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INVESTIGATION OF FLEXURAL BEHAVIOR IN CONCRETE BEAMS WITH RECYCLED COARSE AGGREGATE

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ABSTRACT
This study investigates the flexural behavior of concrete beams containing recycled coarse aggregate (RCA). Three sets of beams were tested: one with 100% RCA, one with 50% RCA, and one with 0% RCA (natural aggregate only). The main focus was on the development of cracks, load carrying capacity, and ductility of the beams.

The results indicate that the crack development in the 100% RCA beam occurred earlier than in the 50% and 0% RCA beams, with wider crack widths. All cracks observed were flexural cracks. Additionally, the ultimate load carrying capacity of the 50% and 0% RCA beams was found to be more than 15.78% and 31.91% higher, respectively, than that of the 100% RCA beam. Furthermore, the ductility of the 50% RCA beam was greater than that of the 0% and 100% RCA beams.

These findings suggest that incorporating RCA in concrete beams can affect crack development, load carrying capacity, and ductility. The use of RCA, particularly at a 50% replacement level, could be beneficial in enhancing the performance of concrete beams in flexural applications.

Keywords: recycled coarse aggregate, flexural behavior, concrete beams, crack development, load carrying capacity, ductility.

INTRODUCTION
Huge quantities of construction materials are required in developing countries due to continued infrastructural growth and also huge quantities of construction and demolition wastes are generated every year in developing countries like India. The disposal of this waste is a very serious problem because on one side it requires huge space for its disposal while on the other side it pollutes the environment. It is also necessary to protect and preserve the natural resources like stone, sand etc. Continuous use of natural resources, like river sand is another major problem and this increases the depth of river bed resulting in drafts and also changing the climatic conditions. So, the sustainable concept was introduced in construction industry due to growing concern about the future of our planet, because it is a huge consumer of natural resources as well as waste producer Sadhan Ghosh, president of the International Society of Waste Management, India reports that estimated waste generation during construction is 40 to 60 Kg. per sq. m. Similarly, waste generation during renovation/ repair work is estimated to be 40 to 50 kg/sq. m. The highest contribution to waste generation is due to demolition of buildings. Demolition of Pucca and Semi-Pucca buildings, on an average generates 500 & 300 kg/sq. m of waste respectively. In India nearly 50% of Construction & Demolition waste is being re-used and recycled, while the remainder is mostly land filled. Increased concern for environmental protection and for promotion of the principles of sustainable development has led some governments to introduce legislation to encourage the use of recycled aggregates. Reffered method is to lower the selling price of recycled aggregates in relation to natural aggregate, and this is largely achieved by increasing landfill costs. Demolition sites and restoration schemes are sources of large amounts of solid waste, which today is being used as mere landfill. On the other hand, building practices are such that reusable materials also become mixed with rubble, stone and soil, reducing their value and making recycling

difficult or uneconomical. This waste material too, is rendered suitable only as infill for construction work, or as landfill. The goal of this study is to investigate the possibility of utilizing old concrete remains as a replacement for natural aggregates in new concrete mixes. Replacement of aging infrastructures and buildings results in large quantities of construction waste, especially concrete waste. Concrete waste generated from demolition work contains many aggregates. Because aggregates occupy the majority of the concrete volume, it is reasonable to investigate reusing the aggregates from concrete waste to create new concrete. Recycled coarse aggregates (RCAs) have been used in many laboratory experiments. Due to the potential economic and environmental benefits, interest in technology for processing waste concrete and the use of RCAs is rapidly increasing .the advantages of using RCAs include a reduction in the use of natural coarse aggregate (NCA) resources and a decrease in the amount of waste disposed in landfills, thereby diminishing environmental pollution. Despite the high demand, RCAs are primarily used in road bases and non-structural concrete. Only a small percentage of RCAs is used in structural concrete because the quality of RCAs is less reliable than that of NCAs. Comprehensive experimental research has been performed to assess the properties of both NCA and RCA concrete at the material level. Several experimental studies have investigated the flexural behaviour of RCA concrete beams at the structural level; however, the results from these studies are contradictory. Therefore, the purpose of this study was to explore the structural behaviour of RCA concrete beams under flexure. A total of three samples were created containing three concrete beams each and then tested under four-point bending. One beam was constructed with RCA concrete, and one control beam was constructed with NCA concrete. The parameters in this study were the RCA content (0%, 50%, and 100%) and tensile rebar ratio (0.50%). the investigation of structural behaviour included the cracking pattern, ductility and ultimate flexural strength.

LITERATURE REVIEW

Recycled Aggregate Characteristics and Mechanical Properties

A multitude of studies have investigated the characteristics and mechanical properties of recycled aggregate concrete (RAC). Research by Xiao et al. (2018) delves into the evaluation of recycled aggregate characteristics and mechanical properties, providing valuable insights into the feasibility and performance of RAC. Similarly, the work of Silva et al. (2019) offers a comprehensive review of recycled aggregate in concrete applications, shedding light on the material properties and potential challenges associated with its utilization. Additionally, the study conducted by Kou and Poon (2019) presents an experimental investigation of concrete with demolished concrete waste as coarse aggregate, contributing to the understanding of material properties and sustainability aspects.

Durability and Enhancement of Recycled Aggregate Concrete

Durability is a crucial aspect of concrete construction, and several studies have explored the durability and enhancement strategies for recycled aggregate concrete. The research by Tang et al. (2017) provides a fundamental overview of recycled aggregate concrete behavior, focusing on durability considerations and enhancement techniques. Furthermore, the study conducted by Sadek et al. (2020) investigates the effect of adding silica fume as a partial replacement for cement in recycled aggregate concrete, elucidating the potential improvements in mechanical properties and durability.

Utilization of Demolished Concrete Waste

The utilization of demolished concrete waste offers a sustainable solution for concrete production, and numerous studies have examined its potential applications and material properties. Research by Rahal et al. (2018) explores the utilization of demolished concrete waste for new construction, highlighting its benefits in terms of resource conservation and waste reduction. Additionally, the innovative study conducted by Shang et al. (2021) presents novel approaches for the reuse of demolished concrete waste, showcasing innovative techniques and practical applications.

Experimental Investigations and Comparative Analysis

Experimental investigations play a crucial role in understanding the performance of concrete containing recycled materials. Studies such as those by Ling et al. (2019) and Li et al. (2021) have performed comparative analyses of the properties of fresh and hardened concrete with different replacement ratios of natural with recycled coarse aggregate. These analyses provide valuable data on the mechanical properties, durability, and sustainability aspects of recycled aggregate concrete.

METHODOLOGY

Test Setup: the beams were tested under simply supported four-point loading conditions. The total length of each test beam was 0.7 m, and the simple supports were located 50 mm from each end of the beam; that is, the clear span length was 0.6m. A steel spreader beam was installed between the test beam specimen and the actuator to distribute the single point load into two point loads. The two loads were applied 200mm from the end simply support. The instrumentation system consisted of Dial Gauges and electrical resistance strain gauges. Electrical resistance strain gauges were used to measure the strain in the concrete and the steel rebar. Single strain gauges were located on the bottom surface of the beam .These strain gauges were mounted on the surface of the rear side of the beam specimen. The length of the strain gauges mounted on the concrete was 60 mm. Individual gauges were used until their readings became unreliable due to cracking in the underlying concrete. They were able to detect strain from small crack openings at each location. However, the concrete strain gauges became unreliable as the crack width increased. In addition, the dial gauges were placed in the midspan and at the loading points to measure the beam deflections. The load was applied to the beams using hydraulic jacks. Each beam test was conducted at a crosshead displacement rate of 1.5 mm/min. the test was performed until beam failure. The applied load, deflection, and strain in both the concrete and the rebar, the development and propagation of cracks, and the width of each crack were recorded until beam failure. Calculating the Ductility and Flexural Strength of the Concrete Beams. the ductility of a concrete structure can be interpreted as a measure of the energy absorption capacity of the structural member. In general, the ductility of a concrete structure can be quantified via the ductility index, which can be expressed in terms of the deflection ductility index . Midspan deflection measurements are necessary only for the deflection ductility index, and its measurement is relatively easy. the deflection ductility index, was used to examine the ductility characteristics of the members as follows:

$$\mu = \Delta u / \Delta y$$

Where μ is the ductility index of the member, Δu is the deflection of the member at the ultimate load, and Δy is the deflection of the member at the yielding load. The deflection at the ultimate load corresponds to the peak point in the load-deflection curve

RESULT AND DISCUSSION

The moment curvature diagram is drawn with help of maximum strain given by the stain gauges and moment curvature calculator, the method of moment curvature calculation is explained in methodology.

Load Deflection Measurement:

Table 1: Load deflection value for 50% RCA:

Load (kN)	Δ in mm
24.1	1
27.9	2
31.5	3
33.7	3.5
33.8	4.1
34.7	4.6
35.5	4.7
36.1	4.9

37	5
38	5.3

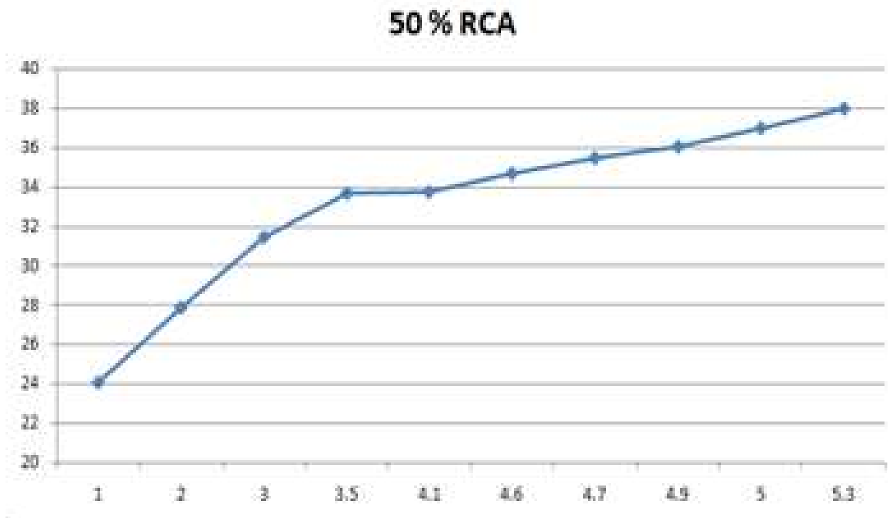

Fig 1: Graph of load Deflection value for 50% RCA

Table 2: Load deflection value for 100% RCA

Load (kN)	Δ in mm
5	0.1
7	0.9
11	1.3
13	1.5
15	1.8
17	2
19	2.3
21	2.5
22	2.7
24	3.2
25	3.5
26	3.8
27	4
28	4.2
30	4.5
31	4.8
32	5.2

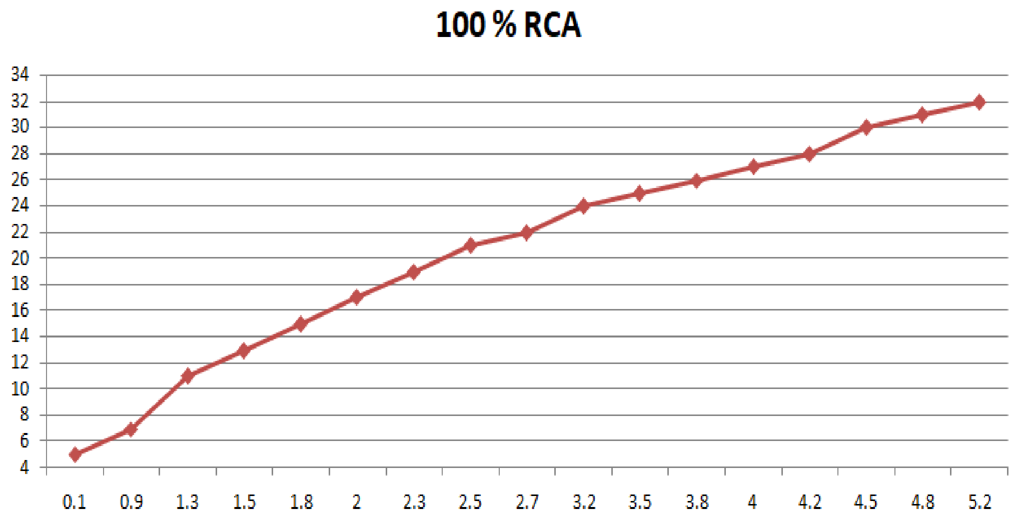

Fig 2: Graph of load Deflection value for 100% RCA

Table 3: Load deflection value for 0% RCA

Load (kN)	Δ in mm
8	0.1
11	0.68
14	1.3
17	1.9
20	2.2
23	2.6
26	3
29	3.6
32	3.8
35	4.4
36	5
37	5.3
38	5.7
39	6
40	6.6
41	6.9
42	7.1
43	7.3
44	7.4
45	8.6
46	9
47	9.9

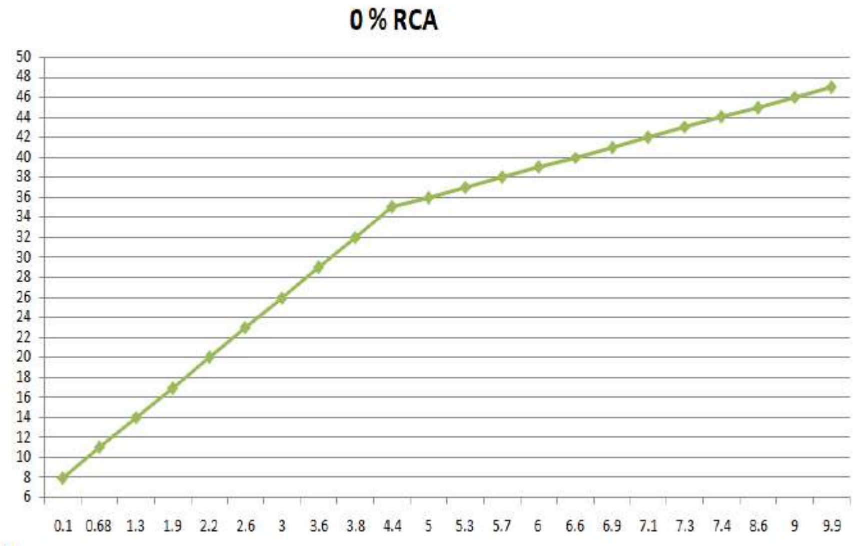

Fig 3: Graph of load Deflection value for 0% RCA

Ductility Index Measurement:

The ductility of RCC beam with varying proportion of RCA aggregate is determined using yield deflection and ultimate deflection, the observation are given below:

Table 4: Ductility Index Measurement

Percentage of RCA	Δ_y	Δ_u	Ductility Index (Δu/Δy)
100% RCA	0.9	5.2	5.777777778
50% RCA	3.5	5.3	1.514285714
0% RCA	4.4	9.9	2.25

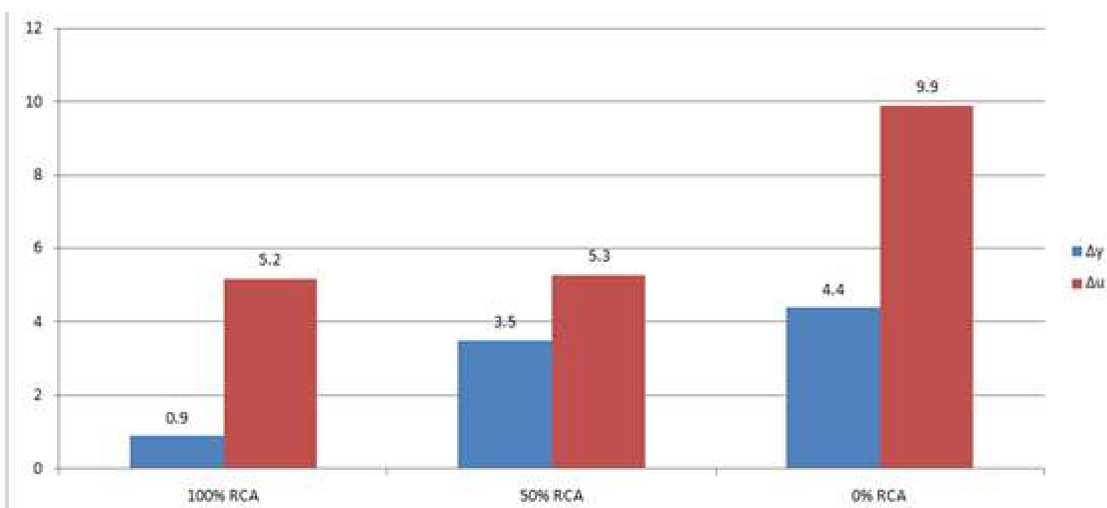

Fig 4: Yield Deflection And Ultimate Deflection

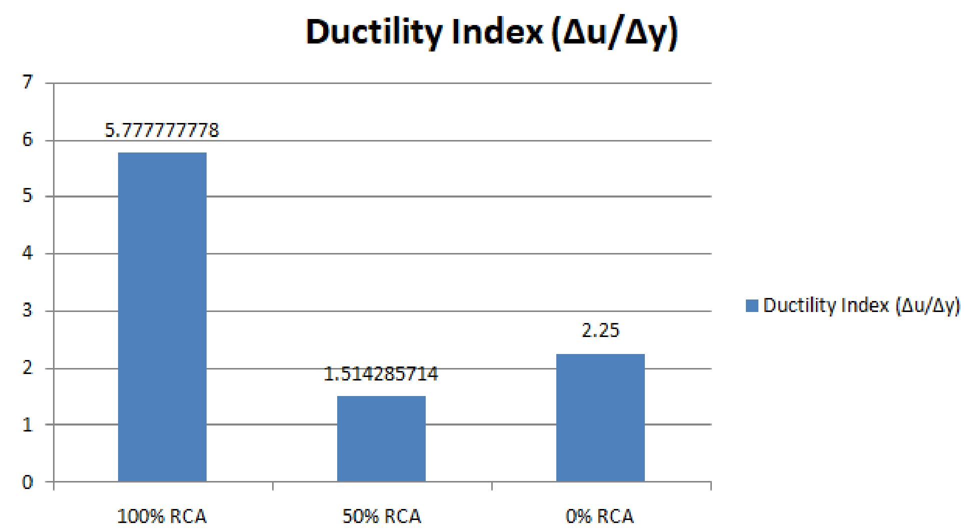

Fig 5: Ductility Index of Various Percentage of RCA

Table 5: Maximum Strain Value

Percentage of RCA	D (mm)	d (mm)	L (mm)	Max Strain
100% RCA	5.2	150	600	0.013
50% RCA	5.3	150	600	0.01325
0% RCA	9.9	150	600	0.02475

100% RCA:

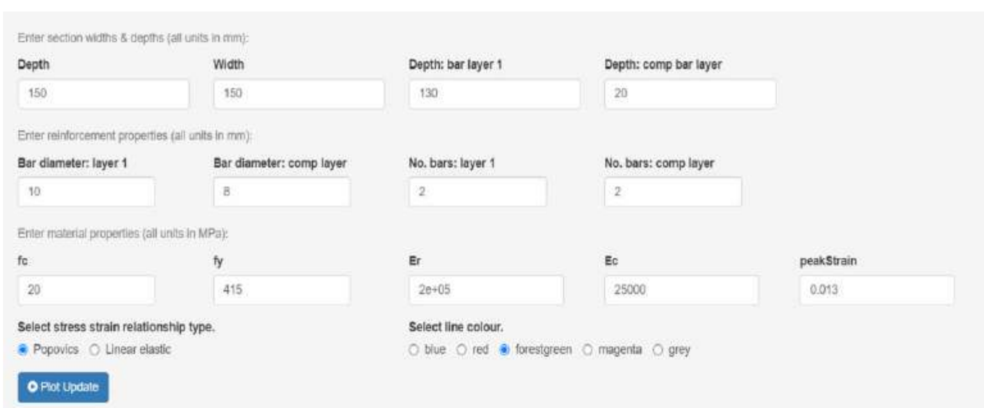

Fig 6: Moment Curvature Calculator

Table 6: Moment Curvature value for 100% RCA

CURVATURE	MOMENT
1.00E-07	2.28
3.10E-06	71.2
6.20E-06	140
9.20E-06	167
1.20E-05	169

1.50E-05	169
1.80E-05	170
2.10E-05	171
2.40E-05	171
3.00E-05	172
3.60E-05	172
4.30E-05	173
5.80E-05	173
7.30E-05	172
1.00E-04	171
1.50E-04	168
2.20E-04	165

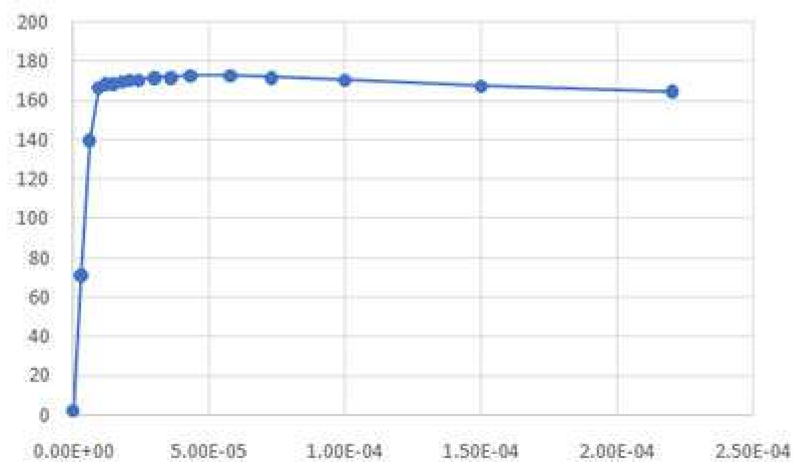

Fig 7: Graph for Moment Curvature value for 100% RCA 50% RCA:

Table 7: Moment Curvature value for 50% RCA

CURVATURE	MOMENT
1.00E-07	0.0341
3.10E-06	1.05
6.20E-06	2.04
9.20E-06	3
1.20E-05	3.93
1.50E-05	4.84
1.80E-05	5.72
2.10E-05	6.57
2.40E-05	7.36
3.00E-05	7.42
3.60E-05	7.47
4.30E-05	7.5
5.80E-05	7.56
7.30E-05	7.6
1.00E-04	7.64
1.50E-04	7.68
2.20E-04	7.71

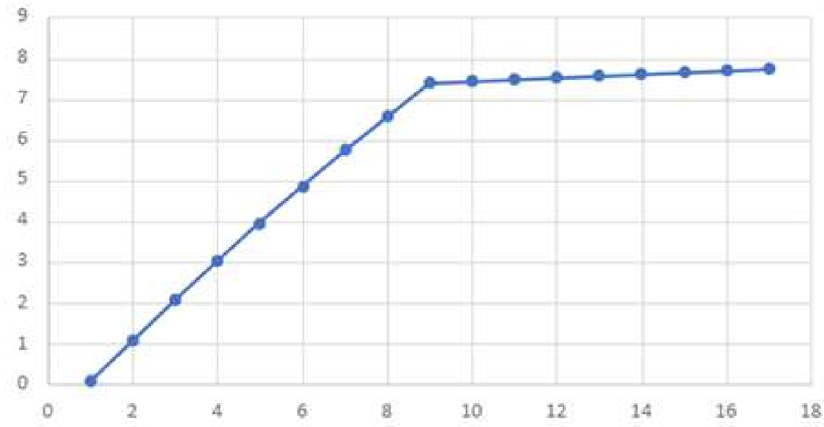

Fig 8: Graph for Moment Curvature value for 50% RCA 0% RCA

Table 8: Moment Curvature value for 0% RCA

CURVATURE	MOMENT
1.00E-07	0.0341
3.10E-06	1.05
6.20E-06	2.03
9.20E-06	2.98
1.20E-05	3.91
1.50E-05	4.8
1.80E-05	5.67
2.10E-05	6.51
2.40E-05	7.33
3.00E-05	7.4
3.60E-05	7.45
4.30E-05	7.48
5.80E-05	7.54
7.30E-05	7.58
1.00E-04	7.62
1.50E-04	7.66
2.20E-04	7.69

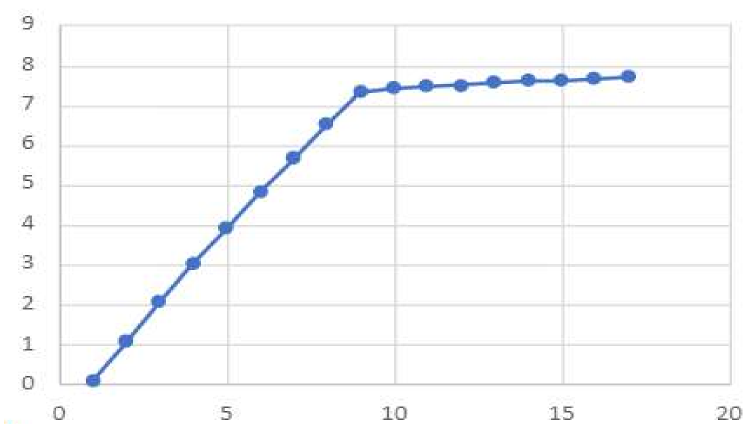

Fig 9: Graph for Moment Curvature value for 0% RCA

Fig 10: Crack Pattern for 100% RCA beam

Fig 11: Crack Pattern for 50% RCA beam

Fig 12: Crack Pattern for 0% RCA beam

CONCLUSION

1. The crack developed in the 100% RCA beam is earlier than the 50% and 0% RCA beam and their width is also predominant, all type of cracks are the flexural cracks.
2. The ultimate load carrying capacity of 50% and 0% RCA beam is more than 15.78% and 31.91% as compared to 100% RCA beam respectively.
3. Ductility of 50%RCA beam is more than 0% and 100% RCA beam.

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