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EXPERIMENTAL STUDY ON BEHAVIOR OF RECYCLED AGGREGATE IN CONCRETE

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Abstract - Concrete is one of the most widely used construction material in the world. Increase in population growth is leading to increase in various demands like cultivation, transportation, construction etc. Nowadays, there is a tremendous increase in the demand for construction works like residential buildings, bridges, dams, roads etc. and because of this increase in demand the availability of sources for concrete ingredients is getting difficult. Hence people are looking for alternative sources for the concrete ingredients in order to full fill their requirements. This dissertation work deals with the study of strength of concrete incorporating Recycled Aggregate concrete(R.A.C).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 byR.C.A. to achieve its target mean strength. In this ongoing 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.

Key Words: Natural Coarse Aggregate, Recycled coarse aggregate, compressive strength, split tensile strength, flexural strength.

I. INTRODUCTION

Construction developments are on its peak in the 21st century around the globe. There are numerous sky- scrapers, bridges, roads, underground tunnels, and deep- water structures all over the world. As well, there are many other types of structure being constructed every year. To accommodate new structures, many structures built in the past centuries are being demolished and destroyed due to their limit of life span, unsuitable position in an ever-growing city, and damaged condition caused by natural disaster. The demolition of structures is generating concrete rubbles and causing environmental problems due to unplanned disposal and scarcity of landfill sites. A large portion of the potentially useful demolition waste is disposed off in landfill sites. The transport and disposal of this waste are economically and environmentally not sustainable. To alleviate these problems, nowadays alternative aggregates are drawing more interest in the construction industry [1]

According to an investigation conducted in 2002 by the Ministry of Land, Infrastructure and Transport (MLIT), the amount of construction waste produced in Japan is approximately 83 million tons per year, most of which is recycled in compliance with related laws and ordinances. Of the total construction waste, concrete waste accounts for approximately 35 million tons per year. Although the recycling rate of concrete waste has reached 98%, most of it is used for roadbed gravel [3].

II. LITRATURERE VIEW

A. A study has been conducted by **M C Limbachiya, A Koulouris, J J Roberts and A N Fried** in Kingston University, UK on “Performance of Recycled Aggregate Concrete”. Theeffectsofupto100%coarse recycled concrete aggregate on a range of fresh, engineering and durability properties have been established and assessed its suitability for use in a series of designated applications. Compressive strength tests on standard 100mm concrete cubes were carried out at ages up to one year after initial curing in waterat20° C at 28 days. Overall, the results show that up to 30% coarse RCA has no effect on concrete strength, but thereafter a gradual reduction with increasing RCA content occurs [4].

B. There search has been conducted by **Song Guetal.** on “Properties of Recycled Aggregate Concrete” concluded that, Because of old mortars adhered on the surface of the aggregate the water absorption rate of recycled aggregate is far more than natural aggregates ,the slump and strength will decrease while the replacement rate of RCA increased and Fly ash can enhance the workability of recycled concrete effectively. While the replacement rate of FA to cement is no more than 30%, the strength of concrete will not decrease obviously [5].

C. **R. Sri Ravindrajah, Y. H. Loo, C. T. Tam** conducted an experiment on "Strength evaluation of recycled-aggregate concrete by in-situ tests". The compressive strength of concrete was determined at various ages up to 90 days using 100mm cubes. Based on the results, they concluded that for a given water- cement ratio, the recycled-aggregate concrete showed a lower strength than that for the natural aggregate concrete. The results also showed that the relationship between the strength and water-cement ratio at both ages follows a similar trend for the recycled-aggregate concrete as well as the natural aggregate concrete [6].

D. **Yong P.C and Teo, D.C.L** conducted a research on "Utilisation of Recycled Aggregate as Coarse Aggregate in Concrete". Recycled concrete aggregates (RCA) from site-tested concrete specimens were used. The main aim of this research project is to utilise recycled concrete as coarse aggregate for the production of concrete. It is essential to know whether the replacement of RCA in concrete is inappropriate or acceptable. Three types of aggregates are used in this project which includes natural coarse aggregate, natural fine aggregate and RCA. Concrete is then produced with replacement of 0%, 50% and 100% of RCA as well as 100% replacement of saturated surface dry (SSD) RCA with the same mix proportion. The compressive strength of concrete with 100% replacement of RCA has the highest 7-day and 28- day strength which reaches 40.24 MPa and 57.99 MPa respectively. The compressive strength of recycled concrete with 50% replacement of RCA is in close proximity with that of the control concrete The split tensile strength of recycled concrete with replacement of 100% RCA and 100% SSD RCA are both higher than split tensile strength of control concrete. From the results,the3-dayflexuralstrengthofcontrolconcreteis lowest compared to 3-day flexural strength of RAC.The 28-day flexural strength of control concrete is highest compared to 28-day flexural strength of RAC [2].

E. A study on "local construction and demolition waste used as a Recycled Concrete Aggregate (RCA) in the production of new concrete" was investigated by **Madan Mohan Reddy.K, Bhavani.R and Ajitha. B.** The performance of compressive strength produced by Recycled Aggregate Concrete (RAC) and results are compared with the Natural Coarse Aggregate Concrete (NAC**).**

F. The studies were conducted with M20 mix with the selected w/c ratio of 0.5 and the development of compressive strength of the RAC and NAC at the age of 7& 28 days were studied. The result shows the compressive strength of RAC is on average 87% of the NAC and the Slump of RAC is low and that can be improved by using Saturated Surface Dry (SSD) of RCA. Based on the obtained results they derived the conclusion that concrete can be successfully produced using RCA that have been produced from demolition and construction waste. Concrete produced by RCA does not perform well as concretes produced by NCA in terms of strength. However, the concrete still has a strength that would make it suitable for some applications [7].

G. Production of recycled aggregates:

Concrete from reinforced concrete structures or precast concrete units which can be used as raw material for production ofrecycled aggregates is termed as Original Concrete. Concrete in structures to be demolished may have various types of finishes, cladding materials, lumber, dirt, steel and hardware" is attached to them. It is necessary to remove all such foreign matter associated with concrete. This will ensure concrete fairly free from contamination due to impurities [8].

Dierkes J.H.has explained clearly how removal of steel from the reinforced concrete rubble can be done. Two large mobile diesel hammers were used for crushing and rubber tired hydraulic excavator with a large armed hard steel picker foot was used for separating concrete from reinforcement. The concrete is then fed into the primary Jaw crusher. A large self cleaning electromagnet placed over the belt coming from primary crusher, collects any leftover reinforcement in the concrete. The usual procedures for producing recycled aggregates are reported by various authors such as Hansen and Narud, Ravindrarajah and Tom, Hansen and Boegh.

E. 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.

i. Grading:

Old concreted ebrisis 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 observed by Ravindrarajah and Tam [8] 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.

ii. 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 [8].

Ravindrarajah and Tom reported that, in general the Recycled Aggregates contain an average of about 50% by volume of mortar from the original concrete.

iii. Density:

Hansen and Narud found densities of coarse recycled aggregates in saturated surface dry condition ranging from 2,340 kg/m^3 (for 4-8 mm material) to 2,490 kg/m^3 (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/m^3. Narud found an s.s.d, density of 2,279 kg/m^3 for fine recycled aggregates produced from one original concrete which was made with a water cement ratio of 0.70[8].

iv. Water absorption:

Hansen and Narud found water absorptions of coarse recycled aggregates ranging from 8.7% for 4-8 mm material to 3.7% for 16-32mm 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.

According to Hansen and Narud (1983), recycled concretes have an approximately 5 percent higher free water requirement, compared to otherwise identical fresh concretes made with natural gravel [8].

III. EXPERIMENTAL INVESTIGATION

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

A. Materials

The materials used in the entire investigation is as follows

i. 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 I below.

TABLE1: 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	3mmexp
6.	Compressive strength of cement for 28days of curing	47.28N/mm^2

ii. ***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 there sults areas given in Table II below

TABLE 2 : 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%

iii. ***Natural Fine Aggregate*:**

The source for fine aggregate used is from natural river bed, the details regarding test conducted on it areas given in Table 3 below.

TABLE3: Preliminary test results of N.F.A

S.No.	Particulars	Results
1.	Water Absorption	1.2%
2.	Moisture content	2%
3.	Specific gravity	2.614

iv. *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. Details regarding sieve analysis of RCA are given in Table VII.

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 IV below

Table 4 : 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%

B. ***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 demoulded 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 at7 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 1stmix 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.

IV. 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 V, VI, and VII respectively.

The variation in pass percentage under various sieve sizes for N.C.A and R.C.A is shown in figure 1. Table VII review the shape test conducted on N.C.A

Referring figure1, it can be noted that there is a little variations in the percentage passing (sieve analysis) between N.C.A and R.C.A. 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. Compressive strength of the trial mixes carried by varying cement content is given in Table VIII.

A. *Compressive strength:*

The cube compressive strength for all the mixes at 7 and 28 days of curing is presented in Table IX. 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. Figure2 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 maximumof10.79% 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/mm^2, which meets the target strength of 27.6N/mm^2. From the obtained results, it is clear that there is a possibility to use 60% recycled coarse aggregate in application ns 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 X represents the tensile strength values for mixes at 7 days and 28 days of curing. The figure-3 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 1.952N/mm^2.

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.

A. *Flexural strength:*

The flexural strength for all the mixes at 7 days and 28 days of curing is presented in Table XI. 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 4 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.

B. ***Modulus of elasticity:***

By comparing all the mixes as given in Table XII, 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 5 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 V: 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

Table VI : 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
600µ	278.55	561.12	27.85	56.11	43.9
300µ	382.76	943.884	38.27	94.39	5.7
l5Oµ	54.108	997.992	5.41	99.80	0.3

Table VII : Sieve analysis of R.C.A

Sieve size (mm)	Wt. of ggregate retained (gm)	Cumulativewt. retained (gm)	%agewt. retained	Cumulative % age wt. retained	%age passing
20.00	72	72	1.44	1.44	98.56
16.00	391	463	7.82	9.26	90.74
12.50	739	1202	14.78	24.04	75.96
10.00	1228	2430	24.56	48.60	51.4
6.73	1653	4083	33.06	81.66	18.34
4.75	917	5000	18.34	100.00	0.00

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

Mix No.	%age replacement of N.C.A by R.C.A	Days of curing	Avg. Load (Tested on 3-Cubes) (tones)	Compressive strength (N/mm^2)
1.	0.00	7-days	55.67	24.27
		28-days	71.00	30.95
2.	20.00	7-days	52.67	22.96
		28-days	67.33	29.36
3.	40.00	7-days	51.00	22.24
		28-days	64.33	28.19
4.	60.00	7-days	50.67	22.09
		28-days	63.33	27.61
5.	80.00	7-days	46.67	20.35
		28-days	55.50	24.20
6.	100.00	7-days	42.33	18.46
		28-days	50.33	21.94

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

Mix No.	%age replacement of N.C.Aby R.C.A	Daysof curing	Avg. Load (Tested on 3-Cubes) (tones)	Split tensile Strength (N/mm^2)
1.	0.00	7-days	16.167	1.122
		28-days	23.00	3.19
2.	20.00	7-days	14.467	1.004
		28-days	20.5	2.85
3.	40.00	7-days	12.833	0.890
		28-days	18.83	2.61
4.	60.00	7-days	12.067	0.837
		28-days	17.33	2.40
5.	80.00	7-days	10.50	0.728
		28-days	14.96	2.08
6.	100.00	7-days	9.823	0.682
		28-days	14.07	1.952

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

Mix No.	% age replacement of N.C.A by R.C.A	Daysof curin g	Avg. Load (Tested on 3-Cubes) (tones)	Flexural strength Strength (N/mm^2)
1.	0.00	7-days	0.770	3.01
		28-days	1.033	4.05
2.	20.00	7-days	0.677	2.65
		28-days	0.95	3.73
3.	40.00	7-days	0.50	1.96
		28-days	0.9	3.50
4.	60.00	7-days	0.475	1.733
		28-days	0.783	3.07
5.	80.00	7-days	0.417	1.635
		28-days	0.667	2.62
6.	100.00	7-days	0.367	1.440
		28-days	0.583	2.29

TableXII: Modulus of elasticity at 28 days strength

MixNo.	%agereplacementof N.C.AbyR.C.A	Modulusofelasticity (GPa)
1	0.00	27.816
2	20.00	27.092
3	40.00	26.547
4	60.00	26.272
5	80.00	24.597
6	100.00	23.420

Fig1: Sieve analysis of NCA and RCA

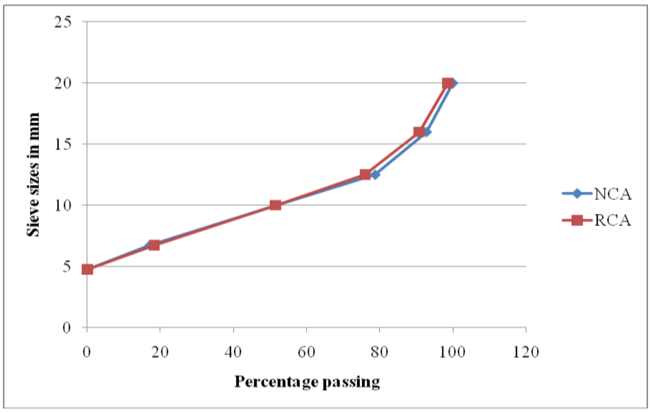


Fig2: Compressive strength at 7days and 28 days

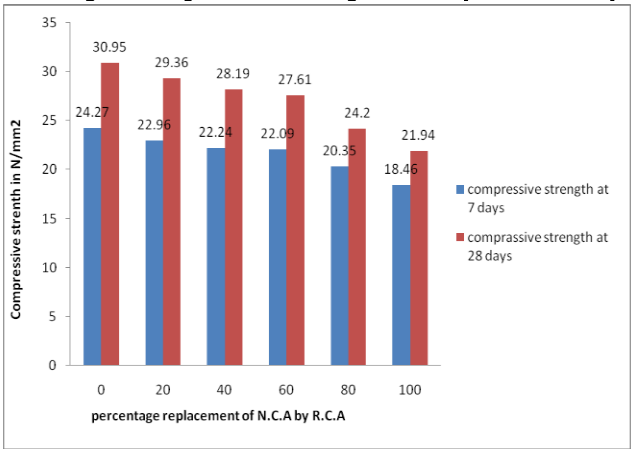


Fig3 : Split tensile strength at 7days and 28days

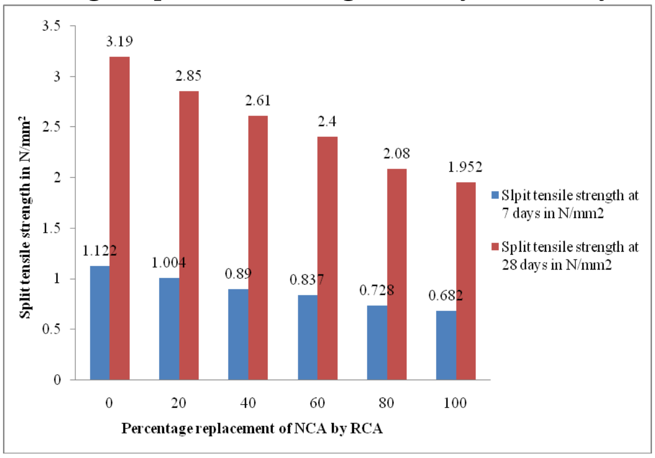


Fig4: Flexural strength at 7days and 28days

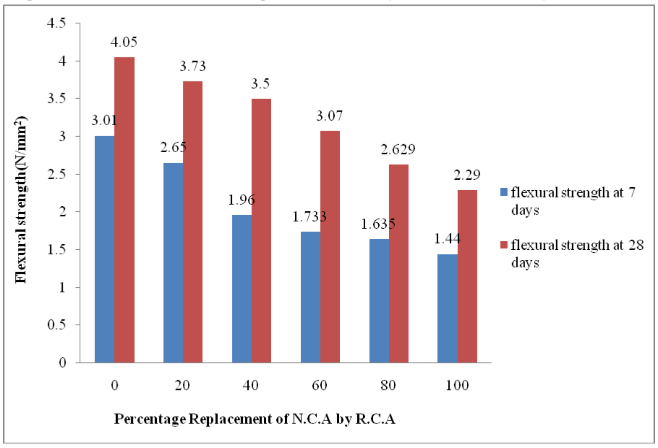
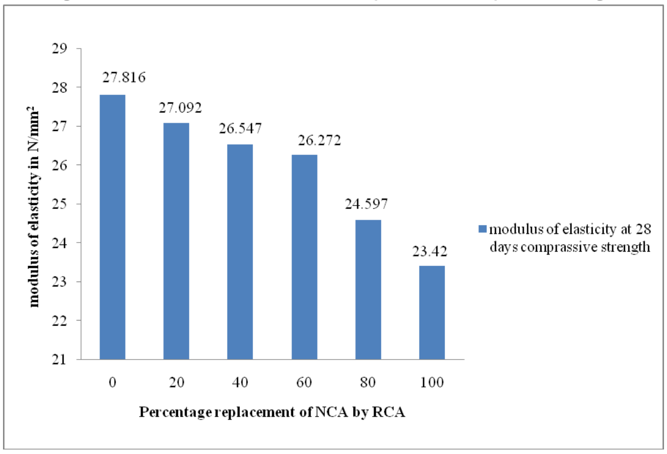


Fig 5: Modulus of elasticity at 28days strength



V. 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. The strength of concrete decreases as the percentage of RCA increases. From the concrete mix design the target mean strength of 27.6 N/mm^2can be achieved for M20 grade concrete by 60% replacement of natural coarse aggregate by recycled coarse aggregates
4. For achieving target mean strength 17.37% of extra quantity of cement is to be added in the concrete mix.
5. As there is considerable reduction in split tensile strength and flexural strength of concrete with recycled aggregates, the loss in strength should be considered while designing members using recycled aggregate concrete

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