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An Experimental Study on Splicing with Helical End Rebar

Ganesh B [1], Srilakshmi P [2], C B K Rao[3]
[1]PG Student, [2]Associate Professor, [3]Emeritus Professor, Department of Civil Engineering (Structural Engineering), JNTUH University College of Engineering Science & Technology Hyderabad, Kukatpally, Hyderabad – 500085, India

Abstract: The bond behaviour between reinforcement and concrete is critical for strength, ductility, and serviceability of reinforced and precast structures. Conventional anchorage systems often face limitations such as long development lengths, premature slip, and radial cracking, compromising joint reliability in precast construction. The system combines chemical adhesion, frictional resistance, and mechanical interlock, while the aluminium sleeve with polymer-modified grout enhances confinement, reduces splitting cracks, and improves durability. This study investigates a novel anchorage system using helically ended rebars embedded in grout-filled aluminium sleeves and confined within M40 concrete cylinders. Pull-out tests were conducted on 10 mm of grade Fe415,12mm of grade Fe500, helical and straight rebars with embedment length of 130 mm,190mm using NS-1Powergrout is a non-shrink grout to ensure dense packing and efficient stress transfer by using a dowel element. The experimental results, including load–slip curves and peak bond strengths, were validated through load displacement curves. The findings confirm that the proposed helical bar–sleeve system ensures enhanced bond efficiency, reduced embedment requirements, improved ductility, and greater reliability for precast and space constrained reinforced concrete applications.
Keywords: Bond, Anchorage Behaviour, Dowel Connection, Peak Load, Slip Failure.

I. INTRODUCTION

Bond between reinforcement and concrete is fundamental to the performance of reinforced concrete (RC) structures, as it enables stress transfer, ensures strain compatibility, and prevents slip of reinforcing bars under service loads. This interaction governs section stiffness, crack control, and anchorage efficiency, while also ensuring that the assumption of plane sections remaining plane holds true in flexural behaviour. Bond is primarily developed through chemical adhesion, frictional resistance, and mechanical interlock of deformed bar ribs.

Bond stress, defined as the shear stress at the steel–concrete interface, is critical in anchorage and splice design. Loss of adhesion and progressive slip often lead to pull-out or splitting failures, depending on concrete cover, transverse reinforcement, and bar spacing. Factors such as development length, transverse confinement, casting position, and splice configuration significantly influence bond strength. A reliable bond ensures that reinforcement achieves its tensile capacity, thereby enhancing strength, ductility, and serviceability of beams, columns, and joints. This is especially vital in precast construction, where joint performance governs overall safety and durability.

Conventional anchorage systems, however, face persistent challenges, including inadequate embedment length, premature slip, radial cracking, and durability concerns under aggressive environments. These limitations become critical in precast elements with restricted dimensions and complex stress states, underscoring the need for innovative reinforcement–concrete interaction mechanisms.

To overcome these shortcomings, this study explores a novel anchorage system integrating helically ended rebars embedded in grout-filled aluminium sleeves confined within concrete. The helical geometry enhances mechanical interlock, while the sleeve–grout assembly provides dense packing, uniform stress distribution, and confinement against splitting cracks. This dowel mechanism reduces slip, improves bond efficiency, and enables shorter development lengths—an essential advantage for precast connections and retrofitting applications.

Experimental investigations involving pull-out tests on was conducted on the bar diameters 10mm and 12mm with straight and helically anchored rebars. This combined approach ensures a comprehensive understanding of bond strength enhancement and establishes the proposed system as a reliable alternative to conventional anchorage methods.

II. MATERIALS

A. Grout

A non-shrink, polymer-modified (NS-1) Power grout was used to fill the annular space between reinforcement and aluminium sleeve. Mix uniform until a smooth paste was formed by manual mixing with water content of 16% of grout. The grout provides dense packing, ensured stress transfer, and satisfied the strength and durability requirements. It is a self-compacting, single component system. The grout material properties are tabulated in Table I.

TABLE I
PROPERTIES OF NS 1 POWER GROUT

NS - 1 Power Grout (designation)	Properties
Wet density	2250-2350 kg/cum
Flowable consistency water ratio (IS 516 - 1959)	16% water ratio
Type of mixing	Manual mixing
Pull Out Bond Strength MPa @ 28 days (IS 2770)	8-9 N/mm^2
Tensile Strength @ 28 days MPa (ASTM 190)	8.5 N/mm^2
Compressive strength N/mm2 (IS 4031 Part 6)	100 N/mm^2

B. Aggregates

Natural river sand, clean and well-graded, conforming to Zone II of IS 383:2016 was used as fine aggregate. Properties such as specific gravity, fineness modulus, and water absorption were determined as per IS 2386:1963 shown in the Table II. Crushed angular granite aggregate of 20 mm maximum size, conforming to IS 383:2016, was used. Physical properties of coarse aggregates were given as per IS 2386:1963 was given in the Table II.

TABLE II
PHYSICAL PROPERTIES OF AGGREGATES

S. no	Property	Fine aggregate	Coarse aggregate
1	Specific gravity	2.63	2.8
2	Finess modulus	2.4	6.06
3	Water absorption	1 %	0.5 %

C. Cement

Ordinary Portland Cement (OPC) of 53 Grade conforming to IS 12269:2013 was used in this experiment. It was fresh, free from lumps, smooth, uniform in colour and ensured the target M40 concrete strength within the curing period. Physical properties were tested as per IS 4031 was given in the Table III.

TABLE III
PHYSICAL PROPERTIES OF CEMENT

S.no	**Property**	**Value**
1	Initial and Final setting time	75 & 270 min
2	Specific Gravity	3.02

3	Compressive Strength:	(N/mm^2)
	3	39.06
	7	46.21
	28	56.43

D. Reinforcement

High-yield deformed bars of 10 mm diameter (Fe-415 grade),12mm diameter (Fe-500 grade) conforming to IS 1786:2008, were used. Both straight and helically wound end configurations were adopted, with the helical ends provided to improve confinement and mechanical interlock within the grout-filled aluminium sleeves. For the 10 mm bars, 3.5 helical turns,12mm bars,4.5 helical turns were introduced, simulating anchorage conditions commonly encountered in precast and jointed concrete systems. The reinforcement details are shown in Figures 1 and Figure 2.

Figure 1 Interlocking of two helical end and a straight rebar for 10mm

Figure 2 Interlocking of two helical end and a straight rebar for12mm

E. Sleeve

Aluminium sleeves of 40 mm and 60mm diameter were used to form annular spaces around the 10 mm and 12mm reinforcement bars, providing sufficient clearance for grout placement and ensuring adequate grout cover for effective confinement. The sleeves are shown in the Figure 3.

Figure 3 Sleeve of diameter 40mm and 60mm

III. METHODOLOGY

A. Mix Design

Based on the calculations and trails the mix design of M40 was explained in this study. The M40 grade concrete was designed as per IS 10262:2019, with OPC 53 grade cement and a water–cement ratio of 0.40. The final mix proportion was established as

1:1.325:2.53 (cement: fine aggregate: coarse aggregate), corresponding to 450 kg/m³ cement, 596 kg/m³ fine aggregate, and 1142 kg/m³ coarse aggregate. The mix provided a workability of 100 mm and confirming its suitability for the pull-out test specimens. The mix proportions for M40 grade concrete are given in the Table IV. Based on the laboratory trails, the three cube specimens were casted and tested after 28 days of curing, obtained an average compressive strength of 49.84N/mm^2. The target mean strength of 48.25N/mm^2 at 28 days of curing which is satisfactorily achieved in the experimental procedure. Therefore, this mix design was adopted for the experiment investigation.

TABLE IV
MIX PROPORTIONS FOR M40 CONCRETE

Mix proportions	**Quantities in kg/m^3**
Grade	M40
Workability	100
Type of cement	OPC 53 grade
Water cement ratio	0.4
Cement	450
Fine aggregates	596
Coarse aggregates	1142
Mix proportion	1: 1.325: 2.53

B. Development Length

As per IS 456:2000 (Clause 26.2.1), the required development length of bars was calculated considering a grout of bond strength 8 MPa, steel of grade 415 N/mm^2, 500 N/mm^2. It is 130mm for 10mm ,190 mm for 12 mm diameter bars.

C. Laboratory Experiment

1) Casting of Test Specimens

A Cylindrical moulds of 150 mm diameter and 300 mm height were employed, with aluminium sleeves placed centrally as illustrated in Figure 4. M40 grade concrete was poured in layers up to 130 mm, corresponding to the calculated development length based on an assumed bond strength of 8 N/mm² (from NS-1 grout), and compacted using a table vibrator. After 24 hours, specimens were demoulded and water-cured for 28 days, resulting in plain concrete cylinders with centrally embedded sleeves suitable for grout filling as illustrated in Figure 5. Repeat the same procedure for 12mm diameter bar by taking splicing length of 190mm of sleeve was centrally placed in to cylinder specimen.


Figure 4 Mould for casting the specimen Figure 5 Hollow cylinder after curing

2) Placing of Reinforcement and Grouting

A cylindrical specimen was prepared using a 10 mm straight bar overlapped with another straight bar through its axis was inserted into the aluminium sleeves to replicate confined anchorage conditions. The annular gap between reinforcement and sleeve was filled with NS-1 Power Grout, prepared with 16% water content and thoroughly mixed to ensure a lump-free, uniform paste. Specimens were left undisturbed for 3–4 hours for initial setting and then water-cured for 28 days to develop full bond strength were shown in the Figure 6 to 8, thereby closely simulating anchorage conditions in precast connections for subsequent pull-out testing. The final specimen obtained from this procedure was named as S1 for 10mm and for 12mm diameter bar specimen is named as S5 were shown in the Figure 9 and Figure 10.

Figure 6 Placing of grout

ure 7 Grouting reinforcing bar into the cylinder

Figure 8 Grouted double cylinder

Similarly, a helical-ended bar with a straight rebar was overlapped for 10mm diameter bar was inserted in the cylinder filled with grout and named as S2. In this same manner for 12mm diameter bar, and named as S6 were shown in the Figure 11 and Figure 12.

Figure 9 specimen single cylinder with two straight bars of 10mm overlapped named as S1

Figure 10 specimen single cylinder with two straight bars of 12mm overlapped named as S5

Figure 11 specimen single cylinder with straight bar and lical end of 10mm bars overlapped named as S2

Figure 12 specimen single cylinder with straight bar and helical end of 12mm bars overlapped named as S6

3) Formation of Dowel-Joint Specimens

To develop extended overlap conditions, two individual concrete cylinders were casted and subsequently joined in an end-to-end configuration. The straight reinforcement bars were arranged to meet exactly at the centre, while a single straight bar was placed to meet the two cylinders to act like a dowel joint. The dowel joint showing the two bars meeting at the centre with an additional straight bar of length of 260mm for 10mm diameter and 380mm for 12mm diameter.

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The specimens designated as S3-10mm and S7-12mm were illustrated as Figure 13 and Figure 14 respectively. The helical reinforcement bars were arranged to meet precisely at the centre, while a single straight bar was placed to run continuously through two cylinders. This fabrication resulted in elongated specimens with uninterrupted reinforcement, which were designated as S4–10 mm and S8–12 mm, corresponding to the respective bar diameters and shown in Figure 15 and Figure 16. These specimens were considered representative of anchorage behaviour and were tested in the experiment.

Figure 13 specimen with dowel joint for 10mm with two straight bars named as S3

Figure 15specimen with dowel joint for 10mm with straight and helical end rebar named as S4

Figure 14 specimen with dowel joint for 12mm with two straight bars named as S7

Figure 16 specimen with dowel joint for 12mm with straight and helical end rebar named as S8

4) Test Setup and Procedure

Pull-out tests were performed using a 1000 kN capacity Universal Testing Machine (UTM), calibrated as per IS 1828:2005 was shown in the Figure 17. Specimens were mounted vertically, with the protruding reinforcement bar gripped firmly between the upper and lower jaws of the machine. The test was conducted under displacement control, applying tensile load gradually until slip or bond failure occurred. Load–slip responses were continuously recorded through a data acquisition system, and the maximum load prior to failure was considered as the bond strength. The procedure was repeated for all specimens, and the peak loads were recorded for analysis and results.

Figure 17 Universal Testing Machine setup with specimen S1

5) Failure Observation and Data Collection

During testing, continuous monitoring was carried out to capture load–slip behaviour and identify failure modes. Typical observations included initial micro-slip, progressive bond stress transfer, and eventual failure by either pull-out or splitting. Peak load values, corresponding bond stresses, and slip readings at different load stages were recorded systematically for each specimen. These data formed the basis for evaluating bond strength, anchorage efficiency, and comparative performance in the subsequent analysis.

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IV. RESULTS AND DISCUSSIONS

A. Load displacement diagram

The experiments have been conducted to study anchorage behaviour of rebar with helical end and without helical end. The test results and load displacement diagrams for the experiments are presented in the subsequent articles. The bond strength of grout

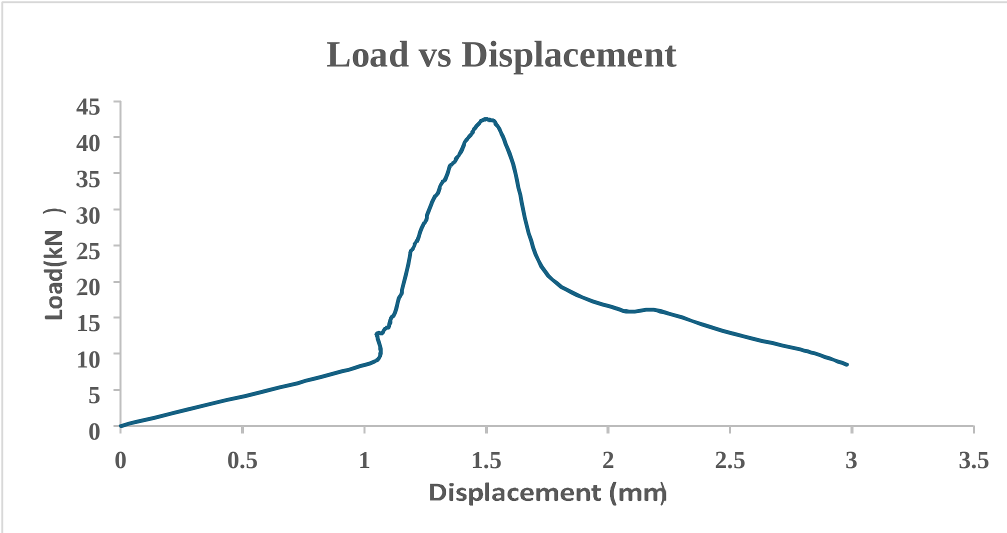

Figure 18 Load-displacement diagram for specimen S1

is taken as 8 N/mm^2 and the yield strength of 10mm and 12mm rebars are taken as 415 N/mm^2 and 500 N/mm^2 respectively. The overlap length for anchorage bond using the grout for 10mm and 12mm is calculated and obtained as 130mm and 190mm respectively. The specimen S1 for 10mm diameter bar as sleeve of 130mm and the 10mm bar is overlapped and grout is filled in the sleeve. The specimen is tested and load deflection curve is given Figure 18. The load increased within the deflection with the peak and dropped immediately after reaching the peak. The peak load is noted as 43kN. The specimen S2 is similarly to specimen S1 but one of the overlapping bars is provided with helical end. The overlap length for specimens S1and S2 is same. The load displacement diagram for specimen S2 is shown in the Figure 19.

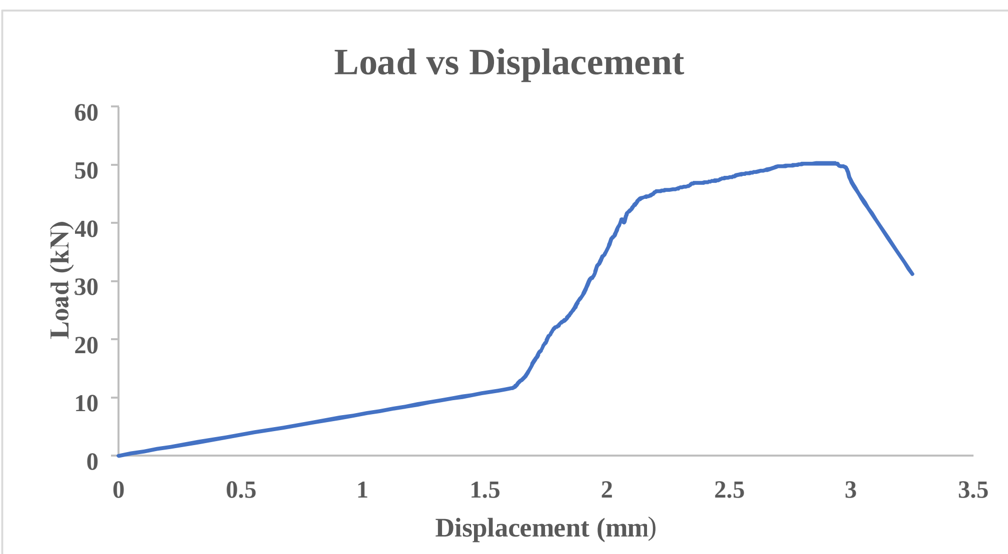

Figure 19 Load-displacement diagram for specimen S2

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On examination of the Figure 18 and Figure 19 that overall behaviour is similar but helical end rebar continued to resist the load even after reaching peak whereas the specimen S1 overlap has dropped suddenly after reaching the peak load.

The specimen S2 has reached a peak load of 50kN. It can be noted that 10mm bar has shown a yield load of 48kN and peak load 56kN.Thus the overlapping of bars with helical has shown better performance in terms of load carrying capacity and load displacement behaviour.

The specimen S3 is the one having two elements joined by a dowel bar. The specimen S3 is casted by inserting rebars in to the sleeve and dowel bar. The sleeve is filled with the grout. The specimens are tested and load displacement diagram is given in the Figure 20. The tested specimen is shown Figure 21.

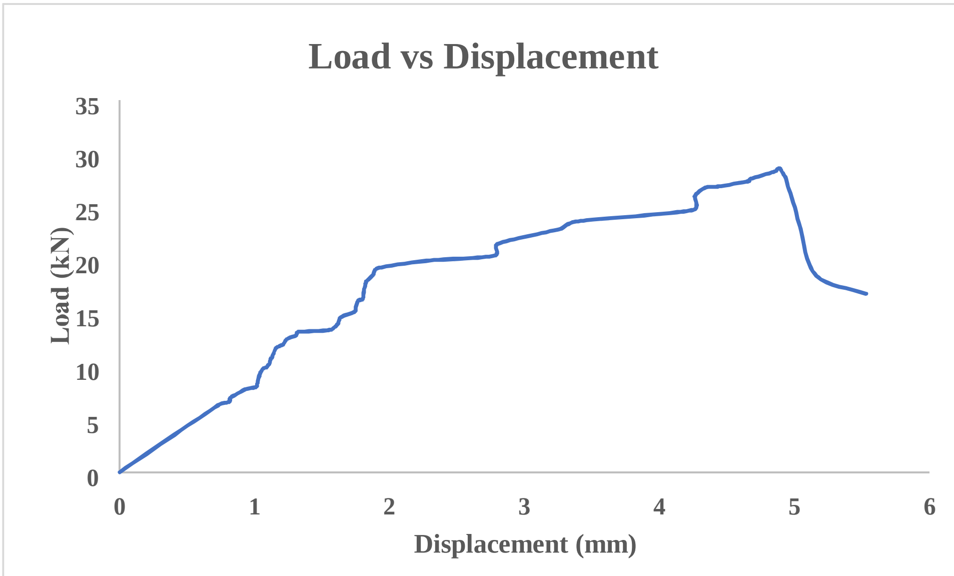

Figure 20 Load-displacement diagram for specimen S3

Figure 21 Failure of dowel joint for specimen S3

The peak value obtained is 29kN against the bar strength of 56kN were overlapped helical end rebar of 50kN. It can be seen that the advantage of overlap when used as a dowel is not ripped. The specimen S4 is similar to specimen S3 but the rebar has helical end in the element. The dowel bar is inserted in to rebar element and the sleeve is filled with grout.

The specimen is tested and load displacement diagram is given Figure 22. The tested specimen is shown in Figure 23. The peak load obtained for the specimen S4 is 51kN which is almost the same as the specimen with overlap and helical end. Thus, it can be understood that the helical end rebar has performed well both as overlap and as a dowel. Similarly for specimens S5 to S8 with 12mm bars were tested and compared the results.

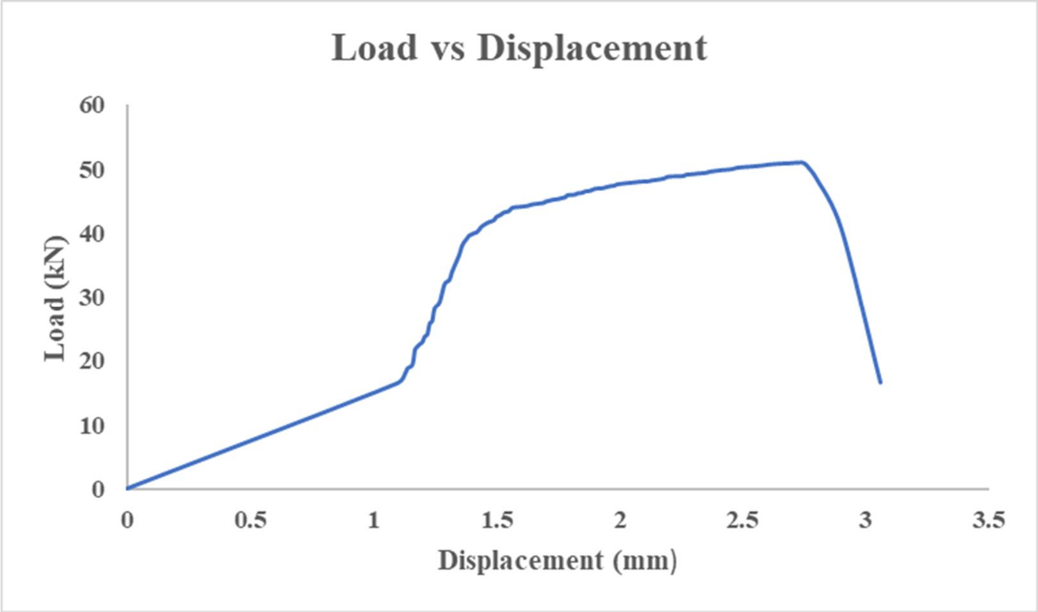

Figure 22 Load-displacement diagram for specimen S4

Figure 23 Failure of dowel joint for specimen S4

The specimens of 10mm diameter helical end rebar are named as S1, S2, S3 and S4 and 12mm diameter specimens are named as S5, S6, S7 and S8 respectively. The load-displacement diagram for the specimens S1 to S8 are obtained from the experimental analysis. The load at yield, peak was recorded and type of failure for all the specimens can be seen in the Table V.

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TABLE V
SUMMARY OF ANCHORAGE TEST RESULTS (S1–S8)

pecimen ID	Bar Diameter (mm)	Overlap / Dowel Type	Anchor Length (mm)	Yield Load (kN)	Peak Load (kN)	Observed Behaviour / Failure Mode
S1	10	Overlap (Straight Bar)	130	39	43	Sudden slip after peak (brittle failure)
S2	10	Overlap (Helical End Bar)	130	46	50	Concrete cracking and gradual post-peak drop
S3	10	wel (Straight Bar)	260	26	29	failure with low capacity
S4	10	Dowel (Helical End Bar)	260	46	51	Slip failure but improved capacity
S5	12	Overlap (Straight Bar)	190	54	58	crete failure at peak
S6	12	Overlap (Helical End Bar)	190	59	66	Concrete failure with higher capacity
S7	12	wel (Straight Bar)	380	29	34	Slip failure
S8	12	Dowel (Helical End Bar)	380	61	69	Bar yielding and eventual bar fracture

The experimental investigation compared anchorage performance of rebars with and without helical ends. For 10 mm bars, overlap lengths of 130 mm were used, with S1 (plain overlap) showing a peak load of 43 kN and sudden post-peak drop. Specimen S2, with a helical end, reached 50 kN and sustained load beyond peak, demonstrating superior ductility. Specimens S3 and S4 evaluated dowel action; S3 (plain) achieved 29 kN, while S4 (helical end) reached 51 kN, nearly matching overlapped helical bar performance. Overall, helical end rebars exhibited improved load transfer, higher peak loads, and better post-peak behaviour. Similar trends were observed for 12 mm bars (S5–S8). The results confirm that providing helical ends enhances anchorage capacity and structural performance under Tensile loading.

V. CONCLUSIONS

From the experiments results the conclusions drawn are listed below:

1) Helical end rebars improved peak load capacity by 15-20% for overlapped specimens (S2 vs S1, S6 vs S5) and by 75-100% for dowel specimens (S4 vs S3, S8 vs S7).
2) Dowel connections with helical end (S4) achieved almost equal strength to overlapping helical rebars, showing their effectiveness.
3) Overall, the use of helical ends enhances bond strength, load transfer and structural safety making them preferable in anchorage and dowel applications.

VI. ACKNOWLEDGMENT

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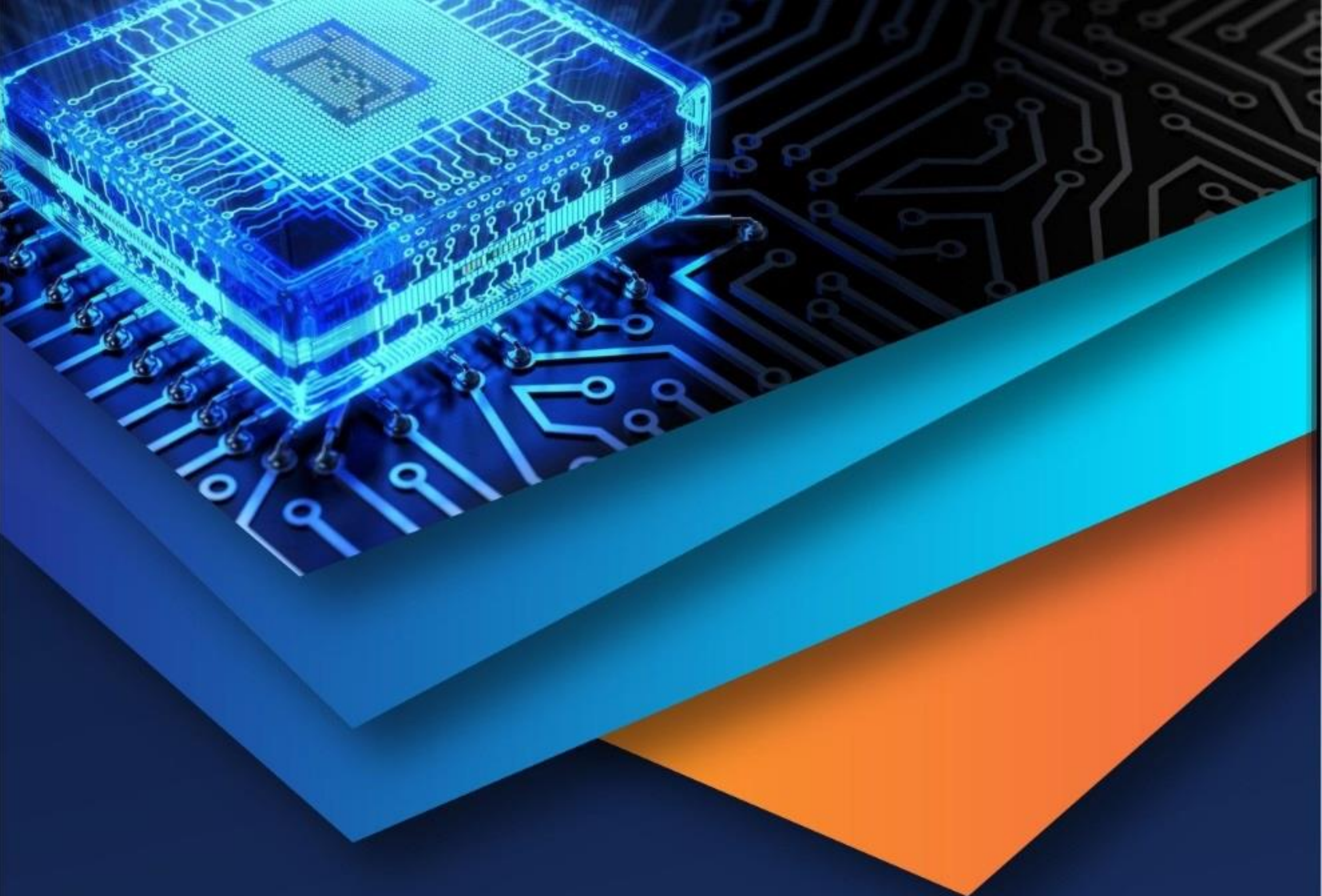

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