EXPERIMENTAL INVESTIGATION ON RECYCLED AGGREGATES FOR SUSTAINABLE CONCRETE ON COLUMN SPECIMENS UNDER AXIAL LOADINGS

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ABSTRACT:*This paper presents the experimental study on compressive behavior of Recycled aggregate Concrete column under axial loading. Reinforced aggregate concrete is prepared by partial replacement of crushed concrete coarse aggregates with natural coarse aggregates. The study also includes treating the recycled concrete aggregates with Nitoflor Lithurin (basically mixture of sodium silicate and lithium silicate solutions) to enhance the surface properties of RCA. Twelve different column were casted with four mixes in consideration viz. (i) C-1 (conventional concrete), (ii) C-2 (50% NCA +50% TRCA containing concrete) (iii) C-3 (30% NCA +50% TRCA +20% RCA containing concrete) and (iv) C-4 (80% NCA +20% RCA containing concrete). At first the RCA were treated with 5% weight of the aggregates and then kept to dry for 7 days. The column was casted and tested at Department of Civil Engineering, UVCE, Bangalore University, Bengaluru, and Karnataka, India. Stress-strain curve was established. First crack load and failure load are determined and also the theoretical and experimental load, strains and young's modulus are compared. It is experimentally observed that C-2, ultimate load has significantly increased when compared to C-3 and C-4 but less than C-1 and also C-2 has shown more stress resistance compare to C-3 and C-4. It is evident from the experimental results from axial loading and the parameter under consideration for C-2 is par with C-1(control column) hence same as been compared with theoretical results and the same is validated.*

1. INTRODUCTION

Concrete is the most favourite material used in construction industry. Because concrete has basic ingredients that are easy to find namely cement, coarse aggregate, fine aggregate and water. According to the concept of Sustainable development the environmental load of a building must be evaluated throughout its life cycle, from design to construction maintenance or repair demolition and Rubber disposal therefore from a Holistic point of sustainable construction means designing a reinforced concrete structure with appropriate durability during a specified service life among the possible solutions favouring greater and environmental sustainability in the construction industry material engineering is considering the use of recycled aggregates from building demolition to produce new concrete. Decreasing natural resources of sand and gravel and increasing problems with waste management support the recycling of accumulating waste materials. Recycled aggregates are composed of original aggregates and added motor physical properties of recycled aggregates depends on both land and water quality and amount of added motor the added motor is a porous material its velocity depends upon the water cement ratio after recycled concrete employed the crushing procedure and the dimension of recycled aggregate have an influence on the amount of adult motor the density and absorption capacity of recycled aggregates are affected by adult water and they must be known prior to the utilisation of recycled aggregates in concrete production in order to control the properties of fresh and hardened concrete.Generally recycled concrete aggregate will have more cementitious particles adhered to it will result in the less specific gravity and more water absorption capacity. Concrete made from this RCA will give less strength compare to conventional concrete. Hence only some partial replacement can be done to NCA to give comparable strength.

Very few tests have been conducted under compression loading for concrete members that contain combination of untreated and treated recycled coarse aggregates. To examine the feasibility of using recycled aggregate as a structural component, project studies were conducted as part of this research.

2. REVIEW OF LITERATURE

The present experimental study is concentrated on axial compression behavior of short columns using RCA and treated RCA as partial replacement for NCA concrete. The columns takes load from the beams and slabs and undergo compression when it is loaded. Nowadays the building waste generated is very huge in quantity hence to make utilize of the waste coarse aggregates many research is going on the building demolition waste. in this research the RCA is used in concrete and RCA is treated with sodium silicate is also used to enhance the properties. Numerous researches have been investigated on columns to know compression behavior and ultimate load carrying capacity. And the relevant literature available in this area has been critically studied.

- **Dr. Shailesh Choudhary et al., (2016)** conducted experiments on RCA concrete with high strength concrete mixes by 0, 15, 25, 35 & 45% for different w/c ratio of 0.45 and 0.35. The 35MPa designation is used in the programme. The cubes of 150x150x150 mm were casted and cured under laboratory conditions in water bath. The slump value decreases with increase in percentage replacement in both cases of w/c. The compressive strength has decreased gradually from 0% to 45% though the drop is 29% in 0.45 w/c ratio whereas 11% in 0.35 w/c ratio. The acid resistance is better for low w/c ratio with very less replacement of 25-35% of RCA concrete. The water absorption is increased with increment in RCA in concrete while there is decrease in saturated water absorption at low w/c ratio.
- **Joel K Mathew1, Dhanya Krishnan2** An experimental study was carried out to investigate the behaviour of concrete columns bonded with Carbon Fiber Reinforced Polymer sheets. In this study, all columns were tested under a concentric axial loading using a testing machine with a capacity of 50 tons. Strain gauges were used to record the axial displacement of columns. The load was applied until complete failure took place. Axial deformations of columns were noted down at equal interval with the help of dial gauge. Then ultimate load and corresponding deformation noted down. The load deformation curve was plotted. Results obtained in this study are while retrofitting with CFRP sheets circular columns attain a strength enhancement in axial load of 8.5%. Thus CFRP sheets can be used as strength enhancing material for retrofitting of damaged columns. The axial load deformation graph shows that the deformation increases to 7.5% for retrofitted circular columns and 11.4% increase for retrofitted square columns. Axial stress-strain graph shows higher stress-strain behavior with 6% increase for retrofitted square columns and 9.8% for retrofitted circular columns.
- **Abhay Mathews1, Gopika Moorthy2** The experimental study involves the reinforced concrete columns with recycled concrete coarse aggregate. Materials used are cement, fine aggregates, recycled coarse aggregates of different proportions (0%, 0%, 20%, 30%, 40%, 50%), Super plasticizers (Polycarboxylic ether polymer with long lateral chain) and M30 grade concrete is used. Two columns are casted of size 150x150x400mm.first column C1 is with 0% replacement of RCA and second column C2 with 30% replacement of RCA. Axial load is applied in compression testing machine till failure of columns and failure load is recorded and also stress and strain curve is plotted for different loads. Control specimen column C1 have maximum ultimate failure load of 880kN, C2 column have ultimate failure load of 620kN. According to the study, it was observed that up to 30 %- 40% replacement Of RCA in Concrete can provide Sufficient Strength for use of Recycled Coarse Aggregate that is obtained from demolished building and can be reused. So the RCA can use for column in construction building,

3. EXPERIMENTAL WORK

The main focus of this experimental study is to utilize recycled concrete as coarse aggregate for the production of concrete as a sustainable development in the construction industry. It is essential to know the optimization % of replacement of RCA to NCA for cement concrete and optimization % of replacement of TRCA to NCA for cement concrete, many trial mixes were done to fix the combination of different % replacement of RCA and TRCA with NCA, finally arrived at following four mixes namely,(i) C-1:100%NCA(conventional concrete of grade M-25) (ii) C-2:50%TRCA+50%NCA (M-25 grade concrete made using 50% treated recycled concrete aggregate and 50% natural coarse aggregate)(iii) C-3:50%TRCA+30%NCA+20%RCA,(M-25grade concrete made using 50% treated recycled concrete aggregate, 30% natural coarse aggregate and 20% recycled concrete aggregate) and(iv) C-4: 80%NCA+20%RCA (M-25 grade concrete made 80% natural coarse aggregate and 20% recycled concrete aggregate)

For the above following mixes the basic compressive strength test were conducted and for the same above mixes the column test specimens were casted and tested in the structural laboratory to study the compressive behavior.

3.1 Materials Used

(i) Cement: Ordinary Portland Cement 53 grade Birla Super cement was used in the present investigation.

(ii) Coarse aggregates: Crushed angular of 20mm down size aggregates are used and tested confirming to IS 2386 Part 1 to Part 4 -1963 (Reaffirmed-2002) to determine Specific gravity, Bulk density and Fineness modulus for NCA and as well as RCA . The results were presented in table 1.

Table-1: Physical characteristics of Coarse Aggregates (20 mm)

Aggregate		Natural Coarse aggregate		
Test specification		IS:383-1970 IS:2386-1963 (Part I, II & III) Reaffirmed to 2011		
SL. NO.	**PARTICULARS**	**OBSERVATIONS**		**AS PER IS:383-1970**
		NCA	**RCA**	
1	Specific Gravity	2.725	2.38	Not specified
2	Absorption value	0.25%	2.25%	Not specified
3	Bulk density (Dry, Loose-Rodded)	1582, 1432 Kg/m³	1384, 1262 Kg/m³	Not specified
4	Elongation Index	11.8 %	11.8 %	Not specified
5	Flakiness Index	10.4 %	8.4 %	Not specified
6	Crushing Value	18 %	27 %	30%
7	Impact Value	17 %	25 %	30%

(iii) Fine aggregates-sand was used. The tests were carried out in accordance with the IS 2386 Part 1 to Part 4-1963 (Reaffirmed 2002) to determine Specific gravity, Bulk density and Fineness modulus of M-sand. The results were presented in table 2.

Table-2: Physical characteristics of Fine Aggregates (20 mm)

Sl. No.	Particular of test	Results
1	Fineness Modulus	**4.34**
2	Specific Gravity	**2.83**
3	Bulk Density (Kg/m³) Dense loaded Loose	 **1736** **1610**
4	**Zone**	**II**

(iv) Water: Potable water as obtained from Cauvery water supply at Civil Engg. Dept. Jnanabharathi, Bangalore was used for the preparation of concrete mix and curing.

3.2 Mix proportion

A concrete mix grade of M-25 was aimed in the present experimental investigation; the design mix proportion was obtained as per **IS10262:2000 Method.** Based on the same the target strength for M-25 was achieved for various % of replacement of NCA with RCA and TRCA.Mix proportion shown in table no 3.

Table-3: Mix Proportions

MIX	cement	FA	NCA	RCA	TRCA	water
	kg/m³	kg/m³	kg/m³	kg/m³	kg/m³	kg/m³
M1:	384	737.72	1169.8			191.58
M2:	384	737.72	1169.8		532	191.58
M3:	384	737.72	1169.8	1012	532	191.58
M4:	384	737.72	1169.8	1012		191.58

Table-4: Designation of Test column specimens

Design Mix	Designation Test Specimen	Mix Proportion
MIX-1	COLUMN-1: C-1	100% NCA
MIX-2	COLUMN -2: C-2	50%NCA+50%TRCA
MIX-3	COLUMN-3: C-3	30%NCA+50%TRCA+ 20%RCA
MIX-4	COLUMN-4: C-4	80%NCA+20%RCA

Table 5: Materials required for respective test column specimen

MIX	cement	FA	NCA	RCA	TRCA	water
	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
C1:	384	19.918	31.58			5.172
C2:	384	19.918	17.216		14.364	5.172
C3:	384	19.918	1169.8	5.464	14.364	5.172
C4:	384	19.918	26.116	5.464		5.172

4. METHODOLOGY OF TEST

The main purpose of compression test on column is to determine the compressive strength and load resistance to fracture of a specimen. The axial compressive load is applied until failure of the specimen to know the ultimate failure load.

After the concrete has hardened its resistance to their loads is called its strength, the strength of concrete plays a very vital role in its structural behavior and design of cement concrete structural members. The strength of concrete is commonly considered as most valuable property of concrete. The strength of concrete usually gives the overall picture of quality of concrete. As the strength is directly related to structures of hardened cement paste.

4.1 Compression Strength Test on standard specimen (CUBE)

As per IS: 516:1959, Clause 5.1 up to 5.6, the compression test is the most important test that can be used to assure the engineering quality in the application of building materials. The compressive strength of concrete is defined as the load which causes failure of the specimen divided by the area of the cross section in uni-axial compression. The optimum content of ingredients in the concrete mix was determined by conducting the compression test on trial mixes to arrive at the mix proportions for the matrix used in the investigation. The cube mould of 150 mm x 150 mm x 150 mm size is taken as per IS: 516-1959 specification. The compression strength is calculated using the formula,

$$f = P/A \quad N/mm^2$$

Where

f = is compressive strength of concrete in N/mm^2

P = ultimate load at which specimen fail in N

A = Cross sectional area in mm^2

4.2 Axial Compressive test on short concrete columns

4.2.1 Casting Procedure for columns.

First of all, the moulds were cleaned, greased and oiled. The next step involves fixing the mould end plates using nuts and bolts. Then cover blocks are placed at suitable positions to maintain proper clear cover. The reinforcement mesh was then placed in the formwork, taking care to provide the required clear cover on the bottom and sides. On the other side, individual materials were batched in an electronic weighing balance. The materials were properly mixed in mixer. Firstly, the aggregates and cementitious materials were mixed randomly in the dry state. The whole dry mixture is then mixed for 5 minutes. The beams were casted with the help of hand trowel and Pick-Mattock electrical Needle vibrator of 25 mm diameter was used for proper consolidation of the concrete. Mould was filled with concrete then the mould was fully compacted by tamping. Sufficient care was taken to see that concrete was properly filled in corners and the edges of the mould. As soon as the air bubbles stopped to rise, the top surface of the mould was finished with trowel by applying little pressure till the lattice layer appears. Total twelve test column specimens were casted. After 24 hours, test column specimens were de-moulded and were cured continuously for 28 days in water tanks.

Table 6: Dimension of Test Specimen

Details	Dimension (mm)
Length	**1200**
Width	**150**
breadth	**150**

Table7: Reinforcement Details

Details	Dimensions
Main bar	4 of 12 mm dia
Lateral ties	150 mm c/c
Clear cover	40 mm

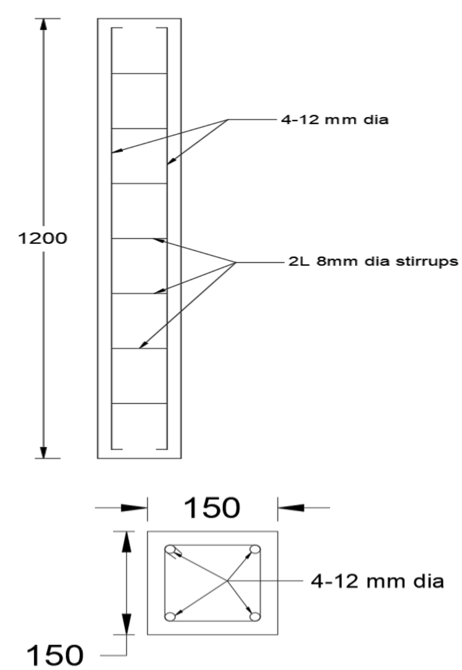


Figure1: Longitudinal and c/s section of column

4.2.2 Experimental setup.

The test was conducted using the loading frame of 200 tons capacity. the arrangement was duly made to make the loading on the specimens by providing circular steel pipe at top of the specimen by fixing it to the frame. To get the pinned support conditions two number of 25mm thick plates are placed above and below the testing specimen. After completing the initial setup, the specimens were placed on the loading gauge and jacked to fix the specimen between two supports. care was taken to maintain verticality along both vertical plane, line of action of load and loading axis.

After setting up of specimen between the supports, the strain gauge was fixed on the column at suitable position. Then strain gauge is connected to strain indicator and dial gauge is placed in position and initial dial gauge reading were noted down. Testing load is applied to check the instrumentation and setup.

The load was applied gradually at an increment of 10kN. The load and corresponding strain gauge reading was noted down. The behavior of specimens like initial crack, ultimate or failure crack and their corresponding loads and strains were observed and noted.

All the twelve specimens were tested in similar procedure with the test setup as described above, the corresponding loads and strains readings were tabulated and graphs were drawn.

Fig 2:

4.3.3 Placing of strain gauge.

The stress and strain will induce when it is loaded, the strain induced in the column can be measured using strain gauges ,the member undergo strain when it is stressed, the stresses induced in the column is varies at different points. The measurement of strain at maximum stress position is determined using Saint-Venants principle.

As per Saint-Venants principle when the load is applied throughout the section, the stress is maximum at a distance is equal to 0.25 % width of the section and later stress decreases and becomes constant till mid section of the column . Since stress is directly proportional to strain, hence strain is also maximum at a distance is equal to 0.25% width of the section.

Since the width of column section is 150 mm, the strain gauge is placed at a distance of 0.25 % of width of section (37.5 mm), the strain induced in the column is measured and recorded.

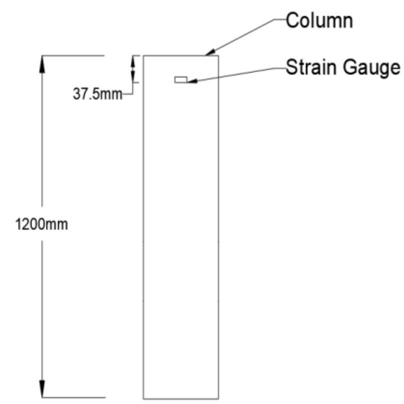


Fig 3: Position of strain gauge.

5. RESULT AND DISCUSSION

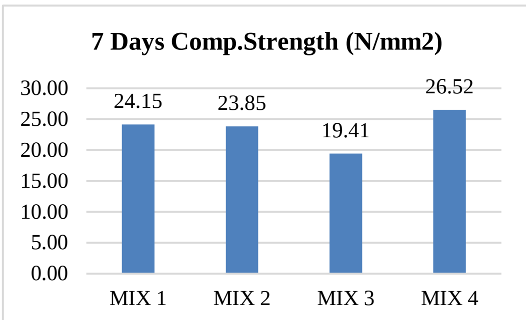
5.1 Results of Compressive strength for concrete cubes

The 7, 14 and 28 days compressive strength after curing for (i) M-1: 100%NCA (conventional concrete of grade M-25) (ii) M-2: 50%TRCA+50%NCA (M-25 grade concrete made using 50% treated recycled concrete aggregate and 50% natural coarse aggregate) (iii) M-3: 50% TRCA+30% NCA+20% RCA (M-25 grade concrete made using 50% treated recycled concrete aggregate, 30% natural coarse aggregate and 20% recycled concrete aggregate) (iv) M-4: 80% NCA + 20% RCA (M-25 grade concrete made 80% natural coarse aggregate and 20% recycled concrete aggregate) concrete matrices were tested in the present investigation.

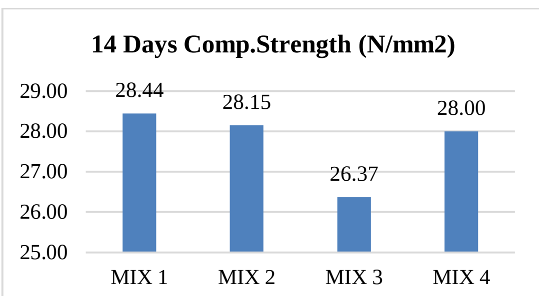
Table8: Summary of 7, 14 and 28 days Compressive Strength of Test Specimens

7 DAYS COMPRESSIVE STRENGTH					
MIXES	Trial 1	Trial 2	Trial 3	Mean	Comp.Strength (N/mm2)
MIX 1	550	540	540	543.33	24.15
MIX 2	530	550	530	536.67	23.85
MIX 3	450	420	440	436.67	19.41
MIX 4	600	590	600	596.67	26.52
14 DAYS COMPRESSIVE STRENGTH					
MIXES	Trial 1	Trial 2	Trial 3	Mean	Comp.Strength (N/mm2)

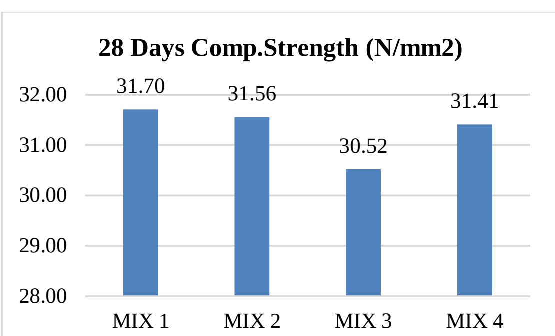
MIX 1	650	640	630	640	28.44
MIX 2	640	630	630	633.3333	28.15
MIX 3	590	600	590	593.3333	26.37
MIX 4	630	640	620	630	28.00
28 DAYS COMPRESSIVE STRENGTH					
MIXES	Trial 1	Trial 2	Trial 3	Mean	Comp.Strength (N/mm2)
MIX 1	710	710	720	713.3333	31.70
MIX 2	710	720	700	710	31.56
MIX 3	690	690	680	686.6667	30.52
MIX 4	710	710	700	706.6667	31.41



7 days Compressive strength



14 days Compressive strength



28 days Compressive strength

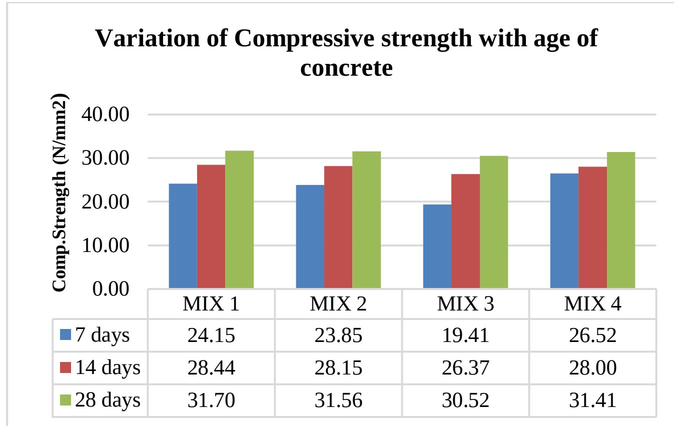


Figure4: Comparison of Compressive Strength with Age of different concrete matrices

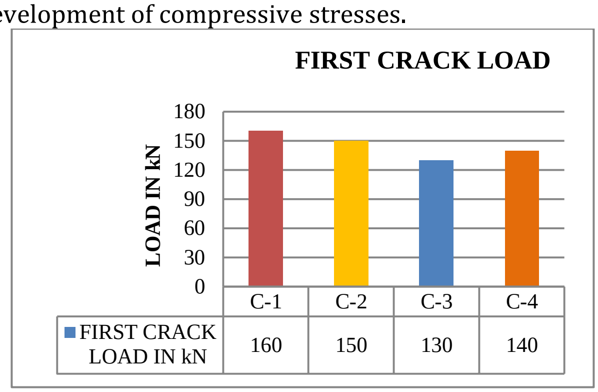
5.2 Results of Axial compression Test for Short Column specimens

The test was conducted at the laboratory of UVCE, Civil Engineering Department, Bangalore University, Bengaluru, the results of compression test of columns specimens under axial loading until failure stage was conducted to investigate:

- First Crack Load
- Ultimate Load
- Behavior of stress-strain curve
- Comparison of theoretical and experimental results.

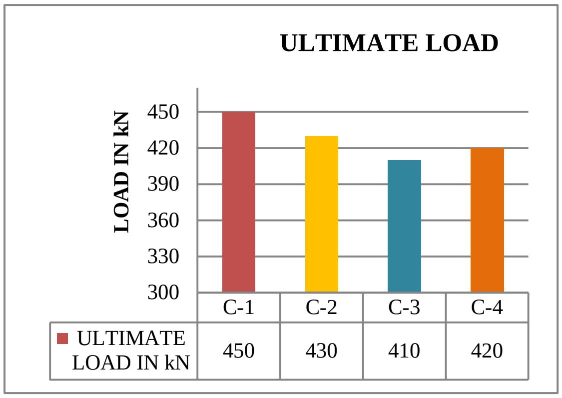
5.2.1 First crack load

This is the load at which the first visible crack appears on the surface of the column due to the development of compressive stresses.



5.2.2 Ultimate load

The ultimate or failure load obtained for different mixes are shown in table



5.2.3 Behavior of stress-strain curve.

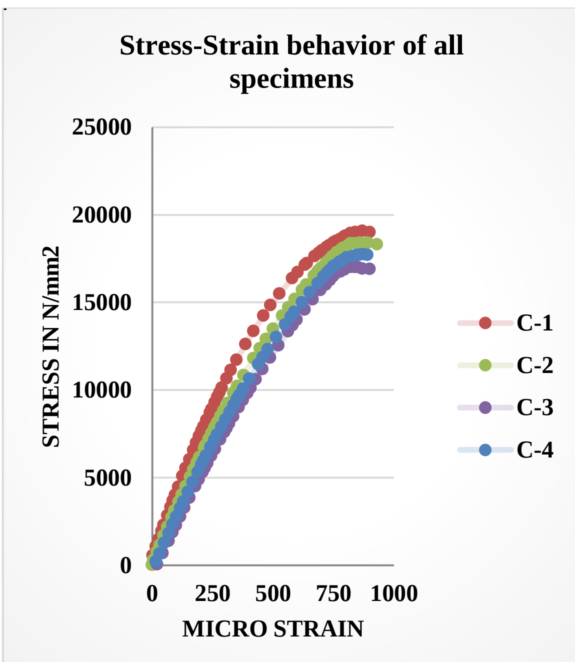


Figure 5: Stress-Strain behavior for all mixes up to failure point

The stress and micro strain at failure point for C-1, C-2, C-3 AND C-4 are 20000 N/mm2 and 762, 19111.11 N/mm2 and 768, 18222.22 N/mm2 and 813, 18667.24 N/mm^2 and 782 respectively.

5.2.4 Comparison of Theoretical and Experimental failure loads.

The theoretical failure load is calculated for different concrete matrices and it is compared with failure load obtained by experiment is given in the table below.

Designation	Theoretical Failure Load(kN)	Experimental Failure Load(kN)	T/E
C-1	482.88	450	1.073
C-2	481.49	430	1.119
C-3	471.17	410	1.149
C-4	480.00	420	1.142

The percentage change of theoretical to experimental failure load for C-1, C-2, C-3 and C-4 is 7.3%, 11.9%, 14.9% and 14.2% respectively. It is noted that from the above values the percentage change is less for C-2 with respect to C-1. And it is observed that for all the matrices the ratio of theoretical to experimental failure loads comes within the acceptable limit.

5.2.5 Comparison of Theoretical and Experimental failure strains.

The experimental strains at failure point is calculated by using Hooks law (stress is directly proportional to strain) by using the value of experimental young's modulus. The strain at failure point is obtained by experiment were noted and the comparison of theoretical to experimental failure strains are given in the table below.

Designation	Theoretical Micro strain	Experimental Micro strain	T/E
C-1	657.161	762	0.862
C-2	635.476	768	0.831
C-3	615.441	813	0.759
C-4	621.290	782	0.786

The ratio of theoretical to experimental micro strain for C-1, C-2, C-3 and C-4 is 0.862, 0.831, 0.759 and 0.786 respectively.

5.2.6 Comparison of Theoretical and Experimental young's modulus

The theoretical young's modulus is calculated by using the value of characteristic strength for 28 days curing cube specimen. the value of theoretical young's modulus is calculated using the formula $5000\sqrt{fck}$.The experimental young's modulus for different mixes is calculated by finding the slope of stress-strain curve. The value of theoretical and experimental young's modulus is given in the table below.

Designation	Theoretical young's modulus(kN/mm²)	Experimental young's modulus(kN/mm²)	T/E
C-1	31.700	33.074	0.958
C-2	31.560	31.595	0.998
C-3	30.520	25.230	1.205
C-4	31.400	27.777	1.130

The ratio of theoretical to experimental young's modulus for C-1, C-2, C-3 and C-4 is 0.958, 0.998, 1.205 and 1.130 respectively. From the above table it is found that the ratio of analytical to experimental young's modulus for all mixes comes within the acceptable limit.

6. Conclusion.

1. The experimentally obtained values of the compressive strength at 28 days for Mix 1 concrete is 31.70 N/mm² whereas for Mix 2, Mix 3 and Mix 4, the compressive strength is found to be 31.56 N/mm², 30.52 N/mm² and 31.41 N/mm2 respectively which is more than the target strength calculated as per IS 10262-2009.

It is observed that from experimental results, compressive strength for Mix 2, Mix 3 and Mix 4 has achieved 99.56%, 96.27% and 99.08% of Mix 1(control Mix) strength respectively. It is experimentally evident that compressive strength of MIX 2 has been significantly achieved 99.56% of strength in comparison with MIX 1(control Mix) concrete.

2. The test result shown that first crack load for C-1 is 160kN, for C-2 is 130kN, for C-3 is 150kN and for C-4 is 140kN. The decrease in load value w.r.t. controlled concrete (C-1) are 6.25%, 18.75% and 12.5% for C-2, C- 3, C- 4 respectively.
3. The average ultimate or failure load obtained for the conventional concrete(C-1) is 450 kN, for C-3 is 410 kN, for C-2 is 430 kN and for C-4 is 420 kN. The percentage load decrease for different matrices w.r.t to conventional concrete is 4.4%, 8.88% and 6.66% for C-2, C-3 and C-4 respectively.
4. The percentage change of theoretical to experimental failure load for C-1, C-2, C-3 and C-4 is 7.3%, 11.9%, 14.9% and 14.2% respectively. It is noted that from the above values the percentage change is less for C-2 with respect to C-1. And it is observed that for all the matrices the ratio of theoretical to experimental failure loads comes within the acceptable limit.
5. The stress developed at failure point for C-1, C-2, C-3 and C-4 is 2000 N/mm², 19111 N/mm², 18222 N/mm² and 18667 N/mm² It is observed that the decrease in stress resistance for C-2, C-3 and C-4 is 4.44%, 8.89% and 6.66% respectively with respect to C-1. The result shows that the C-2 (50%NCA+50%TRCA) has more stress resistance capacity compare to C-3 and C-4 w.r.t C-1. Hence C-2 shown comparable results with C-1.
6. The value of micro strain at failure load is 762, 768, 813 and 782 for C-1, C-2, C-3 and C-4 respectively. It is observed that C-1 has shown less strain compare to all specimens and C-4 has more strain value. And it is noted that strain value of C-2 have given comparable values with C1.
7. The ratio of theoretical to experimental micro strain for C-1, C-2, C-3 and C-4 is 0.862, 0.831, 0.759 and 0.786 respectively.
8. The ratio of theoretical to experimental young's modulus for C-1, C-2, C-3 and C-4 is 0.958, 0.998, 1.205 and 1.130 respectively. It is found that the ratio of analytical to experimental young's modulus for all mixes comes within the acceptable limit.

It is evident from the experimental results that test column specimen C-2 has attained maximum compressive strength, first crack load ultimate load and stress-strain behavior with respect to test column specimen C-3 and C-4.

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