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An Experimental Work on Rehabilitation Method of Beam Reinforcement by Using Meshing & Stitching Method

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Abstract: Structural rehabilitation has become a major strategy that is vital for enhance and upgrading the efficiency of repairing defected structural elements. The deterioration of RC structures along with the dissimilarity and the prices of re- pairing actions have laid to encouragement of innovation of new repair materials and new strategies for structure recovery.The most widely recognized reason for untimely material deterioration is when the structure is subjected to the harsh environment, thus leading to the corrosion of the structure. Corrosion is like a dis- ease for the strengthened structure since it damages the reinforcement in it, which influences its quality and its life expectancy. Due to corrosion, various defects are caused such as reduction in cross section area of the bar, reduction in ductility, brown patches, spalling of concrete cover, etc. Also, reduction in strength, stiffness, serviceability and load carrying capacity is adversely affected. As the bar reduces in diameter, moment carrying capacity and shear capacities are reduced in the member.
Keywords: Structural Audit, Rehabilitation, Corrosion, Repairs, Meshing Method, Stitching Method, CFRP Laminates.

I. INTRODUCTION

After casting and demolding of specimens, they were immersed in water for curing of 28 days. After completion of curing period, cubes were tested in Universal Testing Machine under compressive load. Table 8.1 shows the compressive test results. After casting of the beams, they were exposed to accelerated corrosion technique. Beams were exposed to 14 days of corrosion and then tested under two-point loading in UTM up to failure. Same test setup was adopted for the testing of specimens after repairs as shown in Figure 8.1 and Figure 8.2. At every 4 KN incremental interval, deflection at the center is recorded. The moment carrying capacity, bending stresses after exposed to corrosion and after repair were determined based on the experimental failure load.

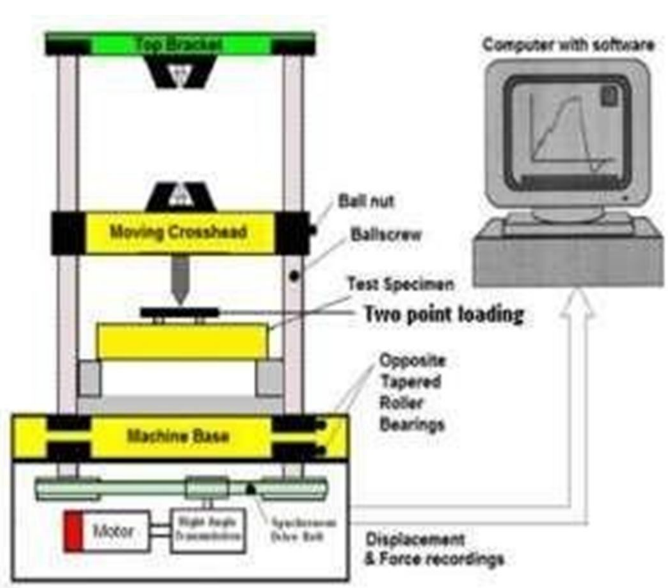

Figure 8.1: Schematic diagram of UTM for two-point loading

Sample	Compressive Strength (MPa)	Average Compressive Strength (MPa)	Modulus of Elasticity (N/mm^2) $5000\sqrt{fck}$
Cube 1	23.11	23.89	24438.7
Cube 2	24.16		
Cube 3	24.41		

Table 8.1: Properties of concrete

Figure 8.2: Testing of corroded beam before rehabilitation

II. METHOD OF REHABILITATION

After testing the beams before repair up to ultimate failure, the beams were observed to have failed in flexure as well as shear. After testing the corrosion dam- aged beams at ultimate load, it is expected that these longitudinal bars have completely failed to resist the external load and these bars are not able to bear any external load. This corrosion damaged beams are rehabilitated using four methods as described.

Conventional method Meshing method Stitching method

Meshing + Stitching Method[15]

A. Section Enhancement method

Rehabilitation by this method is comprised of applying an extra thick layer of repair mortar of 25 mm width on bottom three sides of the beam. The thorough procedure for accomplishing this method is as follows.

Figure 8.3: Removal of damaged concrete

Procedure

After testing the corroded beams, the weak concrete or the damaged part was removed with the help of chisel and hammer. The dust is removed completely with the help of wire brush as shown in Figure 8.3.

Concrete cover is removed up to steel reinforcement. SP Rustcleen, a rust remover is applied as instructed is applied on the bars to break the corrosion process as shown in Figure 8.4.

Figure 8.4: Application of Rust remover on the reinforcement

Figure 8.5: Sealing pot holes and spalled portions with repair mortar

Durocon-49 acts as a bonding agent, so there was no need of external bonding chemical.Curing of beams.

Figure 8.6: Application of repair mortar over three sides of beam

B. Meshing Method

This method consists of wrapping stainless steel mesh around the three sides of the beam. Procedure:

After testing the corroded beams, the weak concrete or the damaged part was removed with the help of chisel and hammer. The dust is removed completely with the help of wire brush.

Concrete cover is removed up to steel reinforcement.

SP Rustcleen, a rust remover is applied as instructed is applied on the bars to break the corrosion process.

The bars were kept open for a day to air dry the Rustcleen.

Wire Mesh made up of stainless steel was wrapped around the three sides of the beam as shown in Figure 8.7.

Figure 8.7: Placing of stainless steel mesh on the three sides of beam

Repair mortar of thickness 25 mm was applied over the mesh.Curing of beams after hardening of repair mortar.

C. Stitching Method

This method consists of rehabilitating the corrosion damaged beams by providing U-type bars and stitching them into the bottom of beam. The bar is bent at 90^o angle at both the ends. The U-type bar is provided as an extra tension reinforcement.

Procedure:

After testing the corroded beams, the weak concrete or the damaged part was removed with the help of chisel and hammer. The dust is removed completely with the help of wire brush.

The weak concrete of the soffit is removed with the help of hammer. Concrete cover is removed up to steel reinforcement.

SP Rustcleen, a rust remover is applied as instructed is applied on the bars to break the corrosion process. The beam is left undisturbed for a day to air dry the Rustcleen. Holes of 14 mm diameter are drilled on the tension side of the beams.

Figure 8.8: Drill pattern of holes for stitching method

The dust from the holes is removed and kept clean. The holes are filled with grouting material .Two bars of 10 mm dia. in the form of U shape is placed across the flexure crack up to 80 mm depth in to the beam as shown in fig 8.9.

Figure 8.9: Placing of U shape bars into the beam

After stitching the reinforcement into the holes of the beam, repair mortar of depth 25 mm was placed throughout the beam.Curing of beams was carried out with the help of wet gunny bags for 28 days.

D. Meshing + Stitching

This method consists of combination of two methods, meshing and stitching. Procedure:

After testing the corroded beams, the weak concrete or the damaged part was removed with the help of chisel and hammer. The dust is removed completely with the help of wire brush.

The damaged portion of the soffit is removed with the help of hammer. Concrete cover is removed up to steel reinforcement.

SP Rustcleen, a rust remover is applied as instructed is applied on the bars to stop the corrosion process.

The beam is left undisturbed for a day to air dry the Rustcleen.

Four holes were drilled on the bottom side of the beams at the corner as shown In fig.8.8.

The dust from the holes is removed with the help of vacuum pressure.The holes are filled with grouting material.Two U-type bars of 10 mm is placed up to 80 mm depth into the beam.Stainless steel mesh is wrapped around the three sides of the beams as shown in Figure 8.10.

Figure 8.10: Application of repair mortar

After fixing the reinforcement into the holes and applying mesh, repair mortar of depth 25 mm was placed throughout the beam as shown in Figure 8.11.To achieve strength of the mortar, curing was done for 28 days after the day of repair.

Figure 8.11: After rehabilitation by Meshing + Stitching method

After rehabilitation of corroded beams by various methods, these repaired beams were re-tested under two-point loading.

E. Closure

This chapter describes the experimental study that is performed using various methods of rehabilitation as mentioned above. The detailed procedure while re- pairing is also described. Also the mechanical properties of the concrete are plotted in the tabular form

III. RESULTS

A. Introduction

This chapter defines details on experimental outcomes of the corrosion damaged beams and rehabilitated beams. Bending stresses, moment carrying capacity, load carrying capacity, mode of failure, load vs. deflection curves and comparative study of all types of beams before and after rehabilitation are described in Table 9.1 to Table 9.3 and Figure 9.1.

Table 9.1: Test results of beams before rehabilitation

Sr. no.	Specimen	Load at Failure (kN)	Average Load at Failure (kN)	Deflection(mm)	Average Deflection(mm)	Mode of Failure
1.	ARSEM	72.90	77.725	11.92	13.43	Flexure- shear crack
		82.55		14.94		
2.	ARSM	85.75	89.35	6.70	7.68	Shear failure
		92.90		8.66		
3.	ARMM	104.25	103.80	12.27	10.80	Flexure crack and de-bonding
		103.30		9.34		
4.	ARMSM	109.60	104.95	19.71	15.91	Hair cracks
		101.85		14.1		
		103.40		13.92		

Table 9.2: Test results of beams after rehabilitation

Sr. no.	Specimen	Load at Failure (kN)	Average Load at Failure (kN)	Deflection (mm)	Average Deflection(mm)	Mode of Failure
1.	BRSEM	76.35	82.15	9.28	10.81	Flexure-shear cracks and concrete crushing
		87.95		12.35		
2.	BRSM	74.30	77.60	9.62	9.94	Flexure-shear cracks and concrete crushing
		80.85		10.25		
3.	BRMM	83.10	83.05	11.6	11.22	Flexure crack and concrete crushing
		82.95		10.85		
4.	BRMSM	84.25	80.90	12.06	10.56	Shear crack and concrete crushing
		78.90		9.78		
		79.60		9.85		

Table 9.3: Percentage strength restored after rehabilitation

Sr. no.	Method of Rehabilitation	Average Loadat Failure before Rehabilitation (kN)	Average Loadat Failure after Rehabilitation (kN)	% Strength Restored
1.	SEM	82.15	77.725	94.61
2.	SM	77.60	89.35	115.14
3.	MM	83.05	103.80	124.98
4.	MSM	80.90	104.95	129.73

Figure 9.1: Variation of Load of beams BR and AR

IV. BEHAVIOR OF BEAMS

A. *Section Enhancement Method*

In corroded beams before rehabilitation, initially vertical cracks occurred in the quarter span of the beam. As the load increased the crack was inclined toward the neutral axis of the beam. Finally, the beams were distressed at average ultimate load of 82.15 kN with an average deflection of 10.81 mm. As the load increased, crushing of concrete is observed.

After rehabilitating the damaged specimen by enlarging the section, 94.61% of the ultimate load was recovered. At average ultimate load of 77.725 kN, flexure-shear cracks were observed in the quarter span of the beam. Also the deflection of the beam was found to be 24.24% greater than the corroded beam. Bending stresses were also reduced by this method. Load vs. deflection curve for this method is indicated in fig no. 9.2. Beams repaired by this method, it was concluded that the moment carrying capacity of the beams was also reduced.

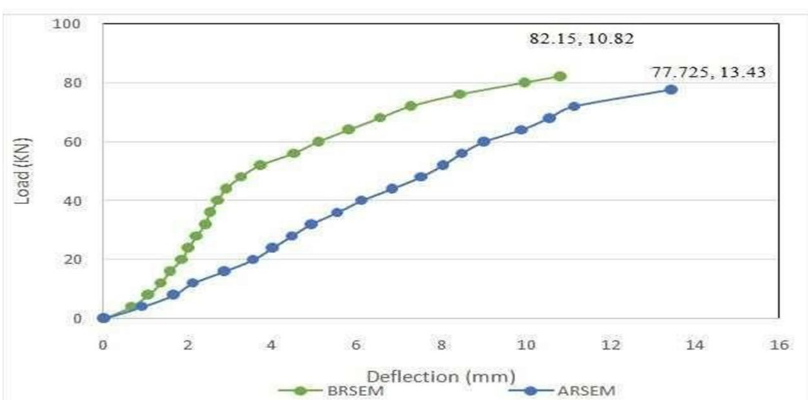

Figure 9.2: Load vs. Deflection graph for Section Enhancement Method

B. Stitching Method

Fig 9.3 shows load vs. deflection graph of stitching method. Before rehabilitation the corrosion damaged specimens were observed to collapse in flexure-shear crack pattern at an ultimate load of 77.60 kN. After rehabilitating the beam by stitching method, 115.14% of the ultimate strength is restored. Also the defection of the rehabilitated 22.73% lesser than the corroded beam.

Bending capacity of the beams repaired by this method was also found to be increased by 15.15% than the corroded beam. After rehabilitation, beam was observed to fail in shear at the ultimate load. Also the internal stresses in the beam were increased to resist the external bending.

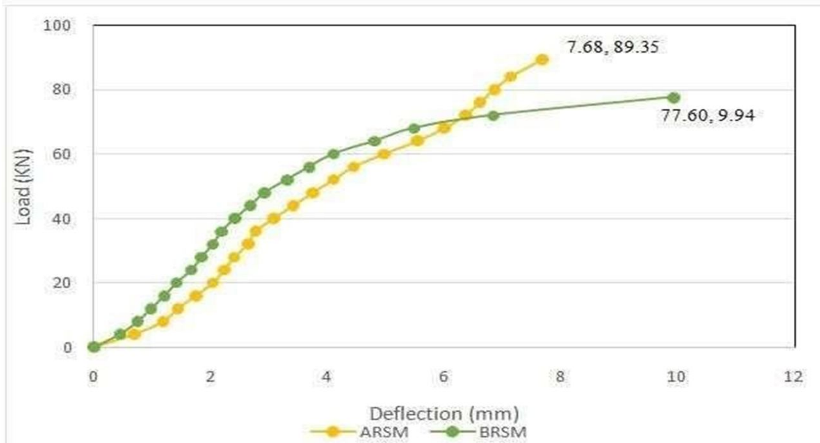

Figure 9.3: Load vs. Deflection graph for Stitching Method

C. Meshing Method

Load vs. deflection graph for meshing method is indicated in fig. 9.4. Before rehabilitation, the corrosion damaged specimens failed in flexure and concrete crushing was also observed. Initially vertical cracks developed in the middle portion of the beam. The beam finally failed in flexure at ultimate load of 83.05 kN accompanied with crushing of concrete. After rehabilitation, this method showed 125 % increase in ultimate capacity and the bending stresses. Also the deflection was observed to be 3.74 % lesser than the original corroded beam. Repairing beams by this method, it is determined that the moment capacity of the beams was found to be increased by 25% than the corroded beams.

Rehabilitation by this technique, resulted de-bonding of additional cover concrete with mesh at the ultimate load. Finally, minor cracks in flexure were observed at the ultimate load.

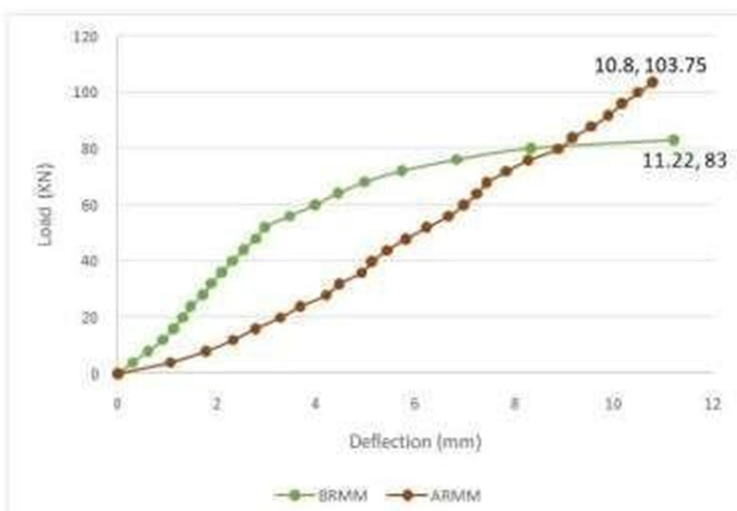

Figure 9.4: Load vs. Deflection graph for Meshing Method

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D. Combination of Meshing + Stitching Method

In corroded beams before rehabilitation, shear cracks were observed in the shear span of the beam. As the load increased crushing of concrete occurred. Finally, the beam collapsed at average ultimate loading of 80.90 kN with an average deflection of 10.56 mm. After rehabilitating the damaged specimen, 129.73 % of the ultimate load was recovered. Minor hair cracks were observed at the ultimate load after repair. The average deflection of the beams was found to be 50.66% greater than the corroded beam. The internal stresses in the beam were found to be increased to resist the external bending. Load vs. deflection curve for this method is indicated in fig no. 9.5. Bending capacity of the beams repaired by this method was also found to be increased by 29% than the corroded beams.

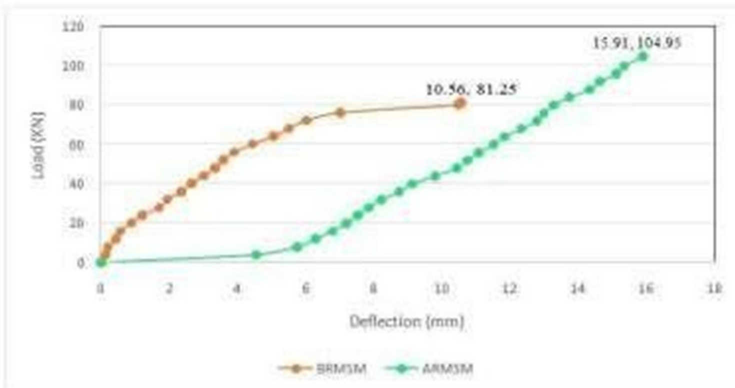

Figure 9.5: Load vs. Deflection graph for Meshing + Stitching Method

V. COMPARISON OF RESULTS

From fig. 9.6, it can be observed that rehabilitation by combination of stitching + meshing method proved to be best in carrying the highest ultimate load while sec- tion enhancement was worst. All methods except section enhancement restored 100 % of the ultimate load. Maximum ultimate load of 104.95 kN is achieved by stitching the U-type bars and meshing method, also minimal hair cracks are observed.

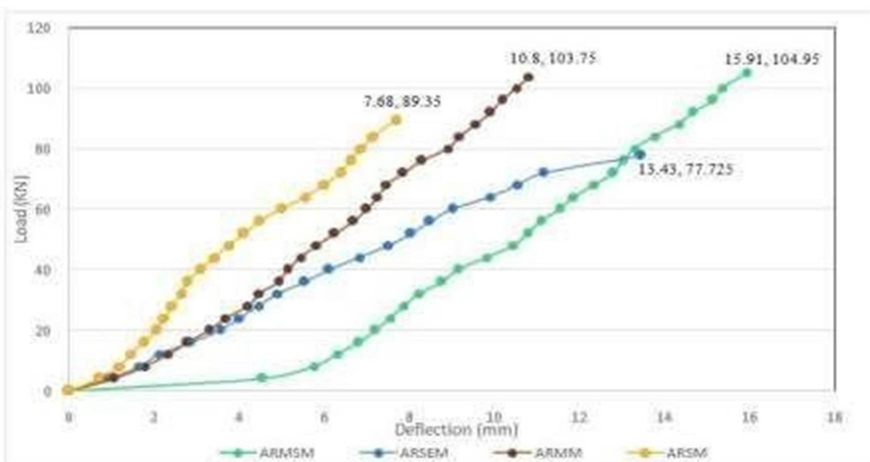

Figure 9.6: Load vs. Deflection curves of all techniques

Stress caused due to bending moment is known as flexural or bending stress and is given by

$$f_b = \frac{P \times Leff}{b \times d^2} \quad (9.1)$$

Fig. 9.7 and Fig. 9.8 shows the variation of bending stresses and moment carrying capacity of damaged beam before rehabilitation and after rehabilitation. Com- bination of stitching plus meshing method showed outstanding result in carrying highest bending stress and moment capacity.

Table 9.4: Bending stress before and after rehabilitation

Sr. no.	Method of Rehabilitation	Bending stress (N/mm^2)	
		Before Rehabilitation	After Rehabilitation
1.	SEM	14.60	13.81
2.	SM	13.79	15.88
3.	MM	14.76	18.45
4.	MSM	14.38	18.65

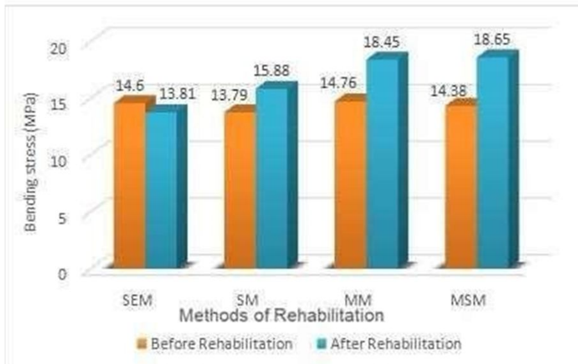

Figure 9.7: Bending stresses of beams BR and AR

Table 9.5: Moment Carrying Capacity before and after rehabilitation

Sr. no.	Method of Rehabilitation	Bending Moment (kNm)	
		Before Rehabilitation	After Rehabilitation
1.	SEM	16.43	15.54
2.	SM	15.52	17.87
3.	MM	16.61	20.76
4.	MSM	16.18	20.99

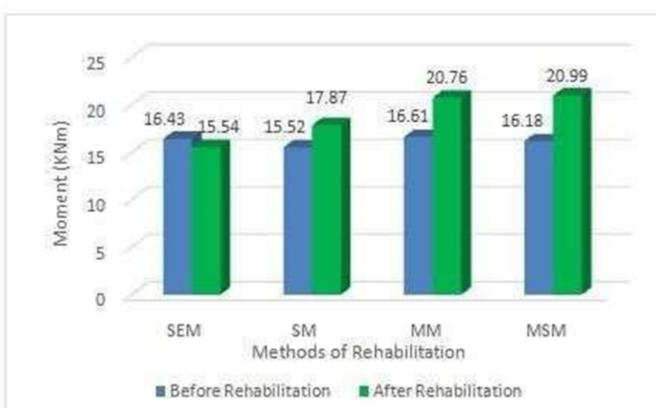

Figure 9.8: Moment capacity of beams BR and AR

A. *Strain Energy*

Work done or total strain energy stored in the beam before and after rehabilitationis the area under the load vs. deflection curve. Table no. 9.6 shows the strain energy stored in the beam at ultimate load before rehabilitation and after rehabilitation. It can be observed that the work done before rehabilitation is more than after rehabilitation at the ultimate loading of the corroded beam. Therefore, it can be concluded that the energy required for the failure of the damaged corrosion

RC beams after rehabilitation is always lesser than the energy required for failure of beams before rehabilitation.

Table 9.6: Work done before and after rehabilitation

Sr. No.	Method of Rehabilitation	Strain Energy before rehabilitation (Joules)	Strain Energy after rehabilitation (Joules)
1.	SEM	583.09	566.08
2.	SM	542.68	343.04
3.	MM	679.39	486.36
4.	MSM	608.26	574.59

B. Closure

This chapter shows experimental results of the rehabilitated beams. Behavior of rehabilitated beams, work done, failure pattern, and load vs. Deflection graphs are described he

VI. CONCLUSION AND FUTURESCOPE

A. Conclusion

Corroded beams rehabilitated using section enhancement, meshing, stitching and combination of mesh + stitch method restored 94.61%, 115.14%, 124.98% and 129.73% strength of their respective control beams.

Corroded beams rehabilitated with combination of stitching + meshing method gives highest load carrying capacity and hence moment capacity in all the techniques used.

The justification for the high strength of combination method is the application of ferro- cement layer consisting of mesh + high strength repair mortar supported by the U-type bars and with minimal hair cracks.

Combination method can be used for the beams that have failed in shear as well as flexure.

The stitching method is most efficient method because the beam rehabilitated with this technique gives better ultimate strength of 89.35 kN (115.14%) and lesser deflection of 7.68 mm (22.73%) compared to controlled beams.

The damaged beams rehabilitated with stitching method gives lesser ultimate strength of 89.35 kN (lesser by 17.46%) and lesser deflection of 7.68 mm (lesser by 107.16%) as compared to combination of mesh + stitch method that failed at 104.95 kN and 15.91 mm deflection. Practically stitching method is simple in application and execution. Strain energy required for failure of beams after rehabilitation is less than the energy required before rehabilitation. The percentage of corrosion in beam was found to be greater than 10%, and was rehabilitated using CFRP wraps and laminates. The rehabilitated beam is in service condition and is working well.

B. Future Scope

In the present work, holes are drilled in to the soffit of the beam at 80 mm depth. Further study can be carried on increasing the depth of the hole and changing angle of bar and hole. Study can be further carried on using various types of mesh with different spacing and diameter of the mesh .Also effect on strength can be studied using different grades of bars.

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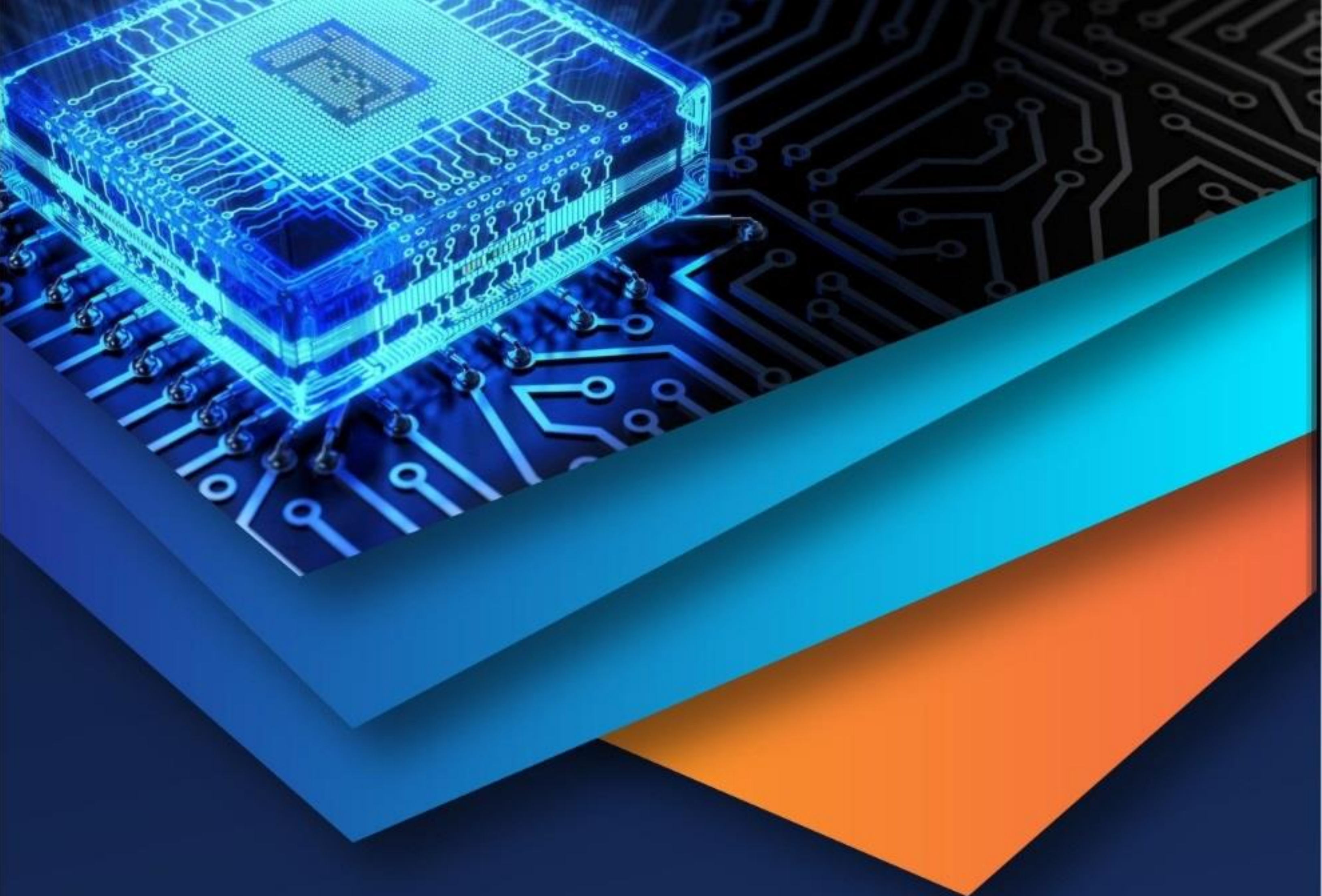

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