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Comparative Study of the Crushing Strengths of Recycled Coarse Aggregates Concretes and Natural Aggregates Concretes

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ABSTRACT: Recycled Coarse Aggregate (RCA) is a recycled concrete material from construction sites, which is being reused for fresh concrete production. The use of this material reduces quarrying of Natural Coarse Aggregate (NCA). Properties of RCA are variable depending on the properties of parent concrete. In a fast-growing economy, the generation of construction waste has increased considerably, and social and environmental concerns on recycling the waste have accordingly increased. Construction Engineers have resorted to recycling these demolition wastes to maintain a friendly green environment. This study compared the crushing strengths of Recycled Coarse Aggregate concrete with Natural Aggregate concretes. The RCA was obtained from demolished drains and culverts while the Natural Coarse Granite Aggregate was from Akamkpa, Cross River State, Nigeria. Using RCA and NCA of maximum size 20mm, concrete cubes were prepared for compressive strength tests. Other properties of the aggregates were determined. Three mix proportions of 1:1½:3, 1:2:4 and 1:3:6 at water cement ratio of 0.6 were utilized and the specimens were tested at curing ages of 7, 14, 21 and 28 days. Results indicated that RCA produced concretes with strengths lower than those using NCA. RCA concretes also had slumps lower than those of NCA concretes.

KEYWORDS: Recycled Coarse Aggregate (RCA), Natural Coarse Aggregate (NCA), Compressive strength, Recycling and workability.

1.0 INTRODUCTION

Concrete remains a basic construction material used across the world and plays an important role in the development of a country. It is used in many Civil Engineering and building infrastructures, low and high-rise buildings, defense installations, environment protection and local/domestic developments.

Concrete is essentially composed of cement, coarse and fine aggregates, water and admixture(s). Aggregates, such as sand, crushed stone or gravel form the major part constituting about 75% of the volume of concrete.

Natural Coarse Aggregates (NCA) is a natural quarried crushed stone or gravel from a source known to produce satisfactory aggregate for concrete and is chemically inert, strong, hard, durable against weathering, of limited porosity and free from deleterious materials that may cause corrosion of the reinforcement or may impair the strength and/or durability of concrete. Traditionally, Natural Coarse Aggregates have been readily available at economic price but recently there has been a decline in the quality and quantity of the aggregates due to over utilization on the account of rapid industrial developments in different Countries. This has led to the search for readily available alternatives; Recycled Concrete Aggregate (RCA) being the immediate substitute.

Recycled Concrete Aggregate (RCA) is a construction material produced by demolishing and crushing previously cast concrete into desirable sizes. The products of this crushing can then be used as a granular fill-type material or as a graded replacement of aggregate in the production of new concrete. Most of the waste materials produced by demolishing structures are disposed by dumping them as landfill or for reclaiming land. Reuse of demolition waste appears to be an effective solution and the most appropriate and large-scale use would be to use it as aggregates to produce concrete for new construction.

RCA is commonly divided into two primary components based on particle size: fine RCA and coarse RCA. This research considered only the coarse type of RCA, which is defined as being composed of particles that would be retained on a 4.80 mm sieve.

For increasing the GDP (Gross Domestic Product) rate of a nation smaller and older structures are being demolished and new and gigantic structures are being built. This results in the accumulation of huge concrete wastes. The waste also creates problem for municipal authorities as it occupies a considerable volume and makes it difficult to collect and transport. This study focused on the use of Recycled Coarse Aggregates in the production of concrete and compares the properties of such concretes with the properties of concrete prepared with natural coarse granite aggregates.

The proper utilization of this old concrete waste as aggregate in concrete would help in reducing the problem of disposal while at the same time reducing the cost of concrete production.

Recently, the use of RCA for concrete production has gained acceptance. Many are quarrying the demolished concrete into acceptable sizes for utilization in concrete while at the same time enriching their pockets from the sales. The strength and other properties of RCA concretes are still doubtful. This study attempts to determine the crushing strength and other properties of concrete using RCA wholly as the coarse aggregate. Attempts are also made to compare these properties with those of concretes prepared with the conventional natural granite coarse aggregate.

1.1 Objectives of the Study: The specific objectives of the study included the following:

1. To determine the Specific gravity, bulk density, and grading of the aggregates.
2. To determine the workability of fresh RCA and NCA concretes of different mix proportions.
3. To determine and compare the compressive strengths of RCA and NCA concretes.
4. Determine and compare the densities of both concretes

Concrete mix proportions of 1:1½:3, 1:2:4 and 1:3:6 were utilized for the study.

2.0 REVIEW OF RELATED LITERATURE

2.1 Recycled Coarse Aggregate (RCA)

Buck (1977) cites the beginning of RCA use to the end of World War II, when there was excessive demolition of buildings and roads and a high need to both get rid of the waste material and rebuild Europe. In the 1970s, the United States began to reintroduce the use of RCA in non-structural uses, such as fill material, foundations, and base course material (Buck 1977). In Nigeria, another possible solution to concrete waste management problem is to recycle demolished concrete waste and produce an alternative aggregate for concrete (Dosho, 2007).

The physical properties of RCA influence the mix proportion and properties of concrete. The basic characteristics such as shape and texture, specific gravity, bulk density, pore volume, and absorption of RCA are generally worse than those of NCA due to the presence of residual cement paste/mortar and impurities (Sagoe-Crentsil et al. 2001; Tu et al. 2006). The magnitude of the effects varies with the nature and quantity of reclaimed cement paste/mortar that is present in RCA (ACPA, 2009).

RCA tends to be very angular and rough due to the crushing of old concrete and because of the presence of hardened cement paste/mortar adhered to the surfaces of original coarse aggregate. Typically, RCA particles contain 30 to 60% old cement paste/mortar, depending on the aggregate size (ECCO, 1999). RCA is similar to crushed rock in particle shape, but the type of crushing equipment influences the gradation and other characteristics of crushed concrete.

The specific gravity of RCA is usually lower than that of NCA (Hansen, 1992; Yong and Teo 2009). The lower specific gravity of RCA is due to the presence of old cement paste/mortar on the aggregate particles that makes it less dense than NCA because of greater porosity and entrained air structure (Anderson et al. 2009). The typical values of specific gravity of RCA range from 2.1 to 2.5 in the saturated surface-dry condition.

According to Yong and Teo (2009), the bulk density of RCA has been found to be 9.8% lower than that of natural gravel aggregate. This is mostly due to the higher porosity of RCA in the presence of adhered cement paste/mortar.

The pore volume of RCA is substantially higher than that of NCA (González- Fonteboa and Martínez-Abella 2008; Safiuddin *et al*. 2011a). The higher pore volume of RCA makes it weak and less dense, as compared to NCA.

Adhered mortar content is an aggregate property unique to recycled aggregates. The term refers to the amount of original cement matrix, which constitutes the particles of RCA. The content is expressed as a percent (by mass) of the overall RCA's oven-dry mass

3.0 MATERIALS AND METHODS

The materials used for the study were cement, sand, recycled coarse aggregate (RCA), natural coarse aggregate (NCA) and portable water.

3.1 Cement: The cement used for the study was the Dangote brand of Portland Limestone Cement grade 42.5. It was sourced from a cement depot in Uyo and transported to the laboratory. The cement complied with the specifications of NIS 444-1: 2014 and ENV 197 – 1: 1992.

3.2 Sand (fine aggregate): Sharp sand fine aggregate was used in this investigation. It was obtained from Odiok Itam River, Itam, Akwa Ibom State and transported in bags to the laboratory. The sand was treated in accordance with BS 882:1992.

3.3 Coarse Aggregate: Two different coarse aggregates were used for this study for comparison purposes. They were Recycled Coarse Aggregate (RCA) and Natural Coarse Aggregate (NCA)

3.3.1 Recycled Coarse Aggregate (RCA): Recycled coarse aggregate was obtained from demolished drains and culverts at Ekom Iman, Uyo, Akwa Ibom State. The materials were treated in accordance with BS 410-1962, and the maximum coarse aggregate size was 20mm. The method stipulated by Butler et al., (2013a) was used for removing adhered mortar content on RCA.

3.3.2 Natural Coarse Aggregate (NCA): Crushed granite stone aggregate of maximum size 20mm from Akamkpa Local Government Area, Cross River State was used. The crushed stones were irregular/angular, rough with fractured planes shaped by crushing.

3.4 Water: Ordinary clean portable water free from suspended particles and chemical substances in conformity with the specifications of British Standards Institution (1980) BS 3148:1980 was used for both mixing and curing of concrete.

3.5 Concrete Mix Proportions used: Three different mix proportions were used for the study 1:1½:3, 1:2:4 and 1:3:6 at water cement ratio of 0.6 and Absolute Volume Method was used to acquire the mix design.

3.6 Methodology: The following experiments were performed in the cause of the analysis: Aggregates sieve analysis, Moisture content test, Bulk relative density determination, Specific gravities of aggregates, Slump test on fresh concrete, and Compressive strength test.

3.6.1 Batching and Mixing: Batching of the concrete was done by weight for each of the concrete mix ratios of 1:1½:3, 1:2:4 and 1:3:6 at 0.6 water/cement ratio. The constituent ingredients were thoroughly mixed manually before potable water was added to produce fresh concrete. The mixing was in accordance with BS 8110-1:1997.

3.6.2 Concrete Workability Test

The slump test was utilized to ascertain the consistency and workability of all the fresh concretes in accordance with BS 1881: Part 102:1983 requirements. This is demonstrated in Figure 3.1. The height difference between the height of slumped concrete and the cone mould was measured to the nearest 5mm.

3.6.3 Preparation of Concrete Cubes

The 150 mm steel cube moulds were used to prepare the concrete cubes in accordance with BS 1881: Part 108:1983. The cube moulds after being oiled internally were filled with concrete in three approximately equal layers. Each layer was compacted using electric concrete compacting vibrator and the top surface was troweled smooth after compaction of the last layer. The prepared cubes are shown in Figures 3.2.

3.6.4 Curing: After 24 hours, the concrete cubes and cylinders were demoulded and cured in water tanks until they were tested at age 7, 14, 21, and 28 days of curing.

Figure 3.1: Slump test

Figure 3.2 Preparation of cubes

3.2.6 Testing of Cubes for Compressive Strength: A hydraulic compressive testing machine was used to conduct the compressive strength test in accordance with BS 1881-116:1983. The load was applied gradually at the rate of 140 kg/cm^2 per minute till the specimen failed. The compressive strength was calculated using equation 6.

$$fc = \frac{P}{A} \qquad [6]$$

Where P = maximum load at failure (N)

A = Cross sectional area (mm^2)

f_c = Compressive strength specimen (N/mm^2)

3.2.7 Density: The cubes were weighed using an electronic weigh balance and with the volume the densities of the concretes were calculated using equation (8) below. The results are presented in Table 4.

$$\rho = \frac{M}{V} \qquad [8]$$

Where,

ρ = density (kg/m^3)

M = mass of the cube (kg)

V = Volume of the cube (m^3)

4.0 RESULTS AND DISCUSSION

4.1 PROPERTIES OF MATERIALS

The physical properties of materials used in this research work are summarized in the table 4.1.

Table 4.1: Properties of Materials

Materials	Properties	Values
Sharp sand	Specific gravity	2.66
	Coefficient of curvature, Cc	1.14
	Coefficient of uniformity, Cu	3.5
	Bulk relative density	1602 kg/m^3
	Moisture content	4 %
Natural coarse aggregate	Specific gravity	2.71
	Bulk relative density	1550 kg/m^3
	Size range	11mm - 20mm
Recycled coarse aggregate	Specific gravity	2.2
	Bulk relative density	1255 kg/m^3
	Size range	11mm - 20mm
Cement	Specific gravity	3.15

	Initial setting time Final setting time Bulk relative density Consistency Soundness	148 minutes 215 minutes 1440kg/m^3 32% 0.58mm

4.2 Sieve Analysis Results: The sieve analysis results for the fine aggregate, natural coarse aggregate and recycled coarse aggregates are presented in Tables 4.1, 4.2 and 4.3 respectively. The results are also presented in Figures 4.1, 4.2 and 4.3 respectively. The result showed that the sharp sand had a range of particle sizes from 0.08mm to 4.75mm with 2.08% retained on 4.75mm and 1.02% on 0.08mm. The Natural Coarse Aggregate particles ranged between 15mm and 25mm. Moreover, the recycled coarse aggregate particle size had the same range as Natural Coarse Aggregate from 16mm to 25mm.

Table 4.2: Sieve Analysis Results for Sharp Sand Used

BS Sieves (mm)	Weight Retained (g)	Percentage retained (%)	Percentage passing (%)
4.75	20.8	2.08	97.92
3.35	7.8	0.78	97.14
2.36	22.4	2.24	94.9
1.18	107.7	10.77	84.13
0.600	298.3	29.83	54.3
0.43	231.2	23.12	31.18
0.25	211.0	21.1	10.08
0.15	85.2	8.52	1.56
0.08	10.2	1.02	0.54
Pan	0.8	0.08	

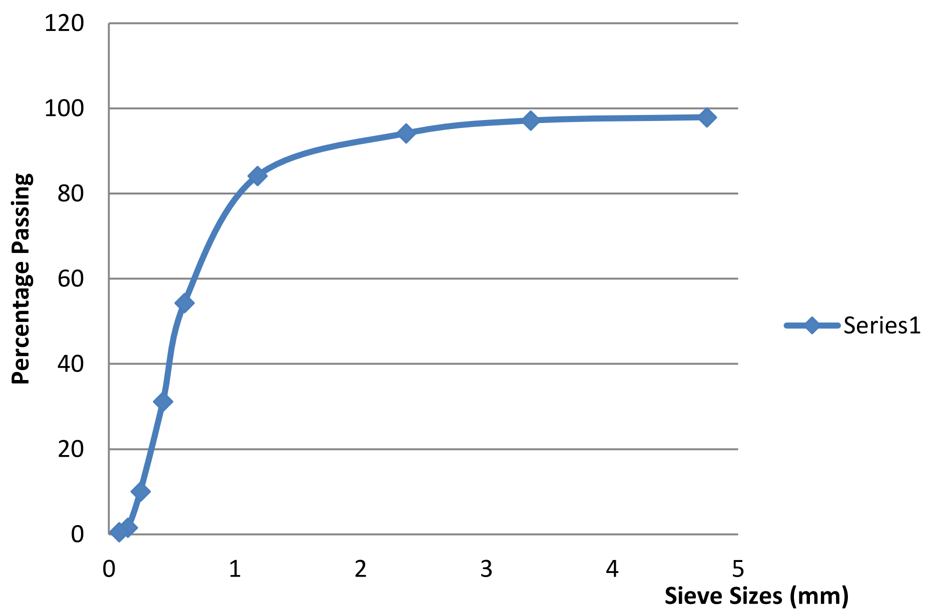

Fig.4.1: Particle Size Distribution for Sharp Sand Used

Table 4.3: Sieve Analysis for Natural Coarse Aggregate (Mass of Sample =1000g)

BS Sieves (mm)	Weight Retained (g)	Percentage retained (%)	Percentage passing (%)
25.0	175.2	17.52	82.48
19.0	347.0	34.7	47.78
16.0	264.2	26.42	21.36
Pan	213.2	21.32	

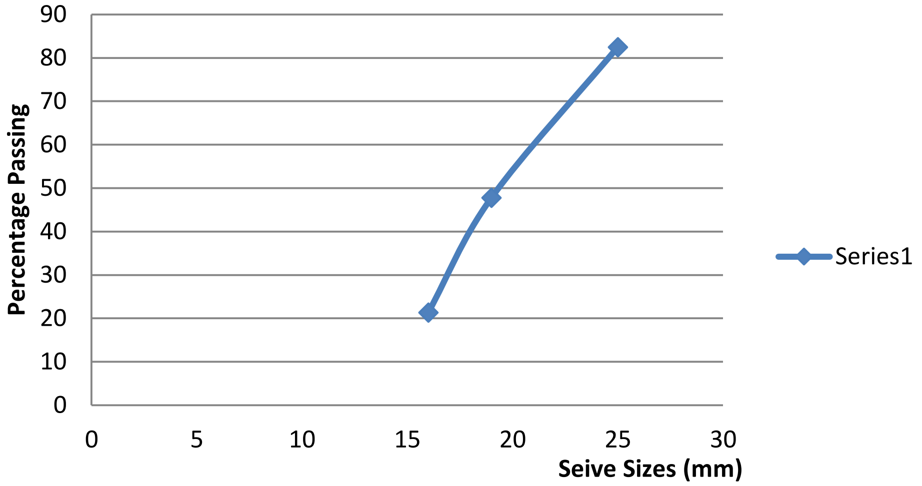

Fig. 4.2: Particle Size Distribution for NCA Used

Table 4.4: Sieve Analysis for Recycled Coarse Aggregate (Mass of Sample = 1000g)

BS Sieves (mm)	Weight Retained (g)	Percentage retained (%)	Percentage passing (%)
25.0	175.2	17.52	82.48
19.0	347.0	34.7	47.78
16.0	264.2	26.42	21.36
Pan	213.2	21.32	

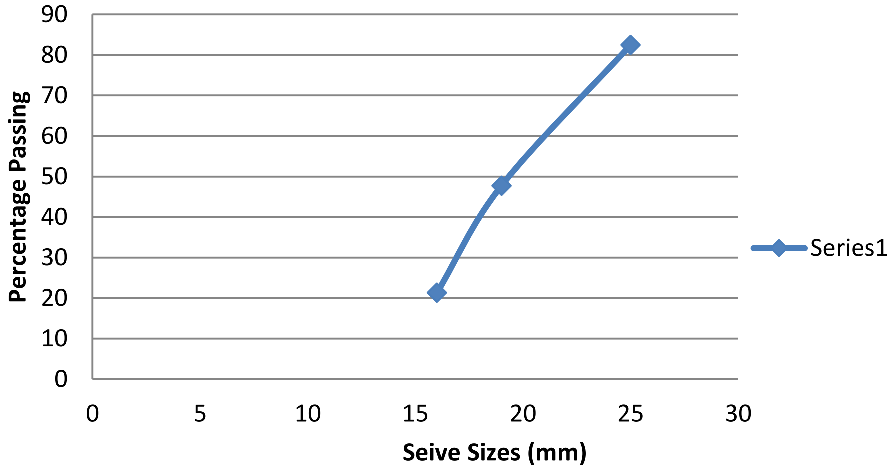

Fig. 4.3: Particle Size Distribution for RCA Used

4.3 Workability (Slump Test): The results of the workability test using the slump experiments are shown on Table 4.4 and Figure 4.4. RCA concretes had slumps lower than those of NCA concretes. For 1:1½:3 concretes the slump stood at 28mm and 35mm for RCA and NCA concretes respectively while for 1:2:4 concretes the slump stood at 22mm and 27mm respectively. The same trend was followed for 1:3:6 concretes.

Table 4.4: Slump of RCA and NCA Concretes

Mix Ratios	Slump (mm)	
	RCAC	NCAC
1:1½:3	28	35
1:2:4	22	27
1:3:6	15	20

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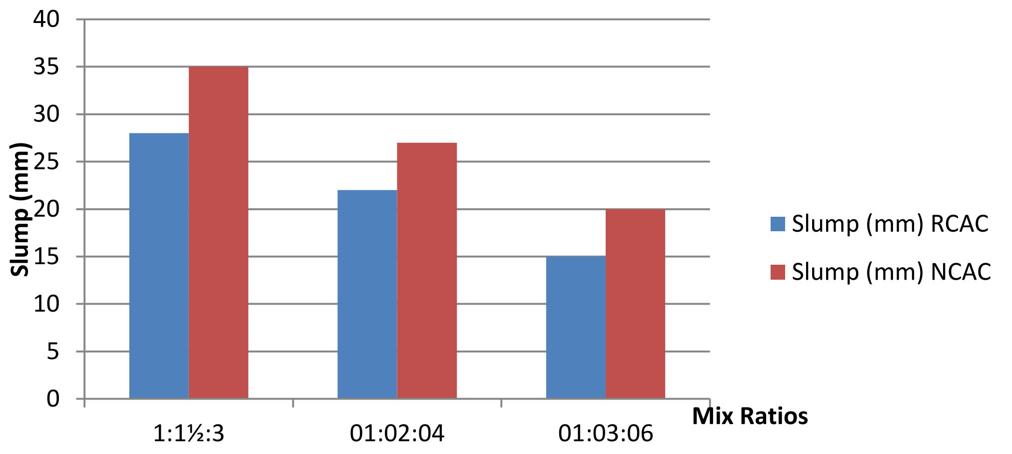

Fig. 4.4: Slump of RCA and NCA Concretes

4.2 Compressive Strength: The Compressive Strengths of NCA and RCA concretes are presented in Table 4.5 and Figures 4.5, 4.6 and 4.7. From Table 4.5, it could be seen that the compressive strength of 1:3:6 RCA concretes is 13% lower than that of NCA concretes; that of 1:1½:3 RCA concretes is 27.7% lower than that of NCA concretes and that of 1:2:4 RCA concretes is 18.7% lower than that of NCA concretes.

Table 4.5: Summary of the Compressive Strengths of concretes

Mix Proportions	Days/Strength (N/mm^2)			
1:3:6	7 days	14 days	21 days	28 days
RCA	16.61±0.45	17.36±0.51	17.96±0.44	18.27±0.32
NCA	19.10±0.15	21.23±0.23	20.98±0.25	21.41±0.44
% difference	13.0%	18.2%	14.4%	14.7%
1:1½:3				
RCA	18.07±0.34	21.54±0.44	22.72±0.43	22.98±0.32
NCA	24.98±0.72	25.84±0.12	26.46±0.31	29.79±0.68
% Difference	27.7%	16.6%	14.1%	22.8%
1:2:4				
RCA	17.47±0.03	17.82±0.05	18.02±0.17	19.61±0.21
NCA	21.49±0.48	22.20±0.15	24.01±0.02	24.27±0.26
% Difference	18.7%	19.7%	24.9%	19.2%

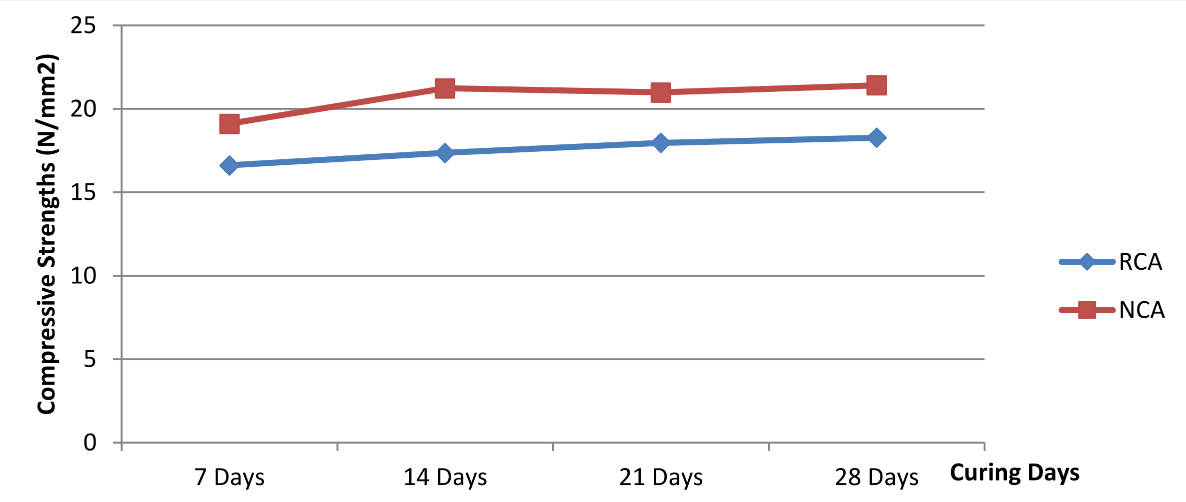

Fig. 4.5: Compressive Strengths of NCA and RCA (1:3:6) Concretes

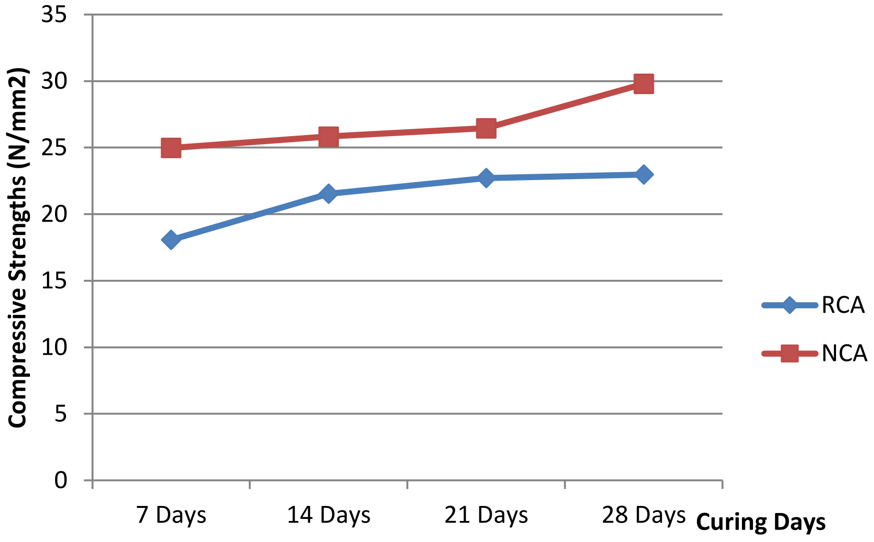

Fig. 4.6:Compressive Strengths of NCA and RCA (1:1½:3) Concrete

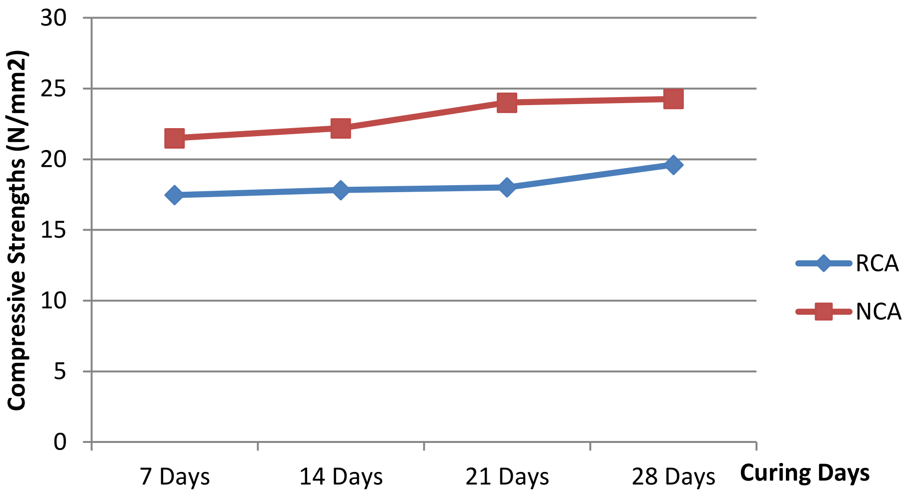

Fig. 4.7:Compressive Strengths of NCA and RCA concretes (1:2:4)

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1: Conclusions

1. At all mix proportions, the crushing strengths of RCA concretes were lower than those of NCA concretes.
2. RCA concretes of 1:2:4 mix and 1:1½:3 have crushing strengths comparable with those of normal weight concretes.
3. Even though the crushing strengths of RCA concretes are lower than those of NCA concretes, the strengths of RCA concretes are still within the range for structural concretes.
4. RCA concretes have reduced workabilities.

5.2 Recommendation

RCA should be used in structural concrete production when considering 1:1½:3 mix proportions.

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