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An Experimental Investigation on Flexural Behavior of One Way Reinforced Concrete Slabs

Dr. B. Madhusudana Reddy[1], P.V.Suresh Babu[2]
[1]Assistant Professor, [2]PG Student, Department of Civil Engineering, Sri Venkateswara Universit College of Engineering, Tirupati, Andhra Pradesh, India)

Abstract: Conservation of natural resources and protection of environment is the key to sustainable development. The investigation on flexural behaviour of recycled aggregate concrete (RAC) slabs presented here is one such attempt to establish performance of recycle aggregate concrete as structural grade concrete. The Experimental investigation examine the crack width and strains of rectangular one way simply supported steel reinforced concrete slabs by using natural and recycled coarse aggregate under simulated uniform loading. The reinforced concrete (RC) slab specimens of size 1300×600×90mm were cast. The experimental programme consisted of casting and testing of twelve slabs. Out of 12 slabs, '6' slabs were cast using natural coarse aggregate and another '6' slabs were cast using 50% replacement of NCA by RCA. Again in each '6' slabs, '3' slabs were cast with 8mm dia reinforcement bars and the other '3' slabs were cast with 6 mm dia reinforcement bars. M20 grade of concrete with various percentages of steel such as 0.30%, 0.40% and 0.50% were cast. All the twelve slabs were 90mm thick. These slabs were subjected to uniformly distributed loads. The investigations indicated encouraging results for RAC slabs in all respects, thus, pointing to recycled aggregate as potential alternative source of aggregate of the 21st Century. Finally a comparison is made between experimental results and theoretical predictions of the same and among specimens made with 6mm rebar and 8mm rebar.
Keyword: one way RC slab, NCA, RCA, Crack width, strain, Deflection, Percentage of steel.

I. INTRODUCTION

Crack width calculation is one of the serviceability requirements in the structural concrete elements. The occurrence of cracks in reinforced concrete elements is expected under service loads, due to the low tensile strength of concrete. Control of cracking is important for obtaining acceptable appearance and for long-term durability of concrete structures, especially those subjected to aggressive environments. Excessive crack width may reduce the service life of the structure by permitting more rapid penetration of corrosive factors such as high humidity, repeated saturation with moisture, vapor, salt-water spray and gases with chemicals, to reach the reinforcement. Cracks are almost unavoidable and reinforcement is needed to control the behaviour after cracking and to limit crack widths. The crack width depends on the nature and the arrangement of the reinforcing steel crossing the cracks and the bond between the steel bars found in the tension zone of concrete.

In this investigation, a study is carried out to over the '12' RC one way a slab specimen by independent experimental programs has been conducted in the laboratory. An attempt is made to know the flexural behaviour of normal coarse aggregate and recycled coarse aggregate concrete slabs having characteristic compressive strength of 20MPa (M20). The under reinforced sections was considered for studying flexural behaviour (ultimate load, ultimate moment, deflections, strains, and crack pattern) of slab specimens.

II. MATERIALS AND METHODOLOGY

A. *Properties of Materials*

1) *Cement:* In this investigation Ordinary Portland cement (OPC) of 43 Grade confirming to IS specifications was used. Normal consistency, specific gravity, initial setting time and final setting time of cement used in this study were 30%, 3.13, 80 minutes and 220 minutes respectively.
2) *Fine Aggregate:* Locally available river sand confirming to IS specifications was used as the fine aggregate in the concrete preparation. Specific gravity and fineness modulus of fine aggregate used in this study were 2.56 and 2.60 respectively. The grading of sand is confirmed to zone-II.
3) *Coarse Aggregate:* Coarse aggregate of nominal size 20mm and 12.5mm, obtained from the local quarry confirming to IS specifications was used. The coarse aggregate used for the preparation of concrete is a mixture of 60% of 20 mm and 40% of

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12.5 mm size aggregates. Water absorption, specific gravity and fineness modulus of coarse aggregate used in this study were 0.4%, 2.67 and 6.53 respectively.

4) *Recycled Coarse Aggregate:* The recycled coarse aggregate of nominal size 12.5 mm used in this investigation is obtained by crushing the tested laboratory concrete cubes. Water absorption and specific gravity of recycled coarse aggregate used in this study were 1.75% and 2.56 respectively.

B. Steel reinforcement

The steel reinforcement used for this investigation is confirmed to IS specifications. In this study, TMT Fe 415 bar size of 6 mm diameter and 8mm diameter were used.

Diameter 6 mm: Yield strength = 420 N/mm^2
Ultimate tensile strength = 480 N/mm^2

Diameter 8 mm: Yield strength = 455 N/mm^2
Ultimate tensile strength = 530 N/mm^2

C. Water

The water used for casting and curing of concrete test specimens was free from acids, organic matter, suspended solids and impurities which when present can adversely affect the strength of concrete. The local drinking water free from such impurities has been used in this experimental programme for mixing and curing.

D. Concrete Mix Proportion

The purpose of the experimental investigation is to obtain the compressive strength, split tensile strength, flexural strength and modulus of elasticity of concrete. M20 grade of concrete was designed as per the Indian Standard code of practice. The cement content used for the mix is 330 kg/m^3. The various ingredients for one cubic meter of concrete are shown in the Table 1.

Table 1: Mix design quantities and proportion ratio

	Cement	Fine aggregate	Coarse aggregate	Water
Mix proportion	1	2.05	3.64	0.50

E. Test Specimens

Concrete cubes of 150 mm size were cast with 100% NCA and with a combination of 50% NCA and 50% RCA. They were cured under the same conditions. The cubes were tested at 3, 7 and 28 days and results were shown in the Table 2.

Table 2: Compressive strength values for all mixes

Type of Concrete Mix	Compressive Strength (MPa)		
	3 Days	7 Days	28 Days
Control mix	13.6	17.8	26.8
RCA-50%	13.3	17.2	25.7

F. RC Slabs

Proper form work is prepared to cast the slabs. Specimens with wooden frame of 1300 mm length, 600 mm wide and 90 mm height. Cover blocks of 15mm thickness were made using a high strength mortar, so that they wouldn't appear as weakness points after hardening of the concrete, to act as concrete clear cover. Steel reinforcement is arranged in either direction as per design Concrete was poured into the formwork continuously and was compacted thoroughly by means of a surface vibrator. After compaction, finishing was done by means of a trowel to achieve a smooth and level final surface.

G. Curing of Slabs Specimens:

The size moulds of one way RC slab specimens were removed after 24 hours of casting. The specimens were numbered for identification and the auxiliary specimens were cured continuously for 28 days using wet gunny bags.

Fig 1: Photos showing the steps of one way slab casting until curing

H. Testing of slabs Specimens

All specimens were tested as simply supported one way slabs subjected to a uniform distributed load. AI8000+ microprocessor based Data Acquisition and control system was used, as shown in figure (2). Load was applied with a 500kN capacity hydraulic jack and was measured with a 600kN capacity load cell. One linear variable differential transformers (LVDTs) were used for each specimen to monitor the vertical displacements; one LVDT was located at mid-span. Six specimens were instrumented with one concrete strain gauge bonded on the top surface of the slab at the center. Strain in concrete is measured using digital data acquisition. The concrete strain gauge used in the experimental program was BKSA type-65, with the following characteristics: wire-type, with a resistance of 120±0.2 Ω, a gauge factor of ± 0.2 %, a gauge length of 65 mm and a gauge width of 5.3mm; see Figure (3b) The strain gauge was bonded, using fevikwik epoxy cyanoacrylate adhesive; see Figure (3c). Figure (3a) shows the arrangement of the concrete strain gauge. A load cell was used to monitor applied load and a data acquisition system was used to record the experimental measures. To measure crack widths, an optical micrometer with an accuracy of (0.01mm), as shown in Figure (4).

Fig 2: Data Acquisition

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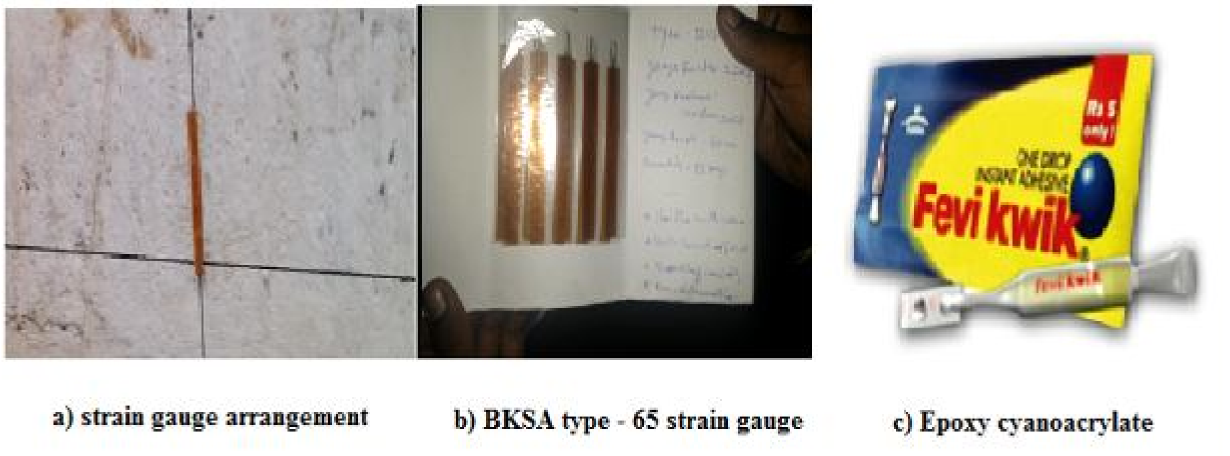


Fig 3: Strain gauge type, Arrangement and Adhesive material

Fig 4: Optical micro-meter

III. EXPERIMENTAL RESULTS

The following tests were conducted on M20 grade of concrete made with recycled coarse aggregate as replacement of natural coarse aggregate and then the results were compared with the controlled concrete specimens. All the results are presented in tabular column as well as graphical representation and are followed by a discussion of the results.

Table 4.Comparison between experimental and theoretical results

Slab No		Experimental Mu / Wu (kN-m / kN)	Theoretical Mu / Wu (kN-m / kN)
S1	S0.3 %(8Ø) + 50% RCA	4.98 / 79.79	5.12 / 81.92
S2	S0.3%(8Ø)	5.16 / 82.58	5.12 / 81.92
S3	S0.4% (8Ø) + 50% RCA	6.72 / 107.46	6.67 / 106.81
S4	S0.4% (8Ø)	6.91 / 110.54	6.67 / 106.81

S5	S0.5% (8Ø) + 50% RCA	8.16 / 130.62	8.15 /130.49
S6	S0.5% (8Ø)	8.28 / 132.45	8.15 /130.49
S7	S0.3 %(6Ø) + 50% RCA	5.74 / 91.84	5.26 /84.25
S8	S0.3% (6Ø)	5.90 / 94.47	5.26 /84.25
S9	S0.4% (6Ø) + 50% RCA	7.21 / 115.42	6.86 /109.84
S10	S0.4% (6Ø)	7.54 / 120.62	6.86 /109.84
S11	S0.5% (6Ø) + 50% RCA	8.77 / 140.36	8.38 /134.20
S12	S0.5% (6Ø)	8.99 / 143.92	8.38 /134.20

NOTE:

- S0.3%, S0.4%, S0.5% = Adopted percentage of steel in the slab design.
- 6 Ø = Dia of the rebars were used as both main and distribution in the cast slab.
- 8 Ø = Dia of the rebars were used as both main and distribution in the cast slab.
- RCA(50%) = 50% of Recycled coarse aggregates were used in the cast slab
- Mu = Ultimate bending moment
- Wu = Ultimate load

Table 5.Experimental results of tested slabs

Slab No		First Crack load, Pcr (kN)	Ultimate load, Wu (kN)	Service mid-span deflection, Δ_s (mm)	Ultimate mid-span deflection, Δ_u (mm)	Service Strain, $\mu*10^{-6}$	Ultimate strain, $\mu*10^{-6}$	Service crack width (mm)	Ultimate crack width, W_{cr} (mm)
S1	S0.3% (8Ø) + 50% RCA	45	79.79	0.276	0.84	163	502	0.275	6.85
S2	S0.3%(8Ø)	50	82.58	0.265	0.84	-	-	0.21	6.72
S3	S0.4% (8Ø) + 50% RCA	62.5	107.46	0.34	0.824	-	-	0.20	5.505
S4	S0.4% (8Ø)	65	110.54	0.32	0.804	184	436	0.187	5.464

S5	S0.5% (8Ø)+ 50% RCA	75	130.62	0.369	0.728	-	-	0.19	4.59
S6	S0.5% (8Ø)	80	132.45	0.358	0.726	270	540	0.117	4.74
S7	S0.3 %(6Ø) + 50% RCA	55	91.84	0.315	0.832	-	-	0.225	6.45
S8	S0.3% (6Ø)	57.5	94.47	0.312	0.814	190	468	0.155	6.245
S9	S0.4% (6Ø) + 50% RCA	70	115.42	0.36	0.80	-	-	0.187	5.365
S10	S0.4% (6Ø)	72.5	120.62	0.352	0.76	240	508	0.135	5.387
S11	S0.5% (6Ø) + 50% RCA	85	140.36	0.364	0.68	274	480	0.153	4.74
S12	S0.5% (6Ø)	87.5	143.92	0.34	0.66	-	-	0.126	4.51

Note:
(-) Indicates no strain gauges were provided for slab specimens.

Fig 5: Behaviour of slabs on the compression (top) side

Fig 6: Behaviour of slabs on the tension (bottom) side

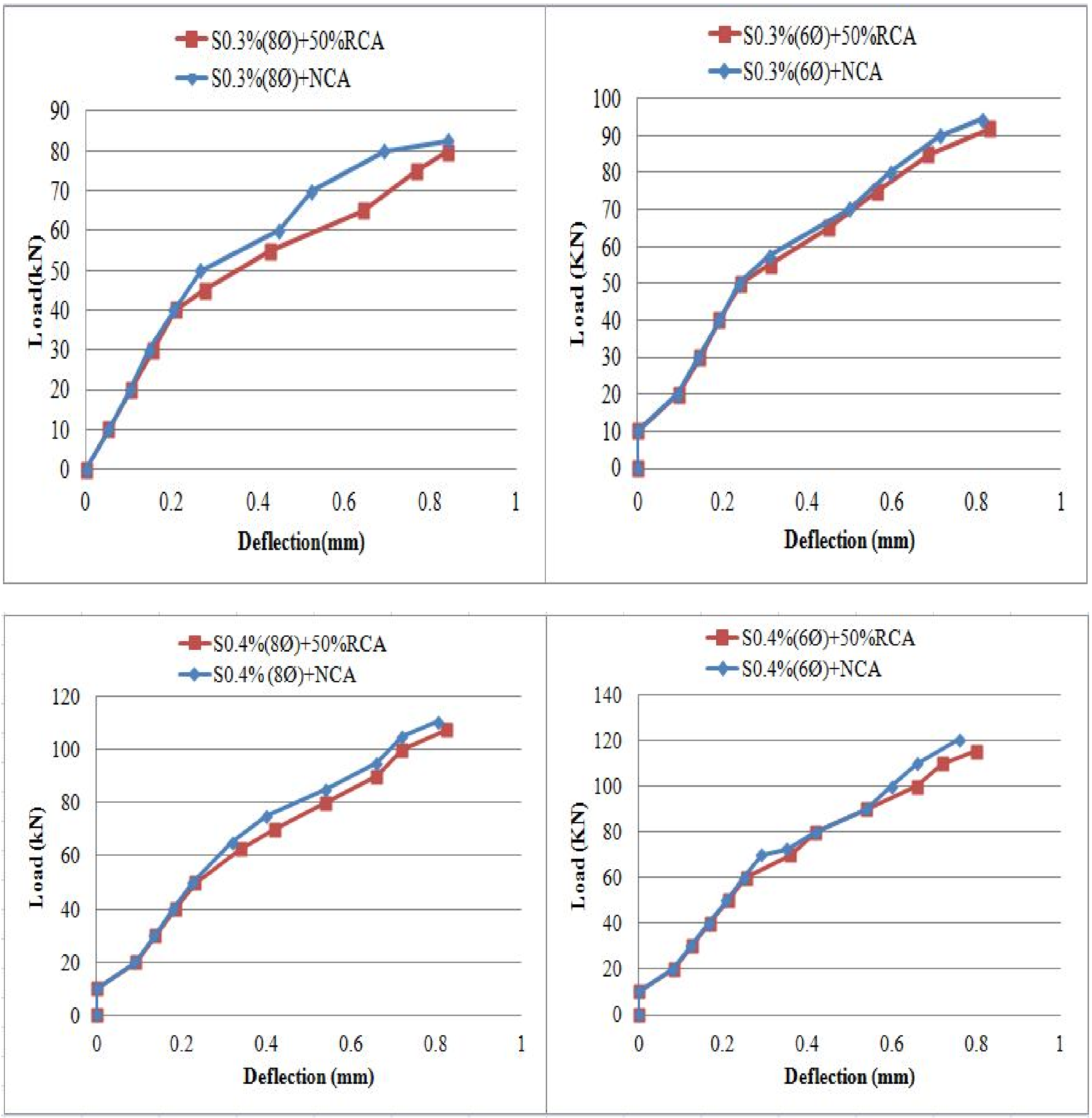
Fig 7: Flexural cracks of the slab specimens

Fig 8: Crack width observation of slab specimens

A. Deflection Behavior of Slabs:

Deflections were measured at the center span of slabs by means linear variable differential transformer (LVDT), and readings from this linear variable differential transformer (LVDT) were recorded for each load increment. The deflection profiles for all specimens are shown in Figures (9). The structural behavior of the slabs is presented in the form of load–deflection curves. The curves of load versus deflection identifying three specific regions; a linear region to yield, a transition region of continuous yield, and a region of full plastic deformation until failure. The slope of linear elastic portion of the load deflection curve represents the modulus of elasticity of the slab. It is clear from the Figures that the curves have a pre-cracking portion that approximates a straight line. At cracking, the slope of the curve changes indicating a reduction in the stiffness. The post-cracking segment for the load–deflection curve is varied continuously upto ultimate failure.

In the graphs of figures (9), it is observed that as the load increases, deflections of slabs are higher for lower steel percentage when compared to slabs with high steel percentages. There is no much influence on load-deflection due to recycled coarse aggregate when compared to natural coarse aggregate. And also there is no much influence on load-deflection due to 8mm dia bars when compared 6mm dia bars. But 6Ø reinforced slabs have shown better serviceability performance than the other 8Ø reinforced slabs.



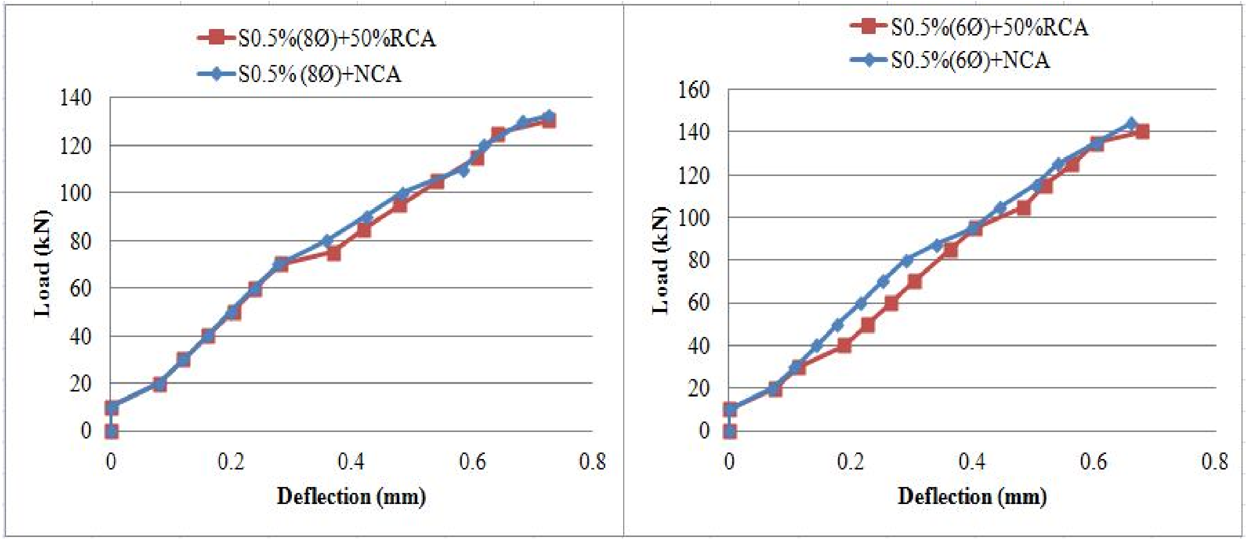
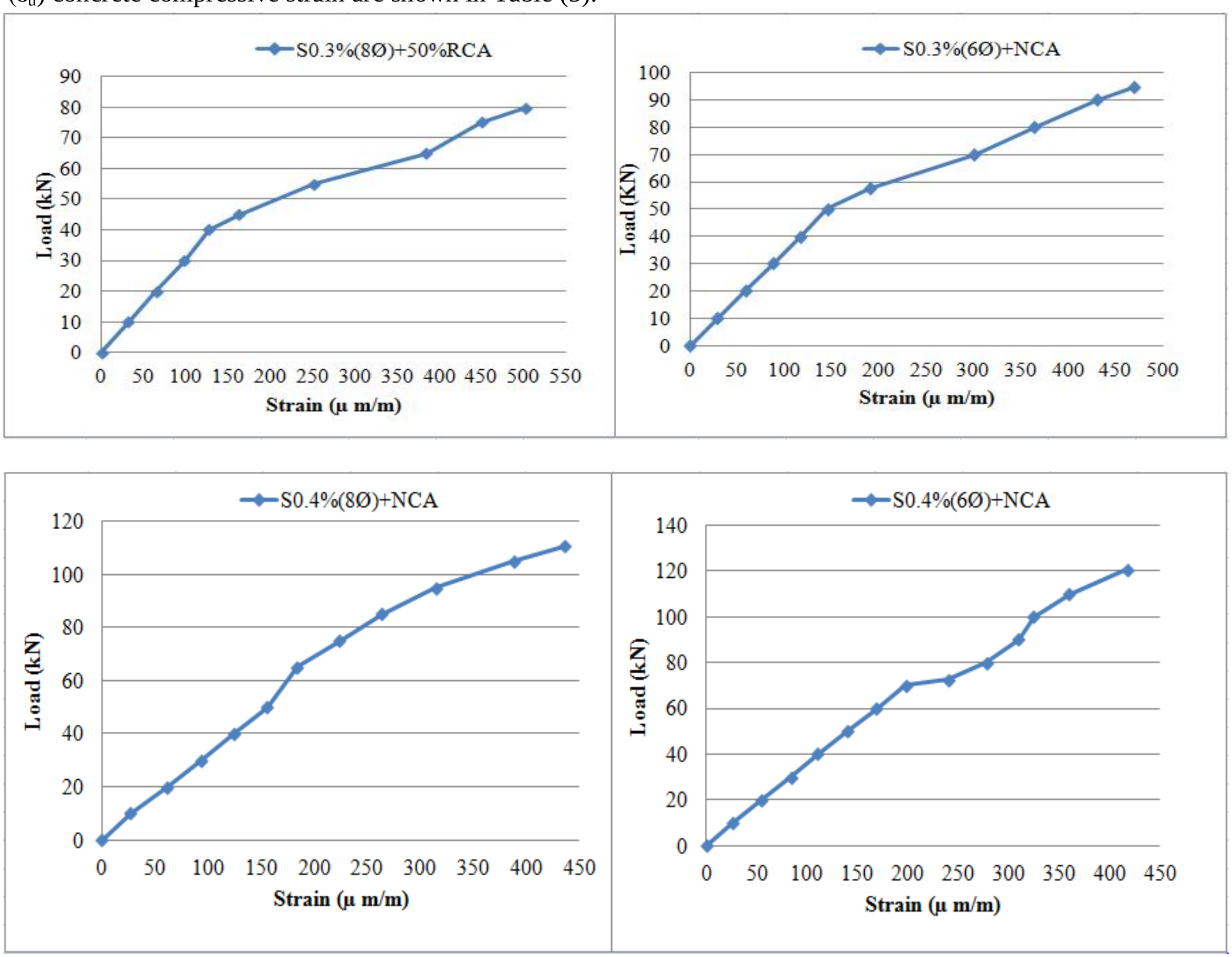


Fig 9.Deflection profile for all slab specimens

B. Effect on Concrete Compressive Strain

The strains in the concrete at compression face of the tested slabs have been measured by strain gauge at mid span. From Figure (10), it can be seen that the concrete compressive strain is small at elastic stage as loading is applied, and then it increases after the first crack when loading is continued. Positive values in the diagrams refer to compression strain. The results of service (ε_s) and ultimate (ε_u) concrete compressive strain are shown in Table (5).



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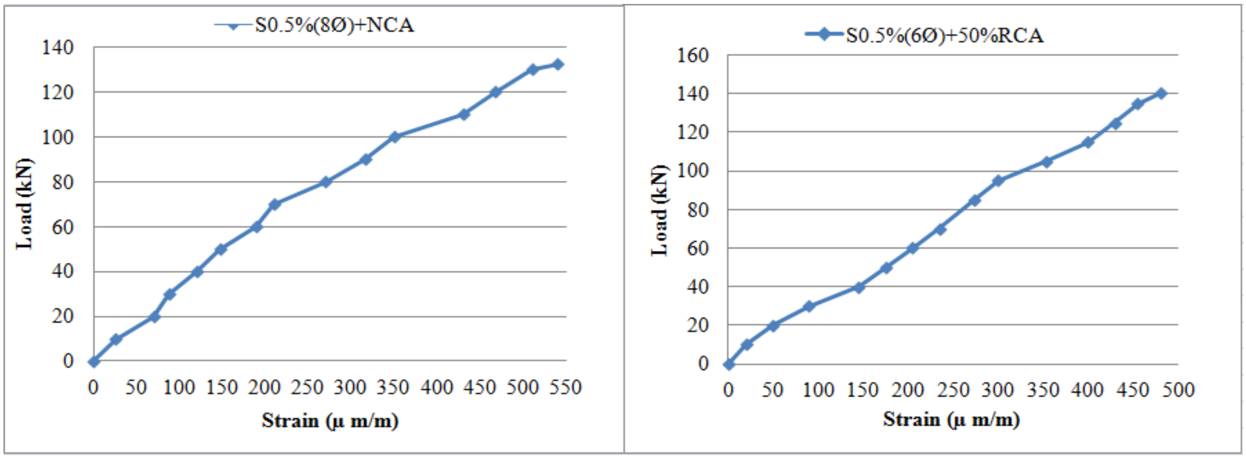


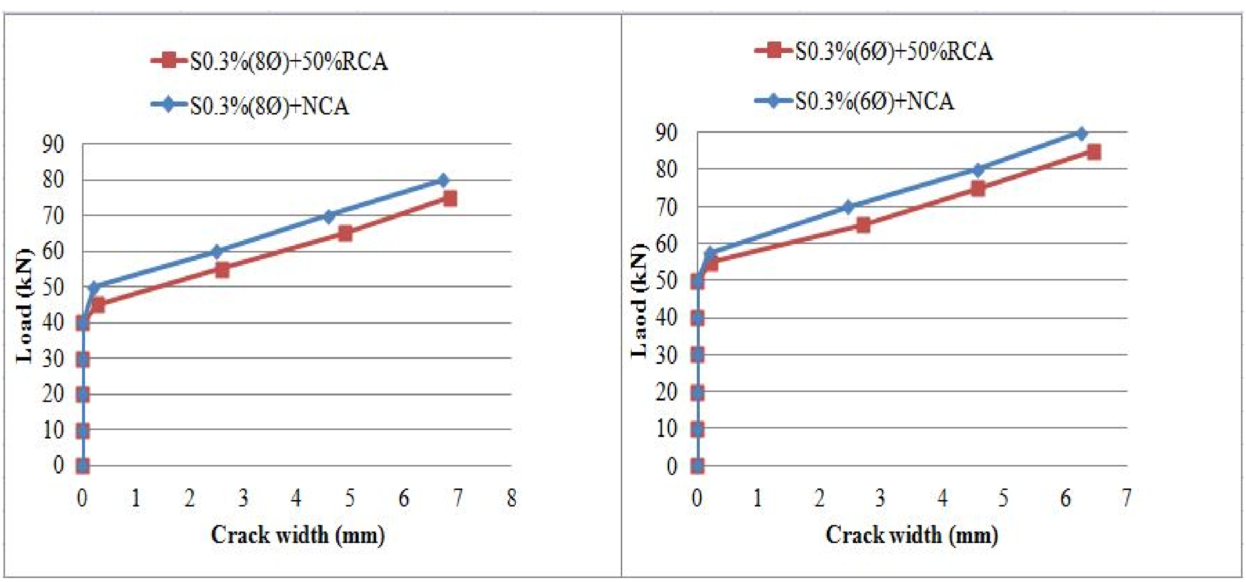
Fig 10.Strain profile for slab specimens

C. Effect on Load Capacity

A general view on the obtained results shows that all the slabs gave a significant increase in the experimental ultimate load carrying capacity when compared with that for the design ultimate load carrying capacity. There was a noticeable improvement in the flexural behavior of the recycled and natural coarse aggregate slabs. The increase in the ultimate load ranges from 1% to 12% for all slab specimens except S1 slab when compared to theoretical results. The decrease in the ultimate load of recycled coarse aggregated slab specimens ranges from to 1 to 8% when compared to ultimate load of natural coarse aggregated slab specimens. The magnitudes of different parameters obtained during testing of slabs specimens are shown Table 5.

D. Crack Width Behavior of Slabs

The crack width is varied continuously with increase in load beyond first crack. As the load was increased further, several flexural cracks initiated in the tension face at intervals throughout the slab, gradually increased in number, became wider and moved upwards reaching the compression face of the slab. As the load was increased further, a loss of stiffness occurred and one mode of failure appeared which can be classified as flexural failure in tension by yielding of the steel reinforcement followed by crushing of concrete. When load is applied to these slab specimens, Figures (11) illustrate crack patterns for all tested slabs. The test results of first and final cracking load of slab is presented in Table (5). There is no much influence on load-deflection due to recycled coarse aggregate when compared to natural coarse aggregate. And also there is no much influence on load-deflection due to 8mm dia bars when compared 6mm dia bars. But 6Ø reinforced slabs have shown better serviceability performance than that of slabs made with 8Ø rebars.



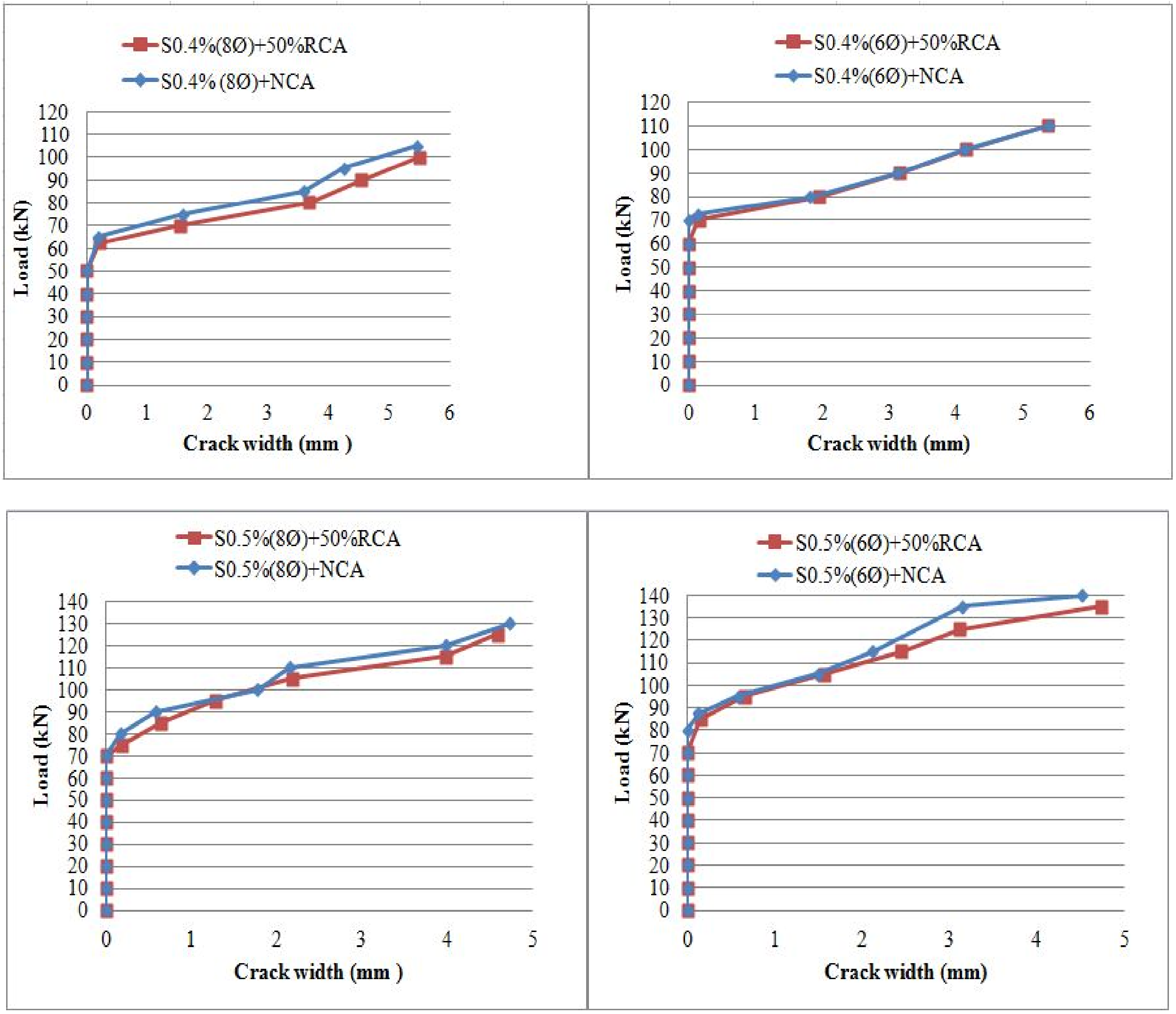


Fig 11.Crack width profile for all slab specimens

E. Modulus of Elasticity

The values of modulus of elasticity are presented in Table 6 and 7. Modulus of elasticity of one way slabs is obtained from load-deflection graphs and load strain graphs. Fig 12 and 13 shows the variation of modulus of elasticity of one way slabs for 6mm and 8mm Dia specimens.

Table 6.Results of Modulus of elasticity for 8mm Dia slab specimens

Slab No		Pt pro (%)	Modulus of elasticity (N/mm2)
S1	S0.3% (8Ø) +RCA (50%)	0.364	21834
S2	S0.3%(8Ø)	0.364	22625
S3	S0.4% (8Ø) +RCA (50%)	0.472	25091
S4	S0.4% (6 Ø)	0.472	26324
S5	S0.5% (8Ø) +RCA (50%)	0.589	26508
S6	S0.5% (8Ø)	0.589	27382

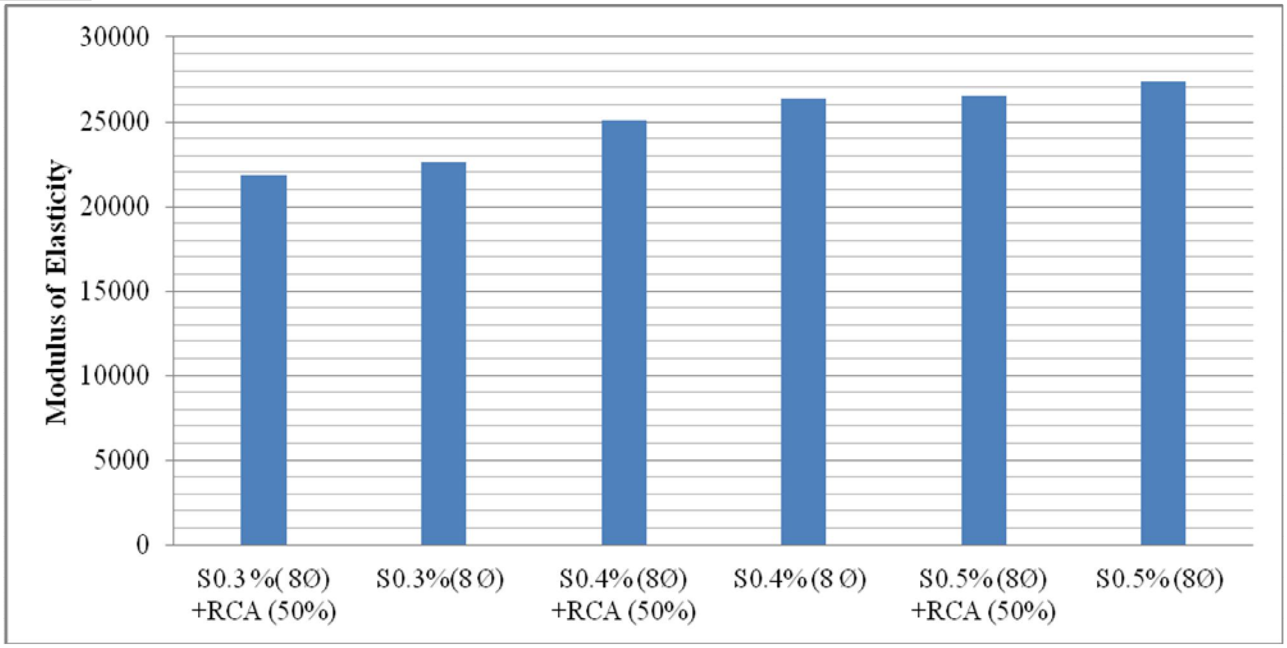


Fig.12. Variation of Modulus of Elasticity for 8mm Dia slab specimens

Table 7.Results of Modulus of elasticity for 8mm Dia slab specimens

Slab No		Pt pro (%)	Modulus of elasticity (N/mm2)
S7	S0.3% (6Ø) +RCA (50%)	0.327	26722
S8	S0.3%(6Ø)	0.327	28155
S9	S0.4% (6Ø) +RCA (50%)	0.436	28909
S10	S0.4% (6Ø)	0.436	30631
S11	S0.5% (6Ø) +RCA (50%)	0.561	29296
S12	S0.5% (6Ø)	0.561	31180

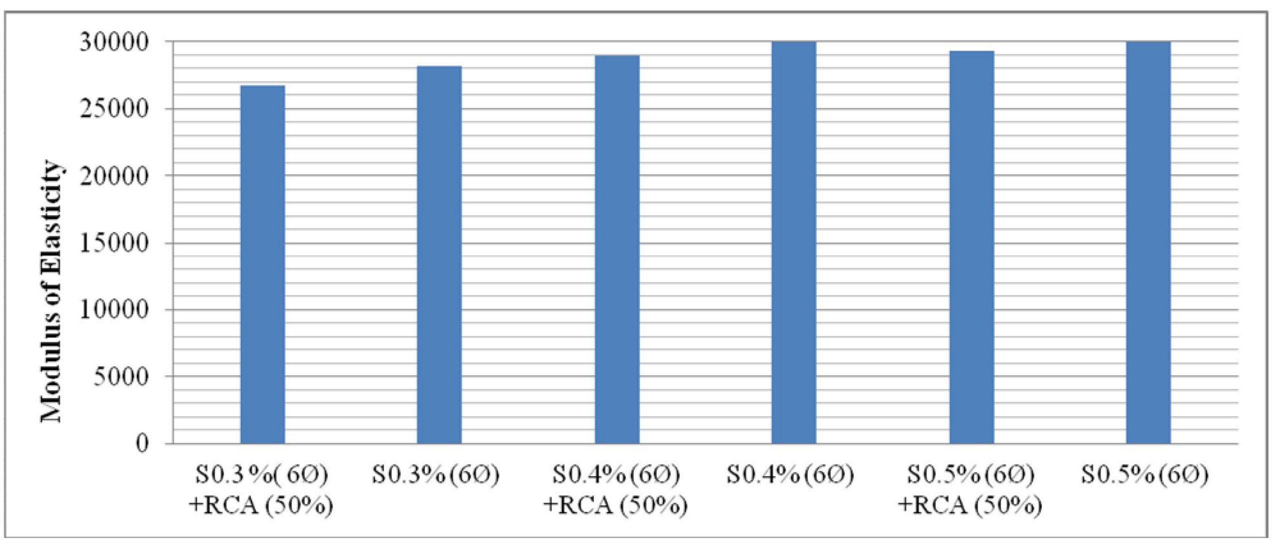


Fig.6.13. Variation of Modulus of Elasticity for 6mm Dia slab specimens

F. Calculation of Modulus of Elasticity

Load Vs Deflection	Load Vs Strain
$\Delta = 5\,Wlx^3/384EI$	Bending Equation : M/I =f/Y =E/R
$E = 5\,Wlx^3/384\,\Delta\,I$	M/I =f/Y
E = Modulus Of Elasticity	Flexural Or Bending Stress,
Δ = Deflection	f = M*Y/ I
Lx = Center To Centre Distance	E= f / ε
I = Moment Of Inertia	M = Moment Of Resistance
W= failure load	Y = Distance Of The Fiber From Neutral Layer

The Modulus of Elasticity obtains by deflections and strains for slabs gives almost equal values. Finally, we considered the 'E' value from load vs deflection curve to account for temperature compensation in strain gauges.

IV. CONCLUSIONS

A. The flexural strength of specimen made by natural coarse aggregate and recycled coarse aggregate gave reasonable correlation between calculated and experimental values.

B. By using 50% recycled aggregate, the strength of the slabs are almost same to the natural aggregate slab strength.

C. Upto the first crack point, the deflections are linear beyond that the deflections are increases rapidly.

D. As the ultimate load carrying capacity of 6Ø bar reinforced slabs is increased by increasing flexural reinforcement ratio of the slabs when compared to theoretical ultimate load. The corresponding deflections, strains and crack width are reduced by increasing flexural reinforcement ratio of the slabs.

E. As the ultimate load carrying capacity of 8Ø bar reinforced slabs is increased by increasing flexural reinforcement ratio of the slabs when compared to theoretical ultimate load. The corresponding deflections, strains and crack width are reduced by increasing flexural reinforcement ratio of the slabs.

F. The ultimate load carrying of reinforced slabs is same for 6Ø reinforcement bars as well as 8Ø reinforcement bars.

G. The modulus of elasticity obtained by deflections and strain of slabs give almost equal values.

H. The modulus of elasticity of reinforced slabs is increased by increasing reinforcement ratio of the slabs.

I. Prediction of crack width using IS 456:2000 equation in simply supported one way slabs did not give a reasonable correlation between calculated and experimental values.

J. From the experimental results it is observed that 6Ø reinforced slabs have shown better serviceability performance than the other 8Ø reinforced slabs.

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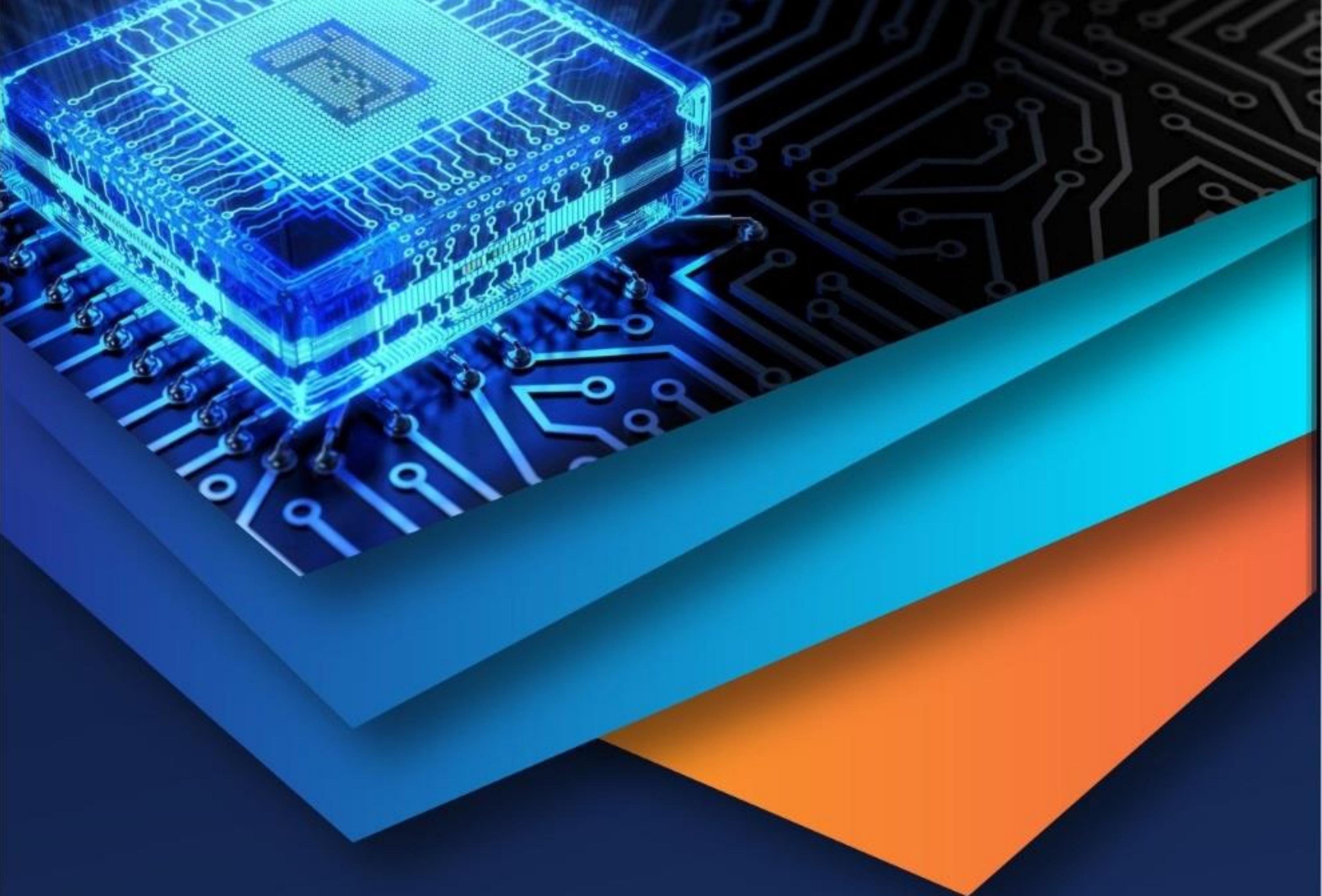

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