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A STUDY ON PARTIALLY USED RECYCLED COARSE AGGREGATE CEMENT CONCRETE

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ABSTRACT

The use of recycled coarse aggregate (RCA) is replacing the natural coarse aggregate (NCA) in the concrete construction and has become popular to answer many environmental problems caused by the large volumes of construction and demolition waste (CADW). This paper presents the experimental results of mechanical properties of RCA concrete and compared with NCA concrete. Recycled coarse aggregate was obtained from crushed laboratory concrete specimens. Three grades of concrete M 20, M 25 and M 30 were produced with 50% and 75% of RCA. RCA concrete has compressive strength comparable to NCA concrete. RCA concrete has low modulus of elasticity compared to NCA concrete. This is mainly due to the attached mortar on the surface of RCA and highly angular nature of RCA leads to poor quality of coarse aggregate. In rapid chloride permeability test (RCPT), the chloride penetrating rate is "moderate" for the grade of concrete. From the results, it can be concluded that RCA can be recommended as structural concrete.

Keywords: Recycled coarse aggregate; natural coarse aggregate; compressive strength; modulus of elasticity; rapid chloride permeability test.

1. INTRODUCTION

The main subject matter of civil engineering is always environment, construction materials and interaction between environment and construction materials. Preservation of the environment and sustainable development have become paramount importance in the construction industry [1]. Recycled aggregate is generally obtained from demolished structural components like the slab, beam etc. Since the quality of these broken materials often unknown, such as water-cement ratio, aggregate source and gradations, thus it should

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refer to historical data of the components, physical characteristics, mechanical characteristics and environmental characteristics [2]. The study on the properties of recycled aggregate and the basic properties of recycled aggregate concrete have been going on over the last few decades, leading to a number of countries recommending their use [2]. The properties like water absorption and specific gravity of RCA are to be evaluated which require in the concrete mix design.

The crushing process affects the characteristics of the resulting recycled coarse aggregate. It has been found that recycled coarse aggregate obtained from concrete are more angular and have more water absorption and specific gravity than natural coarse aggregate. Topcu et al [3] mentioned that the specific gravity of waste concrete aggregate (WCA) was lower than that of normal crushed aggregates. Water absorption was found to be much higher compared with that of normal crushed aggregate. Compressive strength decreased in proportion to low w/c ratio in concrete with WCA [3]. On the other hand, impurities present in the recycled material may cause expansion problems which can result in the formation of cracks. During recycling operations washing of the material is required to remove or reduce the presence of porous limestone-like material [1]. The characteristics of the reclaimed concrete aggregate should resemble to those of the natural aggregate to ensure similar properties. However, it is known that the water absorption behavior of recycled coarse aggregate is more than that of natural aggregates, affecting the concrete mix design. The investigation of the mechanical properties of recycled coarse aggregate concrete is necessary to determine the feasibility of its use as well as the impact on durability of concrete structures [1]. Concrete compressive strength depends on the type and quantity of aggregate used [4]. The levels of replacement of quarried limestone aggregate with recycled demolition aggregate has insignificant effect on the compressive strength [5]. Abbas et al. [6] found that RCA concrete mixes have higher resistance to freeze–thaw action, chloride penetration and carbonation than those designed with the conventional method, and they satisfy the requirements for concrete exposed to severe environments. Nelson et al [7] revealed that a gradually decreasing in compressive strength, tensile strength and modulus of elasticity was observed as the percentage of recycled aggregate used in the specimens increased. Whenever recycled aggregate is used, water content in the concrete mix has to be monitored carefully due to the water absorption capacity of recycled aggregate will vary [7]. The RCA concrete mixes were found to possess mechanical and durability properties similar to the corresponding natural aggregate concrete [8]

Compared to natural aggregate concrete, the recycled coarse aggregate concrete has the following properties [4]:

- increased water absorption
- decreased bulk density
- decreased specific gravity
- increased abrasion loss
- increased quantity of dust particles
- increased quantity of organic impurities if concrete is mixed with earth during building demolition and

This research is focused to find the influence of recycled coarse aggregate as partial replacement of natural coarse aggregate and its effect on the mechanical and durability

properties of the RCA concrete. Therefore, the influence of replacing NCA with RCA is studied using three different grades of concrete. Properties like compressive strength, modulus of elasticity, chloride permeability were studied on the concrete specimens prepared with RCA and NCA and comparisons were made between them.

2. EXPERIMENTAL STUDY

2.1 Experimental program

The basic premise of this investigation is to use "control" concrete mix and determine the effect of replacing the natural coarse aggregates with recycled coarse aggregates for three grades of concrete (M 20, M 25 and M 30). The natural coarse aggregate was replaced by 50% and 75% recycled coarse aggregate. The compressive strength, elastic modulus and chloride permeability properties for recycled coarse aggregate concrete were investigated.

2.2 Materials

The constituents used in the concrete mix are cement, natural and recycled coarse aggregate and sand. The details of each constituent are as follows.

2.2.1 Cement

Ordinary Portland cement 43 grade was used for this study. The physical and chemical properties of cement are within the permissible limits as per IS 8112:1989 [9]. Specific gravity of cement is 3.15.

2.2.2 Fine aggregate

Natural river sand was used as the natural fine aggregate. Properties are shown in Table 1 and grading of fine aggregate as per IS 383:1970 [10] is shown in Table 2 and Figure 1.

2.2.3 Natural coarse aggregate

In this study, graded 20 mm and 10 mm crushed granite was used as the natural coarse aggregate (NCA). The physical properties of the coarse aggregate are shown in Table 1. The grading of coarse aggregate as per IS 383:1970 [10] is shown in Tables 3 and 4 and Figures 2 and 3.

2.2.4 Recycled coarse aggregate

Recycled coarse aggregate (RCA) was obtained by crushing tested concrete specimens. RCA was crushed and graded of size 20 mm and 10 mm. Physical properties are shown in Table 1. The grading of RCA as per IS 383:1970 [10] is shown in Tables 5 and 6 and Figures 4 and 5.

2.2.5. Water

Portable water was used for mixing and curing of concrete.

Table 1: Properties of cement, sand and coarse aggregate

S.No.	Material		Specific Gravity		Water absorption (%)	
			10 mm	20 mm	10 mm	20 mm
1.	Coarse aggregate	Natural	2.6	2.6	0.4	0.2
		Recycled	2.45	2.51	0.82	0.9
2.	Fine aggregate		2.53		0.4	
3.	Cement		3.15		-	

Table 2: Grade analysis of fine aggregate

S.No.	IS sieve designation	Weight retained (gm)	Percentage retained	Cumulative percentage retained	Cumulative percentage passing	Remarks
1	4.75 mm	22	2.2	2.2	97.8	Zone II as per IS:383-1970
2	2.36 mm	40	4	6.2	93.8	
3	1.18 mm	160	16	22.2	77.8	
4	600 μ	334	33.4	55.6	44.4	
5	300 μ	320	3.2	87.6	12.4	
6	150 μ	112	11.2	98.8	1.2	
7	Pan	12	1.2	100	0	

Table 3: Grade analysis of 20 mm natural coarse aggregate

S.No.	IS sieve designation	Weight retained (gm)	Percentage retained	Cumulative percentage retained	Cumulative percentage passing
1	20 mm	272	27.2	27.2	72.8
2	10 mm	728	72.8	100	0
3	4.75 mm	0	0	100	0

Table 4: Grade analysis of 10 mm natural coarse aggregate

S.No.	IS sieve designation	Weight retained (gm)	Percentage retained	Cumulative percentage retained	Cumulative percentage Passing
1	10 mm	0	0	0	100
2	4.75 mm	985	98.5	98.5	1.5
3	2.36 mm	10	1	99.5	0.5

Table 5: Grade analysis of 20 mm recycled coarse aggregate

S.No.	IS sieve designation	Weight retained (gm)	Percentage retained	Cumulative percentage retained	Cumulative percentage Passing
1	20 mm	207	20.7	20.7	79.3
2	10 mm	793	79.3	100	0
3	4.75 mm	0	0	100	0

Table 6: Grade analysis of 10 mm recycled coarse aggregate

S.No.	IS sieve designation	Weight retained (gm)	Percentage retained	Cumulative percentage retained	Cumulative percentage Passing
1	10 mm	0	0	0	100
2	4.75 mm	992	99.2	99.2	0.8
3	2.36 mm	6	0.6	99.8	0.2

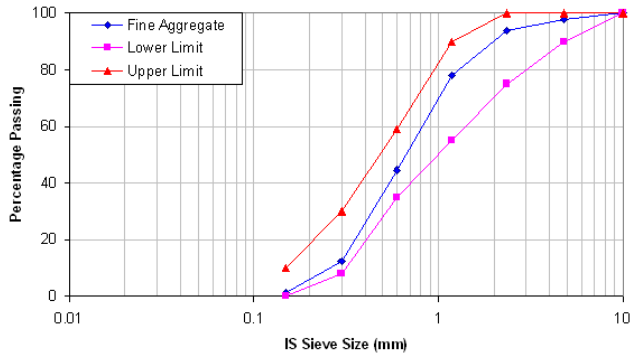

Figure 1. Grading curve of natural fine aggregate

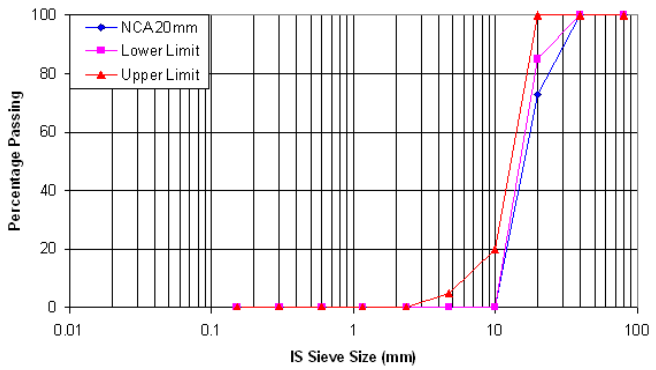

Figure 2. Grading curve of 20 mm natural coarse aggregate

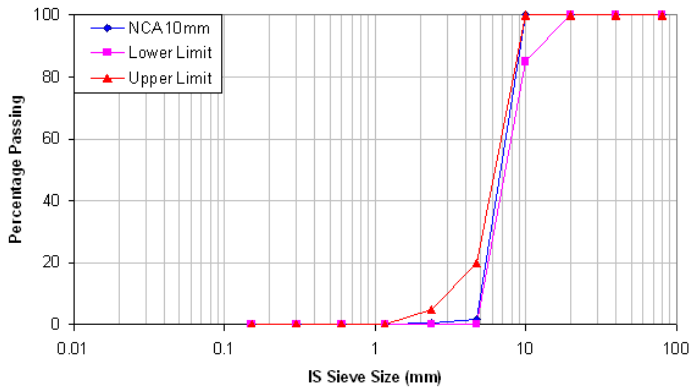

Figure 3. Grading curve of 10 mm natural coarse aggregate

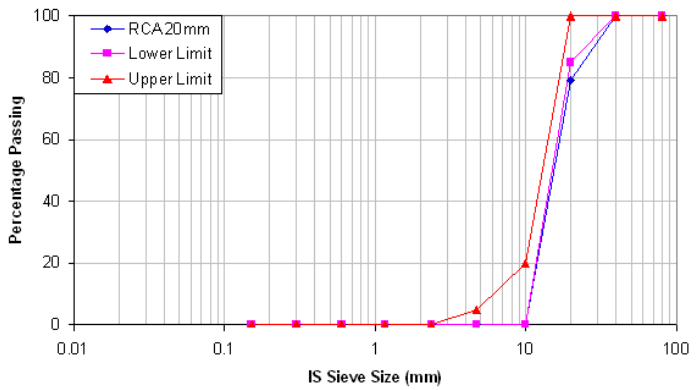

Figure 4. Grading curve of 20 mm recycled coarse aggregate

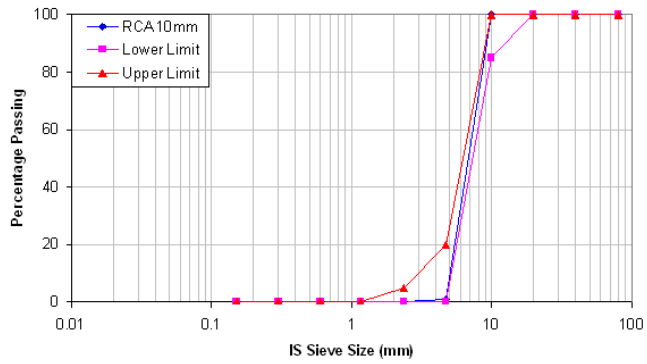

Figure 5. Grading curve of 10 mm recycled coarse aggregate

3. EXPERIMENTAL PROCEDURE

3.1 Mix design

Mix design is the process of selecting ingredients of concrete and determining their relative proportions with the object of producing concrete of required strength and durability as economical as possible. The mix design of recycled aggregate concrete is not different from that of conventional concrete and the same mix design procedure as per Indian Standard Recommended Guidelines IS 10262:1982 [11] and IS 456:2000 [12] was adopted.

Table 7: Mix proportions for different grades of concrete

Grade of concrete	Mix Proportions (cement:sand:coarse aggregate)	% of natural aggregate	% of recycled aggregate	w/c ratio	Slump (mm)
M 20	1:1.87:3.78	100	0	0.55	30
M 25	1:1.71:3.62			0.5	25
M 30	1:1.50:3.29			0.45	30
M 20	1:1.87:3.78	50	50	0.55	30
M 25	1:1.71:3.62			0.5	25
M 30	1:1.50:3.29			0.45	30
M 20	1:1.87:3.78	25	75	0.55	30
M 25	1:1.71:3.62			0.5	25
M 30	1:1.50:3.29			0.45	30

3.2 Mix proportions

The concrete specimens were prepared with different proportions of recycled coarse aggregate (50% and 75%) for three grades of concrete (M 20, M 25, M 30) shown in Table 7.

3.3 Preparation and testing of Specimens

A total of 108 concrete cubes of size 150mm x 150mm x 150mm (36 with NCA, 36 with RCA (50%), 36 with RCA (75%)) and 108 cylinders of size 150mm x 300mm (36 with NCA, 36 with RCA (50%), 36 with RCA (75%)) were tested for compressive strength as per IS 516:1959 [13] at different curing periods 3, 7, 28 and 90 days. A total of 27 cylinders of size 150mm x 300mm (9 with NCA, 9 with RCA (50%), 9 with RCA (75%)) were tested to obtain modulus of elasticity of RCA concrete as per IS 516:1959 [13] after 28 days of casting. Rapid Chloride Permeability test (RCPT) was conducted on cylindrical specimens of size 100mm x 50mm as per ASTM C 1202-07 [14]. A total of 27 specimens (9 with NCA, 9 with RCA (50%) and 9 with RCA (75%)) were prepared and tested after 28 days.

The relationship between chloride penetrating rate and the charge passed in coulombs is given in Table 8.

Table 8: Chloride penetrability characteristics as per ASTM C1202

Charge passed (Coulomb)	Chloride penetrability
> 4000	High
2000 to 4000	Moderate
1000 to 2000	Low
100 to 1000	Very Low
<100	Negligible

4. RESULTS AND DISCUSSION

4.1 Compressive strength

4.1.1 Compressive strength of NCA cylinders and RCA cylinders

Compressive strengths of NCA cylinders and RCA cylinders for different grades of concrete (M 20, M 25 and M 30) at 3, 7, 28 and 90 days of curing are shown in Table 9 and Figures 6, 7 and 8. The above results show that there is marginal reduction in the compressive strength of RCA concrete compared to the NCA concrete. This is due to the rough surface texture of RCA which contains certain amount of mortar from the crushed original concrete. This attached mortar reduces the quality of RCA which leads to poor mechanical properties of RCA concrete. Results also show that there is no significant difference in compressive strength of RCA concrete and NCA concrete at 28 and 90 days of curing.

Table 9: Cylindrical compressive strength (N/mm^2) of different grades of concrete at different periods of curing

Grade of concrete	Percentage of natural aggregate	Percentage of recycled aggregate	Compressive strength (N/mm^2)			
			Period of curing			
			3 days	7 days	28 days	90 days
M 20	100	0	13.87	15.46	26.5	30.9
	50	50	12.49	15.27	24.2	27.3
	25	75	12.87	15.36	25.8	28.6
M 25	100	0	15.23	18.5	28.29	32.82
	50	50	11.13	16.97	25.3	28.4
	25	75	11.78	17.54	27.5	29.8
M 30	100	0	17.54	19.65	33.76	36.9
	50	50	12.44	14.01	30.5	34.14
	25	75	13.58	14.54	32.06	35.6

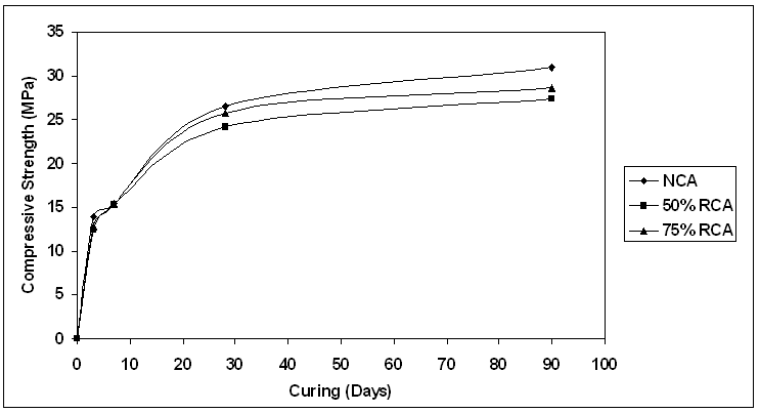

Figure 6. Variation of cylindrical compressive strength of M 20 grade of concrete with curing period

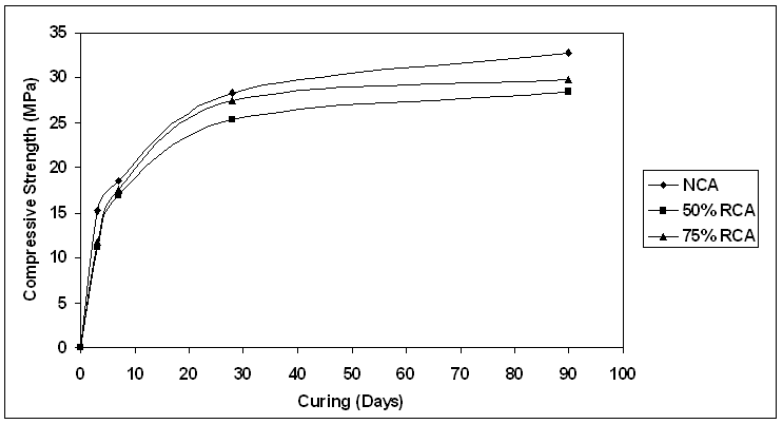

Figure 7. Variation of cylindrical compressive strength of M 25 grade of concrete with curing period

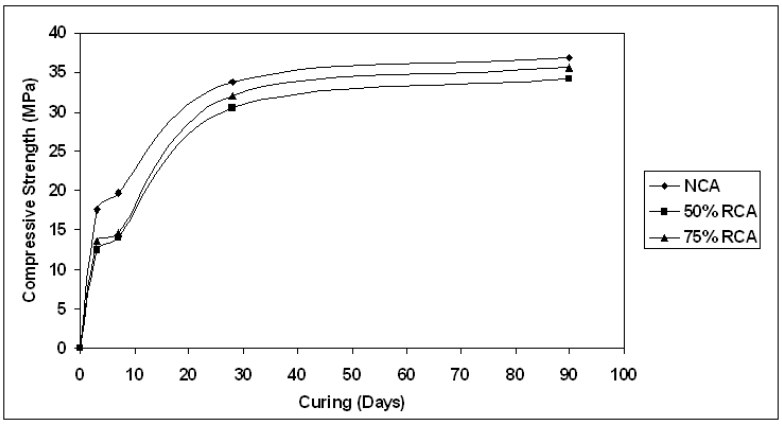

Figure 8. Variation of cylindrical compressive strength of for M 30 grade of concrete with curing period

4.1.2. Compressive strength of NCA cubes and RCA cubes

Compressive strengths of NCA cubes and RCA cubes for different grades of concrete (M 20, M 25 and M 30) at 3, 7, 28 and 90 days of curing are shown in Table 10 and Figures 9, 10 and 11. The above results show that RCA (50%) and RCA (75%) cubes have more compressive strength than NCA cubes for all grades of concrete at 3, 7, 28 and 90 days. RCA (75%) cubes have more compressive strength as compared to RCA (50%) cubes for all grades of concrete at 3, 7, 28 and 90 days of curing. This can be attributed to the cement mortar coat of RCA participates in hydration process and contribute additional strength. It is also observed that the using of NCA and RCA concrete, the cube compressive strength is more than the cylindrical compressive strength.

Table 10: Cube compressive strength (N/mm^2) of different grades of concrete at different periods of curing

Grade of concrete	Percentage of natural aggregate	Percentage of recycled aggregate	Compressive strength (N/mm^2)			
			Period of curing			
			3 days	7 days	28 days	90 days
M 20	100	0	13.63	16.23	36.6	42.51
	50	50	18.08	22.76	37.03	44.14
	25	75	18.54	23.70	39.4	45.03
M 25	100	0	17.03	20.30	38.3	44.7
	50	50	18.4	23.7	39.11	46.3
	25	75	18.97	24.3	40.9	48.0
M 30	100	0	18.84	22.97	44.60	47.7
	50	50	19.36	25.0	45.62	49.18
	25	75	19.87	25.97	46.83	50.3

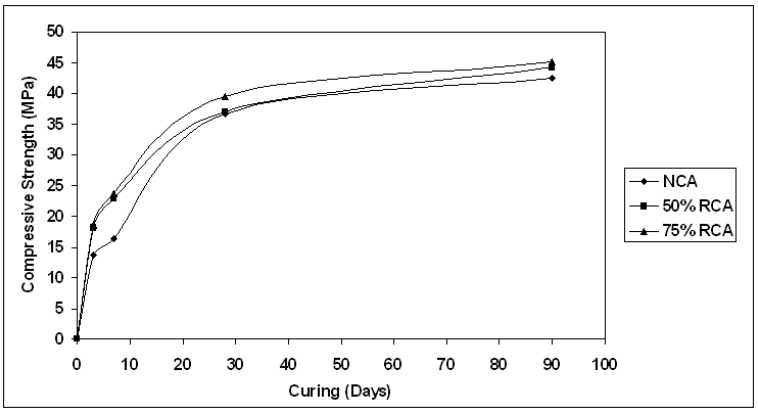

Figure 9. Variation of cube compressive strength of M 20 grade of concrete with curing period

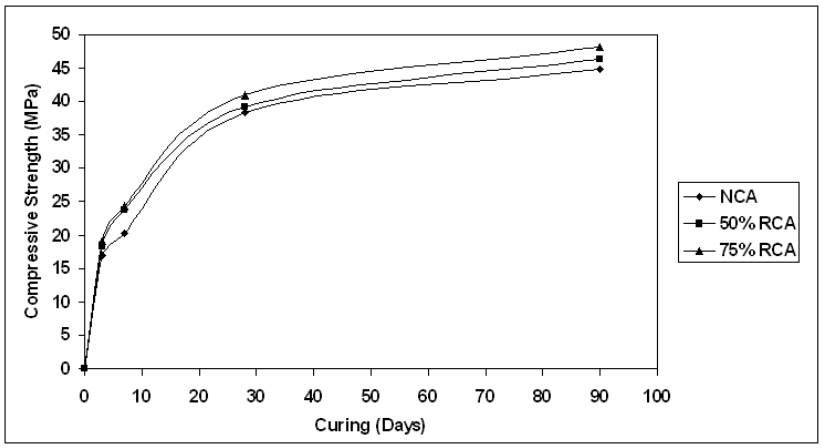

Figure 10. Variation of cube compressive strength of M 25 grade of concrete with curing period

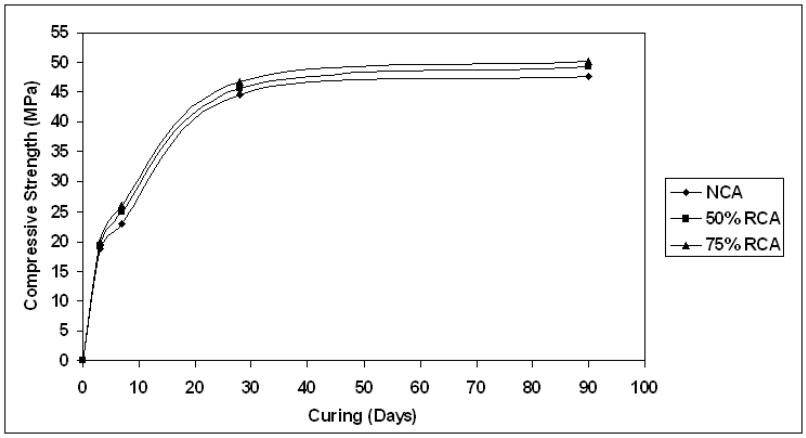

Figure 11. Variation of cube compressive strength of M 30 grade of concrete with curing period

4.2 Modulus of elasticity

Static Modulus of Elasticity of RCA concrete and NCA concrete for different grades of concrete (M 20, M 25 and M 30) are shown in Table 11. The stress-strain curves for the different grades of concrete with various percentages of RCA are shown in Figures 12, 13 and 14. The modulus of elasticity is calculated is the initial tangent modulus as it gives better results for lower stresses. This value has been calculated from the initial tangent of stress-strain curve. From the above results of the modulus of elasticity of concrete, it can be observed that reduction of 8.6% and 18.4% with 50% and 75% replacement of RCA for M 20 grade concrete. Similarly, it can be noted that reduction of 12.9% and 13.1% for M 25 grade concrete and 8.9% and 10.9% for M 30 grade concrete with 50% and 75% replacement of RCA. It clearly indicates a decreasing trend of modulus of elasticity value when the percentage of recycled aggregate is increased.

Table 11: Modulus of elasticity of different grades of concrete at 28 days

Grade of concrete	Percentage of NCA	Percentage of RCA	Modulus of elasticity (GPa)
M 20	100	0	28.33
	50	50	25.90
	25	75	23.12
M 25	100	0	29.96
	50	50	26.10
	25	75	26.05
M 30	100	0	32.33
	50	50	29.46
	25	75	28.78

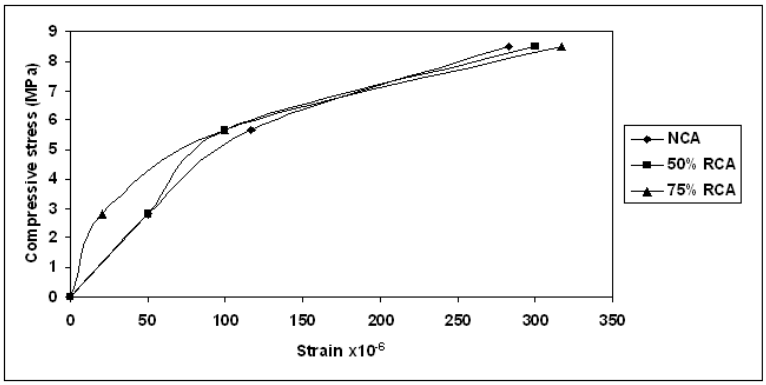

Figure 12. Stress - Strain curve of M 20 grade of concrete

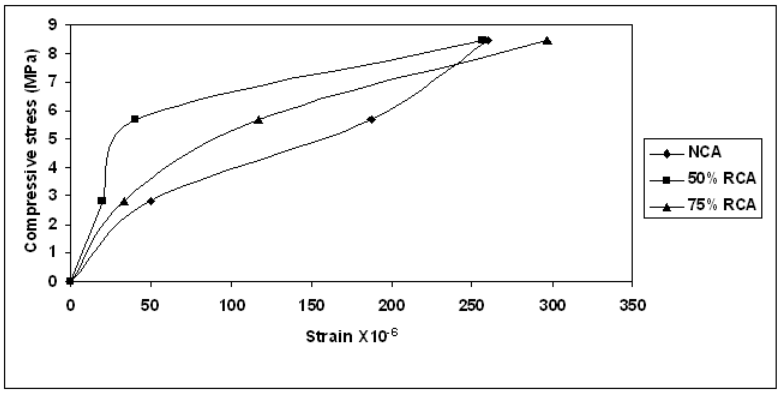

Figure 13. Stress - Strain curve of M 25 grade of concrete

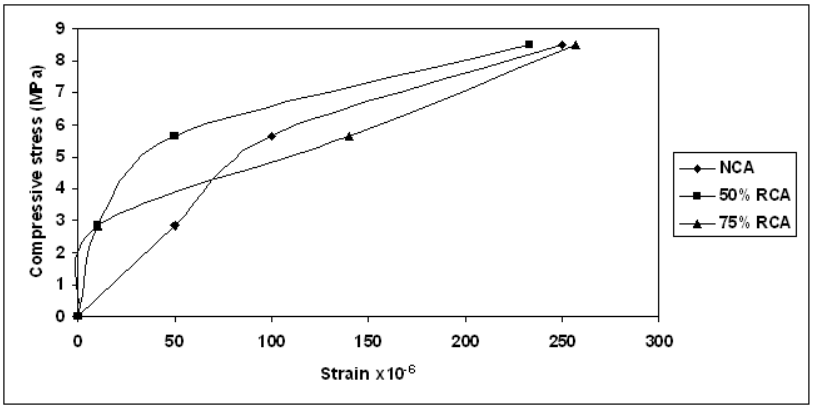

Figure 14. Stress - Strain curve of M 30 grade of concrete

4.3 Rapid chloride permeability test

Rapid chloride permeability test (RCPT) is a quick test to measure the rate of transport of chloride ions in concrete. Rapid chloride permeability of RCA concrete and NCA concrete expressed in terms of charge passed in Coulombs for different grades of concrete at 28 days are shown in Table 12 and Figures 15, 16 and 17.

The chloride ion penetration is measured 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 different percentages of recycled aggregate. Based on the test results it can be considered that the concrete grades M 20, M 25 and M 30 with RCA fall under the category of "moderate" as per ASTM C 1202-07 [14].

Table 12: Rapid chloride permeability of different grades of concrete at 28 days

Grade of concrete	Percentage of NCA	Percentage of RCA	Charge passed in Coulombs	As per ASTM C1202: chloride penetrating rate
M 20	100	0	3697.2	Moderate
	50	50	3824.7	Moderate
	25	75	3899.1	Moderate
M 25	100	0	3422.2	Moderate
	50	50	3820.8	Moderate
	25	75	3221.4	Moderate
M 30	100	0	3085.5	Moderate
	50	50	3338.1	Moderate
	25	75	2910.6	Moderate

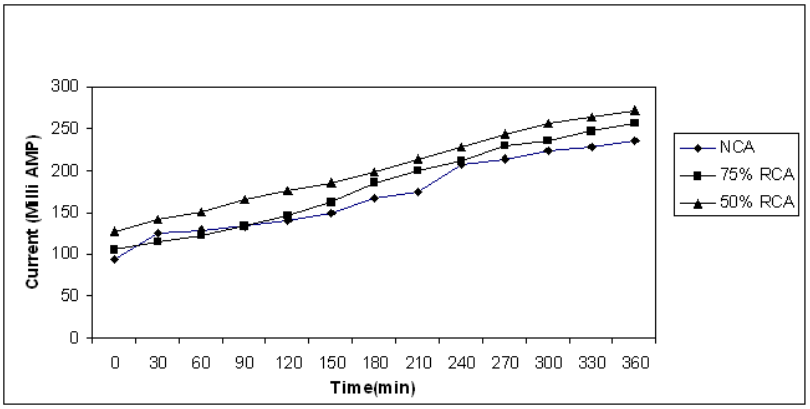

Figure 15. Current passage of M 20 grade of concrete at 28 days

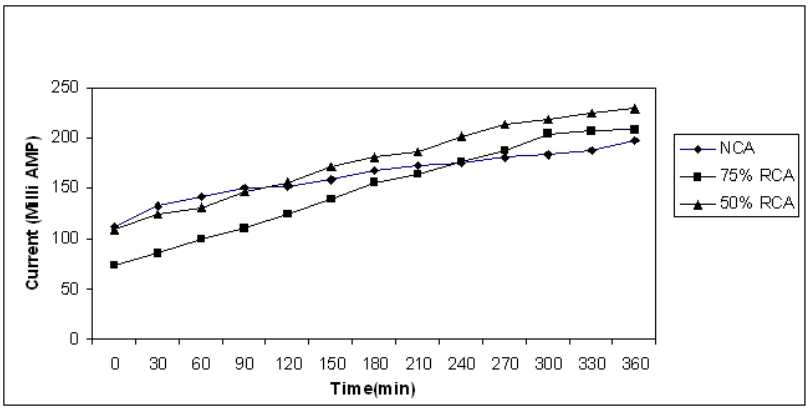

Figure 16. Current passage of M 25 grade of concrete at 28 days

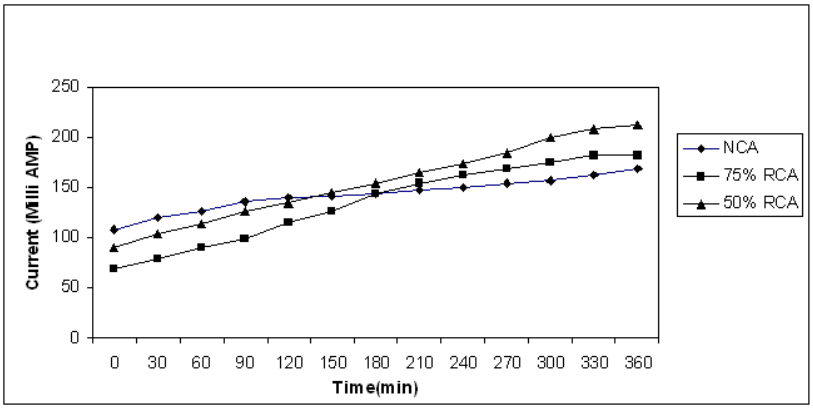

Figure 17. Current passage of M 30 grade of concrete at 28 days

5. CONCLUSIONS

On the basis of comparative studies of the test results of the properties of concrete with two different percentages of recycled coarse aggregate content (50% and 75%), the following conclusions are made.

1. The compressive strength of RCA concrete cylinders increases with the increased quantity of RCA. i.e., 75% RCA concrete cylinders have more compressive strength than 50% RCA concrete cylinders.
2. There is no significant difference in compressive strength of 75% RCA and 100% NCA at 28 and 90 days. It can be recommended that natural coarse aggregate can be replaced with recycled coarse aggregate.
3. RCA concrete has compressive strength compared to the natural coarse aggregate (NCA) concrete.
4. The modulus of elasticity of RCA concrete decreases with increasing recycled aggregate content.
5. Along with strength, concrete should also be durable. The durability properties of concrete were determined using RCPT on the concrete specimens prepared with RCA of different percentages, it is observed that as per ASTM C1202, the chloride penetrating rate is "moderate" for all grades of concrete.

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