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STUDIES ON INFLUENCE OF RECYCLED AGGREGATES ON STRENGTH PARAMETERS OF CONCRETE

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Abstract: The interest in using recycled construction materials is derived from the growth in construction and demolition waste due to rehabilitation and natural and technological disasters. This research work deals with the study of strength of concrete incorporating Recycled Aggregate concrete (R.A.C). The project involves a comparative study of compressive strength, flexural strength and split tensile strength. Recycled aggregate materials were crushed and sieved to give the same grading for each mix. Natural sand was used as fine aggregate. The mixes were adjusted to account for the different water absorption characteristics of the aggregates but were otherwise identical. Prism specimens with a centrally placed reinforcing bar, cylindrical specimens and non reinforced slabs were cast from each of the concretes. The main objective of this investigation is to find out up to what percentage the Natural Coarse Aggregate (N.C.A) can be replaced by recycled coarse aggregate (R.C.A) in the concrete mix and to find out the extra quantity of cement to be added for each percentage replacement by R.C.A. to achieve its target mean strength. In this project work it is concentrated only on the use of R.C.A. A series of tests were carried out to determine the compressive strength, split tensile strength, flexural strength with and without recycled aggregates. Natural coarse aggregates in concrete were replaced with 0%, 20%, 40%, 60%, 80% and 100% of crushed concrete coarse aggregates. For the strength characteristics, the result showed a gradual decrease in compressive strength, split tensile strength, flexural strength and modulus of elasticity as the percentage of recycled aggregate is increased.

Keywords: Concrete, Natural aggregate, Recycle Aggregate, Demolition waste, compressive strength

I. INTRODUCTION

The wide availability of concrete components, the relatively low level of manufacturing technology, and the variety of applications provided by concrete material have been made concrete as the most commonly used constructional material in the world. The global concrete industry uses approximately 10 billion tonnes of sand and rock annually, which makes it the largest consumer of natural resources in the world Mining, processing, and transportation of cement-making raw materials and concrete aggregates consume a great deal of energy. Also, cement production alone contributes approximately 5% of global emissions through the combustion of fossil fuels and the decomposition of limestone. The driving force for recycling concrete is three-fold: preserving natural resources, utilizing the growing waste and saving energy and money. Hence people are looking for alternative sources for the concrete ingredients in order to full fill their requirements. The search for alternative resources instead of existing natural resources, the continuing shortage of landfill sites due to rapid urbanization, the sharp increase in transportation and disposal costs and severe environmental pollution and regulation control have raised a new challenge to planners and engineers to recycle construction and demolition waste (C&D) material. Table1.1, gives a rough estimation of construction and demolition (C&D) waste generated in countries using the most percentage of recycled concrete as aggregates (RCA). While some waste concrete is currently being crushed and used for grading and base material for highways, it has not been used as the aggregate in new concrete in Canada, largely because of the plentiful supply of good quality virgin material. However, crushed concrete is being used in new concrete in other parts of the world where the local aggregate is inferior, and there is now a push within the Canadian cement and concrete sector to improve the industry sustainability, one aspect of which is recycling of materials. The research done to date has emphasized the influence of recycled concrete aggregate (RCA) on the workability and strength of the new concrete with little attention being paid to the behaviour in service. In this project work it is concentrated mainly on the behaviour of concrete with R.C.A. A series of tests were carried out to determine the compressive strength, split tensile strength, flexural strength with and without recycled aggregates.

Table 1. Global consumption of construction and demolition wastes as aggregates

COUNTRY	C & D waste (million tonnes/ year)	Percentage of C&D waste Recycling,%	Recycled concrete (million tonnes/year)
United States	650	20-30	150
Europe	200	28	50
Japan	85	85	35
Hong Kong	14	50	3.5
Canada	11	21	2.3

Australia	3	50	1.5

The Table 1. indicates that in countries which are suffering from a lack of natural resources and landfills, such as Japan and Hong Kong, the percentage of construction and demolition waste recycling is high (about 85% and 50%).

OBJECTIVE OF THE PRESENT WORK

The objective of the work is to study the compressive strength, split tensile strength and flexural strength of reinforced concrete made with old, contaminated and new, clean recycled aggregate. For this purpose, a comparative study has been made of the physical and mechanical properties of RCA and of hardened concrete incorporating RCA. The tests include porosity, water absorption, chloride permeability, abrasion resistance, salt scaling resistance, reinforcement corrosion and compressive strength.

II. THEORITICAL BACK GROUND

Production of recycled concrete as aggregates (RCA)

Recycled aggregate refining and replacing methods are two recycling methods which are currently being used for production of aggregate from demolished concrete. Aggregate refining method is a closed-loop concrete recycling system in which the adhered cement in RCA is made fragile by a thermal treatment to about 300 C and is removed selectively from original aggregate by rubbing crushed concrete. The retained coarse and fine aggregates can be applied to concrete mix. The by-product powder, which has a large specific surface area, can be used as clinker raw material, cement production and deep or shallow ground improvement as a partial substitute for cement. Figure 1., shows the schematic diagram of the close-loop concrete recycling system.

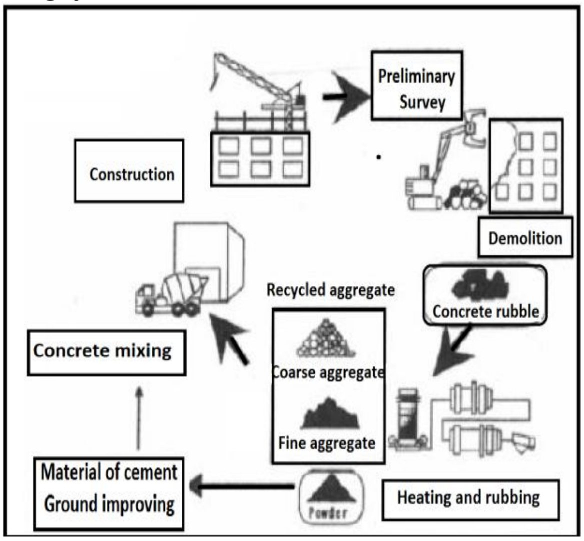

Figure.1 Closed-loop concrete systems

In this manufacturing process, the demolished original concrete undergoes crushing with a jaw crusher and foreign materials such as steel reinforcement are separated magnetically. The aggregate with larger size than 20 mm goes through secondary crushing with an impact crusher and after impurity removal by human power, coarse and fine recycled aggregates are separated based on the their sizes. The ratio of original coarse aggregate replacement by recycled coarse aggregate is determined by relative quality value method according to the desired construction specifications. The remaining fine recycled aggregates can be used for manufacturing of precast concrete products. The advantages of this system are simple manufacturing process with mobile and general-purpose facilities.

MECHANICAL PROPERTIES OF RCA CONCRETE

It has been demonstrated that replacement of natural aggregates with RCA which has lower strength than that of natural aggregate causes a reduction in mechanical properties such as compressive, tensile and flexural strengths of RCA concrete. In table 2 the mechanical properties of concrete made with recycled concrete aggregate (RCA) and natural aggregates are compared.

Table 2. Concrete relative properties made with natural and RCA

CONCRETE PROPERTY	RCA CONCRETE COMPARED TO NATURAL AGGREGATE CONCRETE
Slump control	Higher water demand in RCA
Flexural strength	RCA comparable to NAC
Compressive strength at equal w/c	Less than 90% of NAC
Strength development to 7 days	RCA comparable with NAC
Modulus of elasticity	RCA generally lower than NAC
Drying shrinkage	RCA generally higher than NAC
Expansion	TCA comparable with NAC

III. MATERIALS AND METHODOLGY

A. MATERIALS

Rapid hardening cement was used as the main binder in producing concrete. It conformed to the requirements of. Potable water supplied by Ghana Water Company was used in mixing materials for production of concrete. It appeared clean and free from any deleterious material and conformed to the requirements of . Sand, of bulk density 1550kgm3 was used as fine aggregate. It was sourced from a local supplier in Cape Coast. Crushed granite (Figure 2) and recycled concrete aggregates (RA) were used as coarse aggregates. Crushed granite was obtained from Sarobi quarry near Elmina in the Central Region of Ghana while RA was obtained by manually crushing demolished concrete (Figure 3) and sieving through 5mm BS sieve.


Figure 2. Natural aggregate


Figure 3. Demolished concrete

B. PROPERTIES OF RECYCLED AGGREGATES

Before using R.A. for producing concrete, it is necessary to know the various properties of it. Number of research workers has made an attempt to study the various properties of recycled aggregates.

Grading:

Old concrete debris is crushed to obtain R.C.A of suitable sizes with the help of crushers. By the slight adjustment of the openings of the crushers, we can obtain a well graded R.C.A. It was that the grading of the crusher product was not significantly affected by the grades of the original concrete. The amounts of the fine material (passing 5mm B.S. Sieve) generated by high, medium and low grades of original concrete are 23.1, 25.7 and 26.5% by weights respectively. In general lower the grade of original concretes, the higher was the percentage of fine materials. This is partly due to the presence of a higher proportion of F.A in lower grades of concrete.

Attached Mortar And Cement Paste:

When old concrete is crushed, a certain amount of mortar from the original concrete remains attached to stone particles in R.A. Hansen and Narud reported the percentage volume of mortar which remains attached to gravel in R.C.A. They found the volume percent of mortar attached to natural gravel particles to be between 25% and 35% for 16-32 mm coarse recycled aggregates, around 40% for 8-16 mm coarse recycled aggregates and around 60% for 4-8 mm coarse recycled aggregates, in general the Recycled Aggregates contain an average of about 50% by volume of mortar from the original concrete.

Density:

Densities of coarse recycled aggregates in saturated surface dry condition ranging from 2,340 kg/m3 (for 4-8 mm material) to 2,490 kg/m3 (for 16-32 mm material), independent of the quality of original concrete. Corresponding s.s.d. densities of original coarse aggregates ranged from 2,500 to 2,610 kg/m3. Narud found an s.s.d, density of 2,279 kg/m3 for fine recycled aggregates produced from one original concrete which was made with a water cement ratio of 0.70.

Water absorption:

Water absorptions of coarse recycled aggregates ranging from 8.7% for 4-8 mm material to 3.7% for 16-32 mm material, regardless of the quality of original concrete. Corresponding water absorptions of original aggregates ranged from 3.7 to 0.8%.Narud found water absorption of 9.8% for a fine recycled aggregate produced from an original concrete with a water-cement ratio of 0.70. Recycled concretes have an approximately 5 percent higher free water requirement, compared to otherwise identical fresh concretes made with natural gravel.

C. COMPRESSIVE STRENGTH TO BE ACHIEVED USING RECYCLED AGGREGATES

Recycled aggregates to occupy a role in high strength concrete it is necessary that the composition in the first place provides the necessary compressive strength. Various research works carried out on recycled aggregates have pointed the following parameters to be addressed to achieve the required strength.

1. Adhered mortar
2. Water absorption
3. Los Angeles abrasion
4. Size of aggregates
5. Strength of parent concrete
6. Age of curing
7. Interfacial transition zone
8. Ratio of replacement
9. Moisture state in which used
10. Impurities present
11. Controlled environmental condition

IV. EXPERIMENTAL INVESTIGATION

The total experimental investigations involved in this dissertation work have been done in details. The details of the work are given below.

MATERIALS

The materials used in the entire investigations is as follows

Cement:

Cement used is 53 grade Ordinary Portland Cement (OPC) and the results of various preliminary tests conducted on this cement are as given in Table 3. below.

TABLE 3.: Preliminary Tests Results of Cement

S.NO	PARTICULARS	RESULTS
1	Normal consistency	34%
2	Initial setting time	30min
3	Final setting time	2:42mm
4	Specific gravity	3
5	Soundness	3mm exp
6	Compressive strength of cement for 28 days of curing	47.28 N/mm^2

Natural Coarse Aggregates:
The N.C.A used here are of 20 mm down size. Preliminary test such as water absorption, moisture content, sieve analysis, specific gravity and crushing strength tests have carried out and the results are as given in Table 4. below

TABLE 4: Preliminary test results of N.C.A

S.NO	PARTICULARS	RESULTS
1	Water absorption	0.9%
2	Moisture content	0.908%
3	Specific gravity	2.73
4	Crushing strength	16.67%
5	Flakiness index	19.60%
6	Elongation index	20.60%

Natural Fine Aggregate:
The source for fine aggregate used is from natural river bed, the details regarding test conducted on it are as given in Table 5 below.

TABLE 5: Preliminary test results of N.F.A

S.NO	PARTICULARS	RESULT
1.	Water absorption	1.2%
2.	Moisture content	2%
3.	Specific gravity	2.614

Recycled Aggregate Concrete:
The waste concrete was brought from the demolished structure situated at city bus stand. The coarse aggregate (C.A) is separated from the concrete by hammering. Mortar adhered to the aggregate is also removed from the aggregate as much as possible. Obtained C.A is sieved under 20mm sieve (passing) and 4.75mmsieve (retained), later these aggregates can be used as R.C.A for further work.
Preliminary tests conducted on Recycled Coarse Aggregates:
After obtaining the R.C.A from original concrete, preliminary tests such as sieve analysis, water absorption, moisture content, specific gravity and crushing strengths have been carried out. The results of above tests are as given in Table 6. Below

Table 6: Preliminary tests results of R.C.A

S.NO	PARTICULARS	RESULTS
1.	Moisture content	1.2%
2.	Water absorption	2.5%
3.	Specific gravity	2.55
4.	Crushing strength	19.64%

CASTING, CURING AND TESTING WORK:
For each mix six cubes of 150mm x 150mm x 150mm in size, six cylinders of 150mm diameter and 300mm height and six flexural beams of size 100mmx100mmx500mm were cast using steel moulds. The cast specimens were kept in ambient temperature for 24 hours. After 24 hours they were de-moulded and placed in water for curing. Cubes were used to determine the compressive strength of concrete at 7 days and 28 days. Six cylinders were used to determine the split tensile strength of concrete at 7 days and 28 days. Flexural beam were used to find out the flexural strength of concrete at 7days and 28 days by two point bending test with a supporting span of 133.33mm, using a universal testing machine of capacity 1000 kN. Quantities of the concrete ingredients which are obtained based on N.C.A and R.C.A have been co-related with each other. Using the material quantities obtained after co-relation, cubes cylinders and flexural beams are cast. Here, six different mixes are made and in each mix the N.C.A are replaced by R.C.A by 20% i.e., in the 1st mix 100% N.C.A are used in concrete mix where as in 2nd, 3rd, 4th and 5th mix, 20%, 40%, 60% and 80% replacement of N.C.A by R.CA is made. In the final 6th mix N.C.A are completely replaced 100% by R.C.A. Prepared specimens were kept immersed in water and tested for their strength after 7-days and 28-days of curing.


Figure 4. Concrete mixer used


Figure 5. Concrete cube specimens

V. RESULTS AND DISCUSSION

The results of various experiments which were carried out in the dissertation work are given in this chapter. Based on the obtained results, some of the salient points are discussed below. The results showing sieve analysis carried out for N.C.A, N.F.A and R.C.A are given in Table 6, 7, and 8 respectively. The variation in pass percentage under various sieve sizes for N.C.A, N.F.A and R.C.A is shown in figure 6,7 &8. Before using R.C.A as concrete ingredients, the aggregates are sieved under 20mm (passing) and 4.75mm (retaining) sieve sizes. Also surface of R.C.A are rubbed thoroughly using dry cloth to remove the surface dirt as much as possible, because of which little variation in percentage is observed between N.C.A. and R.C.A.

Table 6. Sieve Analysis of N.C.A

Sieve Size(mm)	Wt. Of Aggregate Retained (gm)	Cumulative Wt. Retained (gm)	% Age Wt. Retained	Cumulative % Age Wt. Retained	% Age Passing
20	0.00	0.00	0.00	0.00	100
16	356	356	7.12	7.12	92.8
12.50	720	1076	14.40	21.26	78.74
10.00	1362	2438	27.24	48.50	51.5
6.73	1720	4158	34.40	82.90	17.10
4.75	842	5000	17.10	100.00	00.00

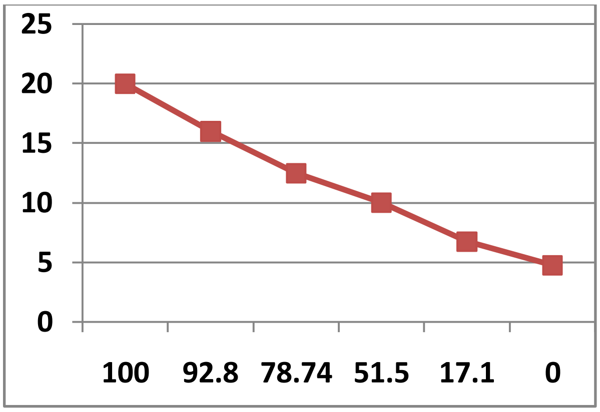

Figure 6. Sieve Analysis graph of N.C.A

Table 7: Sieve analysis of N.F.A

Sieve Size(mm)	Wt. Of Aggregate Retained (gm)	Cumulative Wt. Retained (gm)	% Age Wt. Retained	Cumulative % Age Wt. Retained	% Age Passing
4.75	64.128	64.128	6.41	6.41	93.6
2.36	40.08	104.208	4.0	10.41	89.6
1.18	178.35	282.564	17.8	28.25	71.75
600	278.35	561.12	27.85	56.11	43.9
300	382.76	943.884	38.27	94.39	5.7
150	54.108	997.992	5.41	99.80	0.3

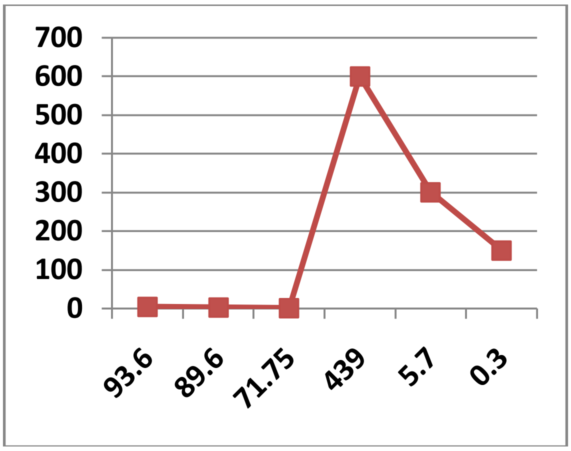

Figure 7. Sieve analysis graph of N.F.A

Table 8 : Sieve analysis of R.C.A

Sieve Size(mm)	Wt. Of Aggregate Retained (gm)	Cumulative Wt. Retained (gm)	% Age Wt. Retained	Cumulative % Age Wt. Retained	% Age Passing
20	72	72	1.44	1.44	98.56
16	391	463	7.82	9.26	90.74
12.50	739	1202	14.78	24.04	75.96
10	1228	2430	24.56	48.60	51.4
6.73	1653	4083	33.06	81.66	18.34
4.75	917	5000	18.34	100	0.00

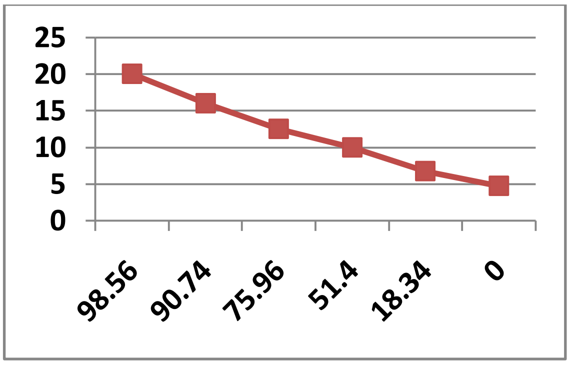

Figure 8. Sieve analysis graph of R.C.A

COMPRESSIVE STRENGTH:

The cube compressive strength for all the mixes at 7 and 28 days of curing is presented in Table 9. The results show that the concrete specimens with more replacement of recycled aggregate have the lowest compressive strength when compared to the concrete specimens with less recycled aggregate for both 7 days and 28 days of curing. 7 days compressive strength is generally 60-80% of the 28 days compressive strength. Figure 9 shows that the compressive strength at 28 days for 20% replacement of R.C.A has dropped around 5.14%. Even up to 60% replacement of recycled aggregate, the compressive strength gets reduced only to a maximum of 10.79% with respect to that of control concrete. There is a drop of 29.11% compressive strength for the 100% recycled aggregate. The compressive strength of the concrete specimens for 60% recycled aggregate is 27.61N/mm2, which meets the target strength of 27.6N/mm2. From the obtained results, it is clear that there is a possibility to use 60% recycled coarse aggregate in applications like concrete blocks and pavements.

SPLIT TENSILE STRENGTH:

The split tensile test indicates a decreasing trend of split tensile strength at 7days and 28 days of curing, when the percentage of recycled aggregate is increased. Table 10 represents the tensile strength values for mixes at7 days and 28 days of curing. The Figure 10 shows that the 28 days split tensile strength is significantly greater than 7 days split tensile strength. The concrete specimen with 100% recycled coarse aggregate at 28 days of curing has the lowest tensile strength, which was only 1.952 N/mm2. It is around 38.81% drop when compared to control concrete specimen. There is a drop in tensile strength of 10.66%, 18.18%, 24.76% and 34.79% for the concrete specimens with 20%, 40%, 60% and 80% recycled coarse aggregate respectively. Even up to 60% replacement, the split tensile strength gets reduced to a maximum of 24.76% with respect to that of control concrete.

FLEXURAL STRENGTH:

The flexural strength for all the mixes at 7 days and 28 days of curing is presented in Table 11. The results show that the concrete specimens with more replacement of recycled aggregate have the lowest flexural strength when compared to the concrete specimens with less recycled aggregate. Figure 11 shows that there is a drop in flexural strength of 7.9%, 13.58%, 24.20%, 35.31% and 43.45% for the concrete specimens with 20%, 40%, 60%, 80% and 100% coarse aggregates respectively.

MODULUS OF ELASTICITY:

By comparing all the mixes as given in Table 13, the specimen with natural coarse aggregates has the highest value of modulus of elasticity while the specimens with 100% recycled aggregate has the lowest. From the experimental results, the modulus of elasticity of full natural coarse aggregate specimens as indicated from Figure 13 was 27.816 GPa, while the modulus of elasticity of full R.C.A specimens was 23.42 GPa. It indicates a drop of 4.4 GPa, which is 15.8% difference between the 0% and 100% recycled coarse aggregate batches. There is a drop in modulus of elasticity of 2.6%, 4.56%, 5.55% and 11.57% for the concrete specimens with 20%, 40%, 60% and 80% of recycled aggregate respectively.

Table 9: Compressive strength using correlated properties in concrete mix design with %age replacement of N.C.A. by R.C.A

MIX NO	% replacement of N.C.A by R.C.A	Days of curing	Avg. Load (Tested on 3-cubes)(tonnes)	Compressive Strength(N/mm^2)
1.	0.00	7-days	55.67	24.26
		28-days	71.00	30.94
2.	20.00	7-days	52.67	22.95
		28-days	67.33	29.35
3.	40.00	7-days	51.00	22.23
		28-days	64.33	28.18
4.	60.00	7-days	50.67	22.08
		28-days	63.33	27.60
5.	80.00	7-days	46.67	20.34
		28-days	55.50	24.19
6.	100.00	7-days	42.33	18.45
		28-days	50.33	21.93

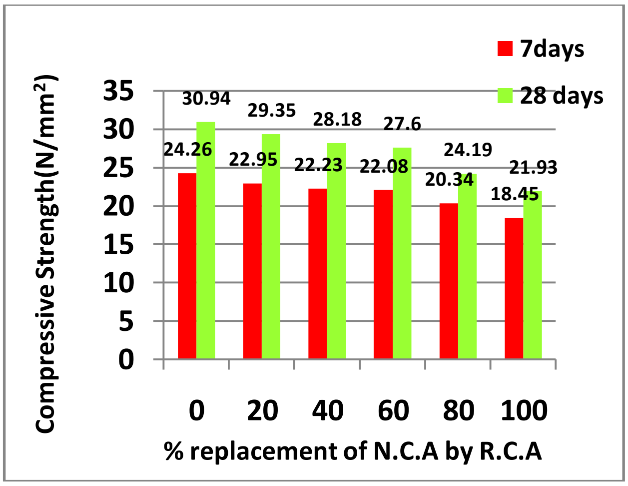

Figure 9 Compressive strength using correlated properties in concrete mix design with %age replacement of N.C.A. by R.C.A

Table 10: Split tensile strength using correlated properties in concrete mix design with %age replacement of N.C.A. by R.C.A

MIX NO	% replacement of N.C.A by R.C.A	Days of curing	Avg. Load (Tested on 3-cubes)(tonnes)	Split Tensile Strength(N/mm^2)
1.	0.00	7-days	16.167	1.121
		28-days	23.00	3.18

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2.	20.00	7-days	14.467	1.003
		28-days	20.5	2.84
3.	40.00	7-days	12.833	0.890
		28-days	18.83	2.60
4.	60.00	7-days	12.067	0.836
		28-days	17.33	2.39
5.	80.00	7-days	10.50	0.727
		28-days	14.96	2.07
6.	100.00	7-days	9.823	0.681
		28-days	14.07	1.951

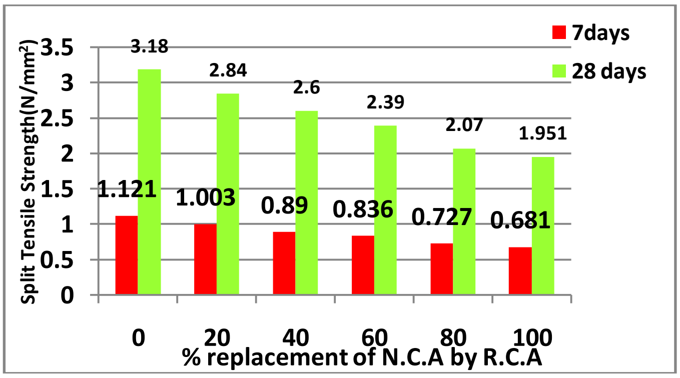

Figure 10. Split tensile strength using correlated properties in concrete mix design with %age replacement of N.C.A. by R.C.A

Table 11: Flexural strength using correlated properties in concrete mix design with %age replacement of N.C.A. by R.C.A

MIX NO	% replacement of N.C.A by R.C.A	Days of curing	Avg. Load (Tested on 3-cubes)(tonnes)	Flexural Strength(N/mm^2)
1.	0.00	7-days	0.770	3.01
		28-days	1.033	4.04
2.	20.00	7-days	0.677	2.64
		28-days	0.95	3.72
3.	40.00	7-days	0.50	1.95
		28-days	0.9	3.49
4.	60.00	7-days	0.475	1.732
		28-days	0.783	3.06
5.	80.00	7-days	0.417	1.634
		28-days	0.667	2.61
6.	100.00	7-days	0.367	1.439
		28-days	0.583	2.28

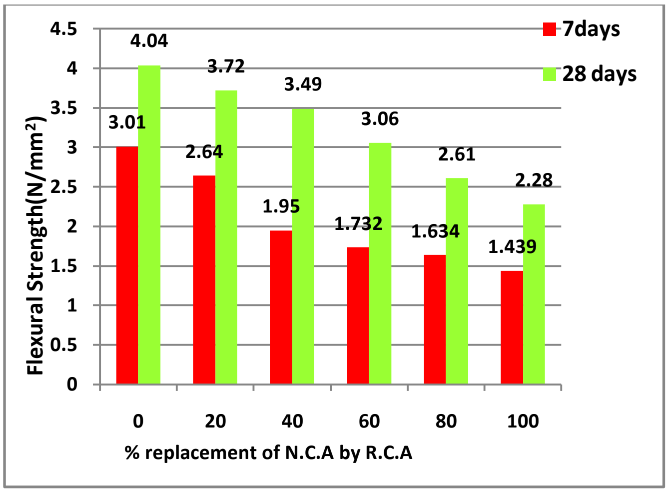

Figure 11. Flexural strength using correlated properties in concrete mix design with %age replacement of N.C.A. by R.C.A

Table 12: Modulus of elasticity at 28 days strength

MIX NO	% age replacement of N.C.A by R.C.A	Modulus of elasticity (Gpa)
1	0.00	27.815
2	20.00	27.091
3	40.00	26.546
4	60.00	26.271
5	80.00	24.596
6	100.00	23.419

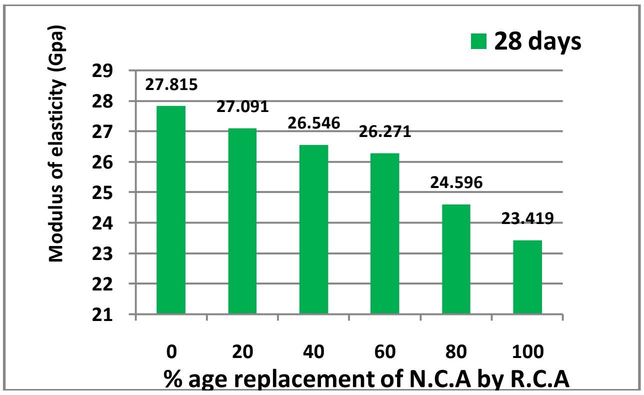

Figure 12. Modulus of elasticity at 28 days strength

VI. CONCLUSIONS

Based on the results and discussions given in the previous chapter, some of the conclusions drawn are as listed below.

1. Little variation in %age passing (Sieve Analysis) is observed between N.C.A and R.C.A. this is mainly because of carrying out proper sieve analysis of R.C.A and by removing the surface dirt present on R.C.A by rubbing with

dry cloth
2. Water absorption of RCA is more than the water absorption of NCA due to the older mortar adhered to the surface of aggregate which contribute towards decrease of strengths
3. From the obtained results, it is clear that there is a possibility to use 60% recycled coarse aggregate in applications like concrete blocks and pavements.
4. The split tensile test indicates a decreasing trend of split tensile strength at 7days and 28 days of curing, when the percentage of recycled aggregate is increased.
5. The results show that the concrete specimens with more replacement of recycled aggregate have the lowest flexural strength when compared to the concrete specimens with less recycled aggregate.
6. By comparing all the mixes the specimen with natural coarse aggregates has the highest value of modulus of elasticity while the specimens with 100% recycled aggregate has the lowest.

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