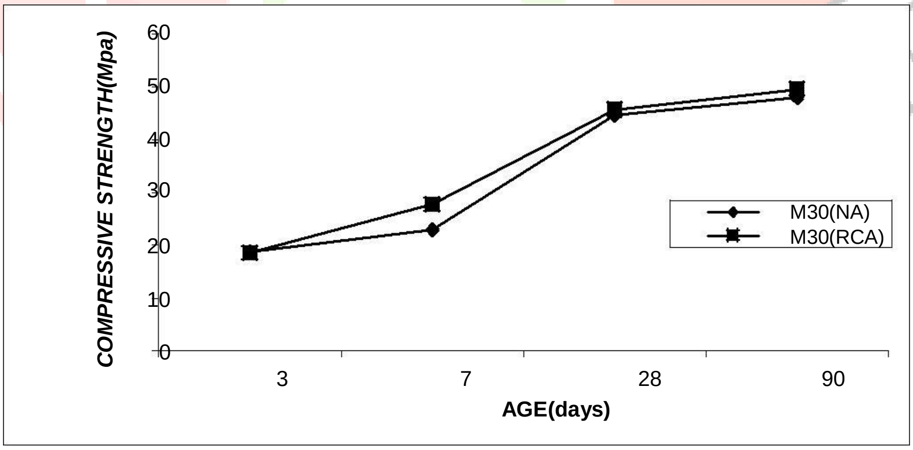

Figure 6: Variation of Compressive Strength of M 30 Grade Concrete with Curing Period

The above results shows that the cube compressive strength of recycled aggregate concrete is comparable to have more compressive strength of natural aggregate concrete for all grades of concrete at 3, 7, 28 and 90 days. This can be attributed to the cement mortar coat of RCA participates in hydration process and contribute additional strength.

Compressive strength of NCA and RCA cylinders for different grades (M 20, M 25 and M 30) at 3, 7, 28 and 90 days of curing are shown in Table 5 and figures 7-9.

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Table 5: Average Compressive Strength (N/Mm^2) Of Tested Cylinders for Different Grades at Different Periods of Curing

Aggregate	Grade of Concrete	Days of Curing			
		3 days	7 days	28 days	90 days
Natural Coarse Aggregate Concrete	M 20	13.87	15.23	26.6	30.9
	M25	14.74	18.50	28.90	32.82
	M30	17.54	19.65	33.76	36.90
Recycled Coarse Aggregate Concrete	M 20	13.20	16.41	25.90	29.05
	M25	12.64	18.67	27.73	31.13
	M30	13.21	19.24	32.06	35.27

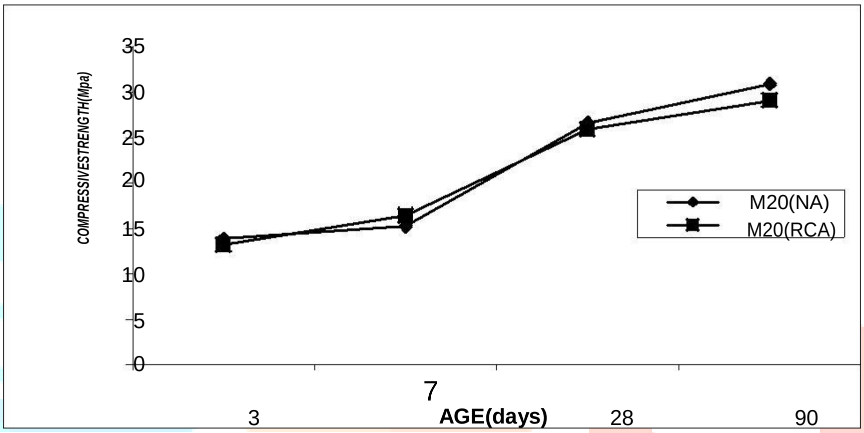

Figure 7: Variation of Compressive Strength of M 20 Grade Concrete with Curing Period

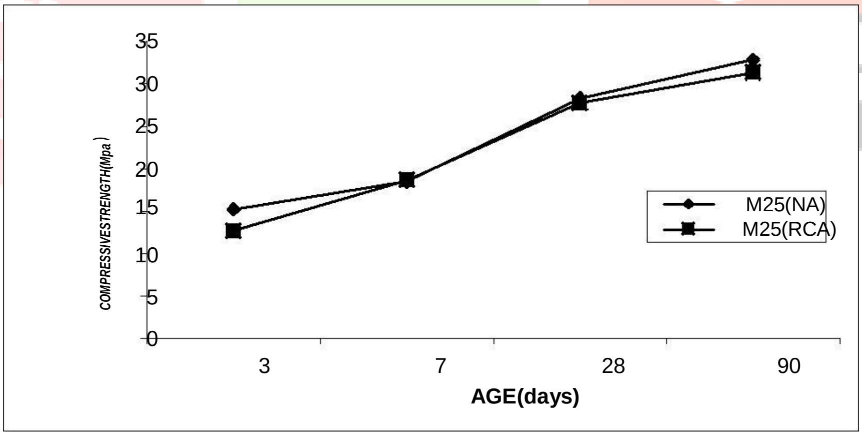

Figure 8: Variation of Compressive Strength of M 25 Grade Concrete with Curing Period

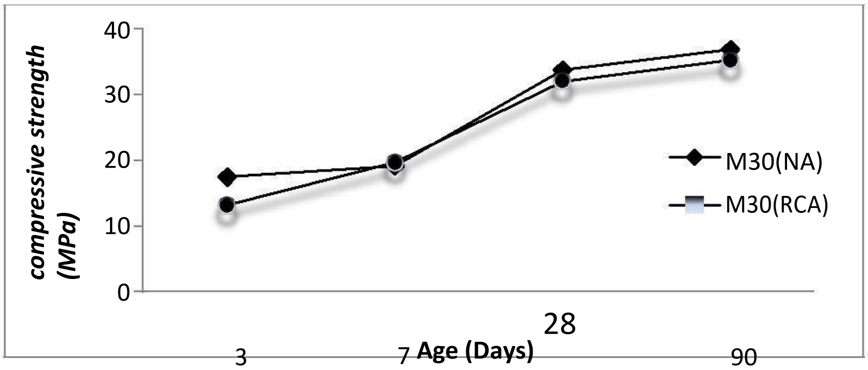

Figure 9: Variation of Compressive Strength of M 30 Grade Concrete with Curing Period

The above results show that the cylinder compressive strength of RCA concrete is also comparable to the compressive strength of the NCA concrete.

Rapid Chloride Permeability Test

Corrosion is mainly caused by the ingress of chloride ion into the concrete. Rapid chloride permeability test (RCPT) has been developed as a quick test to measure the rate of transport of Chloride ions in concrete. Concrete disc specimens of size 100mm diameter and 50mm thick were cast using, with and without copper slag. After 24 hours, the disc specimens were removed from the mould and subjected to curing for 28 days in chloride free water. After curing, the specimens were tested for chloride permeability. All the specimens were dried free of moisture before testing. This is a two component cell assembly checked for air and watertight. The cathode compartments filled with 3%NaCl solution and anode compartment is filled with 0.3 NaOH solutions. Then the concrete specimens were subjected to RCPT by impressing a 60V from a DC power source between the anode and cathode. Current is monitored up to 6 hours at an interval of 30 minutes.

From the current values, the chloride permeability is calculated in terms of coulombs at the end of 6 hours by using the formula.

Q= 900 (I0 + 2I30 + 2I60 + 2I90 + ………… + 2I300 + 2I330 + 2I360)

Where,

Q = Charge passed (Coulombs)

I0 = Current (amperes) immediately after voltage is applied It = Current (amperes) at t min. after voltage is applied

The chloride penetrability of the concrete can be assessed using the Table 6.

Table 6: Chloride Ion Penetrability Based On Charge Passed

Charge Passed,(Coulomb)	**Chloride Penetrability**
> 4000	High
2000 to 4000	Moderate
1000 to 2000	Low
100 to 1000	Very low
<100	Negligible

RCPT of concrete is expressed in terms the of charge passed in coulombs for different grades of concrete at 28 days of curing of specimens is shown in table 7 and figure 10, 11 and 12.

Table 7: Chloride Penetrating Rate for Natural Aggregate and Recycled Aggregate

Type	**Grade Of Concrete**	**Charge Passed in Coulombs**	**As Per ASTMC 1202:Chloride Penetrating Rate**
Natural Coarse Aggregate Concrete	M20	3697.2	Moderate
	M25	3422.2	Moderate
	M30	3085.5	Moderate
Recycled Coarse Aggregate Concrete	M20	6165.5	High
	M25	5758.8	High
	M30	5342.4	High

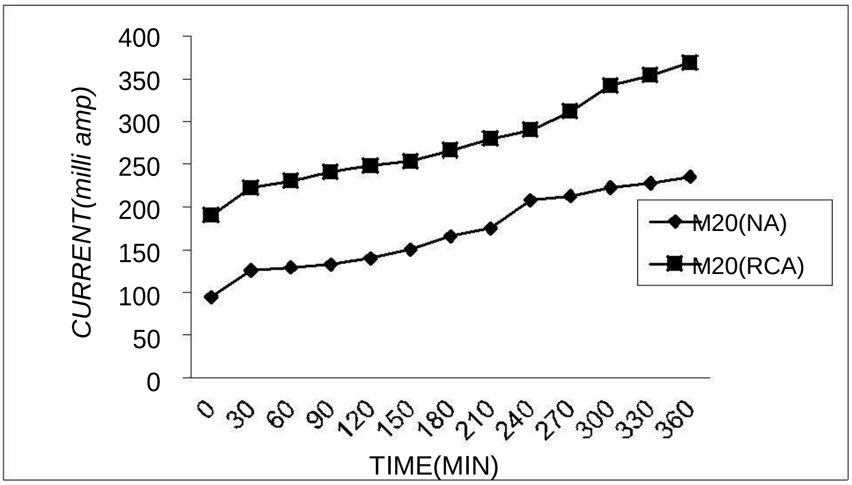

Figure 10: Current Passage of M 20 Grade Concrete at 28 Days

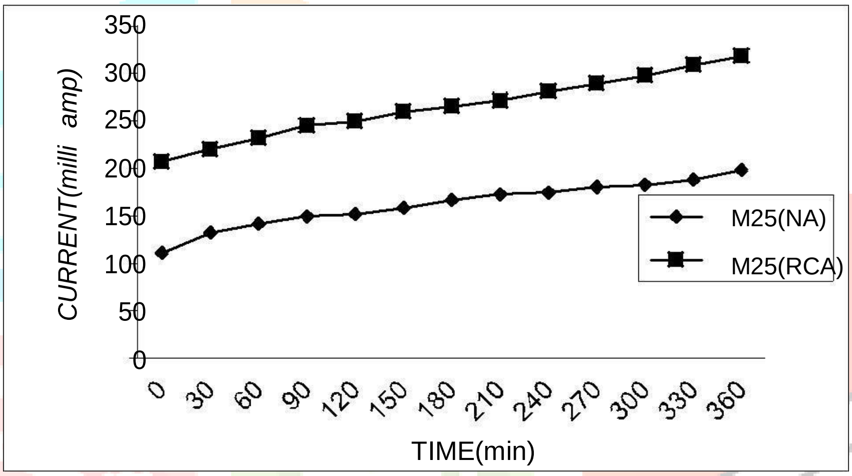

Figure 11: Current Passage of M 25 Grade Concrete at 28 Days

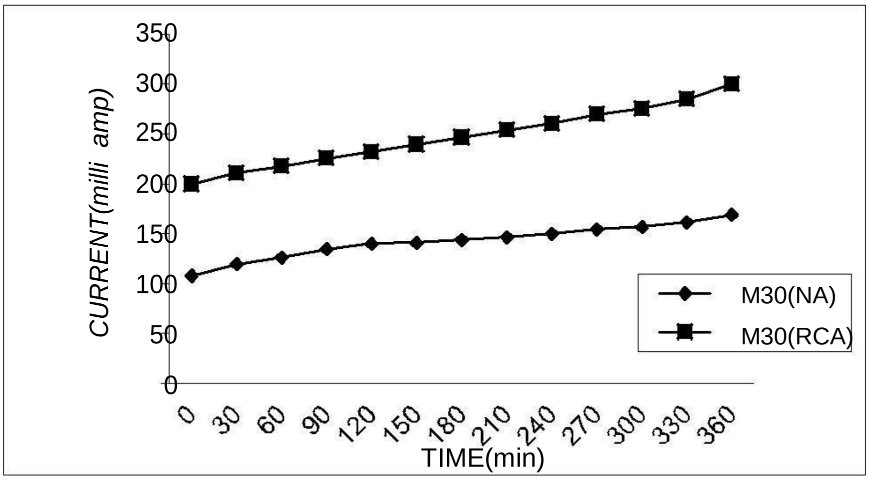

Figure 12: Current Passage of M 30 Grade Concrete at 28 Days

The chloride ion penetrations are measure in terms of the current passed through the specimen. The current passage will be more if the resistance offered by the specimen is less. The charge passed changes with the grade of concrete for natural and recycled aggregate. Based on the test results the chloride penetrating rate is "Moderate" for all grades of concrete with NCA and "High" for all grades of concrete using RCA.

V. CONCLUSIONS

Based on the test results of the present investigation, the following conclusions are drawn.

Recycled aggregate concrete (RCA) has compressive strength comparable to the natural coarse aggregate concrete compressive strength for all grades of concrete at 3, 7, 28 and 90 days. This can be attributed to the cement mortar coat of RCA participates in hydration process and contribute additional strength.

Along with strength, concrete should also be durable. The durability property of concrete is determined using RCPT on the concrete specimens prepared with natural coarse aggregate and recycled coarse aggregate. It is observed that as per ASTM C1202, the chloride penetrating rate is
"high" for RCA concrete and "moderate" for NCA concrete for all grades of concrete.

Based on the test results, it can be recommended for the full replacement of NCA concrete with RCA concrete in structural concrete. RCA concrete can be effectively used to meet the objective of disposal of waste and also to meet the replacement for the depleting natural coarse aggregate.

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