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Experimental Study of Comparison between GFRP and Steel bars

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Abstract:** This experimental study investigates the viability and performance of replacing traditional steel reinforcement with Glass Fiber Reinforced Polymer (GFRP) bars in concrete structures. With the increasing demand for sustainable and durable infrastructure, the construction industry seeks alternatives to steel reinforcement due to its susceptibility to corrosion and associated maintenance costs. GFRP bars offer a promising alternative due to their non-corrosive nature, high tensile strength, and light weight. The experimental program involves casting concrete specimens with varying percentages of GFRP bars as a substitute for steel reinforcement. Mechanical properties such as tensile strength, flexural strength, and bond strength between GFRP bars and concrete are evaluated and compared with conventional steel-reinforced concrete. The results indicate that GFRP-reinforced concrete exhibits comparable or even superior mechanical properties compared to traditional steel-reinforced concrete. The tensile strength of GFRP bars matches or exceeds that of steel, ensuring adequate structural performance. Moreover, the non- corrosive nature of GFRP bars eliminates the risk of corrosion-induced deterioration, leading to longer service life and reduced maintenance costs. Furthermore, the bond strength between GFRP bars and concrete is found to be satisfactory, indicating effective load transfer between the reinforcement and the surrounding concrete matrix. In conclusion, the experimental study supports the feasibility and effectiveness of replacing steel reinforcement with GFRP bars in concrete structures. This alternative offers numerous advantages including enhanced durability, reduced maintenance requirements, and increased sustainability, making it a promising solution for modern construction practices seeking to address both structural and environmental concerns.

***Keywords:** Glass Fiber Reinforced Polymer, Steel Reinforcement, Alternative Reinforcement, Sustainable Concrete.*

I. INTRODUCTION

Concrete, a composite material made of cement, aggregates, and water, is known for its strength in compression but its weakness in tension. Incorporating steel helps concrete elements withstand tensile forces. Traditional steel bars have long been reinforce concrete structures in the construction industry. However, due to used fatigue, there has been a steel's limitations, such as tendency to corrode finding alternative reinforcement materials. [1] One of the growing interest preferred solutions adopted globally for reinforcing concrete elements is the use of fiber-reinforced polymer (FRP) bars, which have shown positive results over the years Fiber- reinforced polymer (FRP) composites, made from fibers and resins, include types such as GFRP (glass), AFRP (aramid), and CFRP (carbon).[2]

These FRPS are commonly applied in civil engineering for prestressed and reinforced concrete existing structures, and for repairing. strengthening elements, as well manufacturing ground anchors. Despite their benefits, the lack of comprehensive information and design specifications has limited their widespread adoption as reinforcements. [3] Recently, FRP bars have been introduced as an alternative to steel for internal reinforcement in concrete structures, especially in environments prone to corrosion. Many countries now prefer FRP for internal reinforcement concrete elements, though only a few have started to use FRP bars extensively in their concrete structures. Fiber-reinforced polymer (FRP) bars are resistant to corrosion and chloride attack because they are non-metallic.[4] Using FRP bars eliminates t durability issues and reduced service life associated with steel bars. They are cost-effective due to their superior tensile strength-to-weight ratio compared to standard steel bars.[5] The main advantages of FRP bars over steel include their three times higher tensile strength, lower density, resistance to fatigue, chemical attack, and corrosion, as well as their long-term durability.[6] One FRP alternative that has garnered significant attention recently is Glass Fiber Reinforced Polymer (GFRP) bars. These bars are composed of high-strength glass fibers embedded in a resin matrix, making them significantly lighter than steel.[7]

II. LITERATURE REVIEW

This Section contains literature Review of the various researches going on GFRP and its application in construction Industry worldwide. Some of the research papers analysis and its review are as follows.

Raffaello Fico's: research focuses on improving the design and reliability of concrete structures reinforced with FRP bars, exploring failure modes like shear and bond failure. The study evaluates various FRP types, including CFRP and AFRP, and examines design guidelines like CNR-DT 203/2006 for calculating crack widths and development lengths. It emphasizes the effect of FRP bar properties on concrete strength and safety factors, aiming to enhance the design methodology for more robust and safe FRP-reinforced concrete structures in engineering applications.

Ali S. Shanour et al.'s study shows that locally produced GFRP bars perform well compared to commercial ones in terms of fiber volume fraction, tensile strength, and elastic modulus. They found that GFRP Reinforced Concrete beams' failure modes depend on the reinforcement ratio. Excessive reinforcement causes compression failure, while insufficient or balanced reinforcement leads to GFRP rupture. Increasing concrete compressive strength reduces crack width, and a higher reinforcement ratio enhances the beam's ultimate capacity, with bilinear load-deflection behavior and some ductility at a ratio of 2.7.

H. A. Abdalla's: study on FRP-reinforced concrete beams and slabs reveals that these structures behave linearly up to cracking, after which they exhibit reduced stiffness. FRP-reinforced concrete shows smaller deflections and strains compared to steel-reinforced concrete due to FRP's lower modulus of elasticity and bond characteristics. The balanced reinforcement ratio for FRP is lower, potentially leading to over-reinforcement. The study also highlights that ACI-440 guidelines underestimate deflections beyond cracking, while other methods like ISIS Canada align better with experimental data.

Maher A. Adam's: study highlights that locally produced GFRP bars exhibit similar mechanical properties to commercial GFRP bars, making them a viable option for concrete reinforcement. It emphasizes the importance of selecting the correct reinforcement ratio, as ratios below the balanced level lead to rupture, while higher ratios cause compression failure. The study also suggests that increasing concrete compressive strength could enhance structural performance, reducing crack formation and improving load resistance, underscoring the importance of proper design and reinforcement selection.

Liu Jun et al.'s: study reveals that GFRP bars have distinct mechanical properties compared to steel, including lower elastic modulus, non-ductile behavior, and tensile strength dependent on cross-sectional area. GFRP bars are stronger in tension along fibers but weaker in shear, with shear strength ranging from 16% to 20% of tensile strength. Larger bar diameters can handle higher loads, but shear strength remains consistent. The study emphasizes the need for higher reinforcement ratios in areas with stress concentrations, such as shaft holes.

VG Kalpana et al.'s: study highlights that GFRP bars in high-strength concrete perform better than in normal- strength concrete, with superior deflection control and load-carrying capacity due to higher tensile strength. It also shows that reduced GFRP bar stiffness leads to wider cracks, though concrete strength has minimal impact on crack width. Additionally, Finite Element (FE) models closely match experimental data but overlook factors like bond slip and micro-cracks, leading to higher stiffness predictions in the models.

Shahad Abdul et al.'s: study demonstrates that GFRP bars offer superior mechanical properties compared to steel rebars, including 13% higher tensile strength and 58% greater yield strain. GFRP bars also show good bend strength, achieving 72% of steel's yield strength with 20% higher yield strain. Their corrosion resistance and moderate flexural strength make GFRP bars a promising alternative for foundation applications. Additionally, unreinforced concrete in the study meets the British Standard's compressive strength requirement of 25.67 MPa.

Pratik P. Patil et al. highlight that GFRP rebars offer superior shear strength (170 N/mm²) and tensile strength (1000 N/mm²) compared to steel, making them an attractive alternative in construction. Despite lower elongation requiring prefabrication, GFRP rebars prove effective in applications like underground water tanks. Additionally, they offer cost savings of 30.82% compared to steel structures. These strengths and cost-efficiency make GFRP rebars a promising, reliable, and economical choice for modern construction.

Ahmed Ghobarah and A. Said's experimental study on shear strengthening of beam-column joints demonstrates that applying GFRP fiber-wrap rehabilitation schemes significantly increases the shear resistance of the joint. The study highlights improved performance, particularly in terms of ductility, as the failure mode shifts from shear to flexural hinging in the beam, a more ductile mode of failure. This shows that GFRP jackets can effectively enhance the shear strength and ductility of structural connections.

Kumar et al. (2007): found that retrofitting damaged columns with CFRP jackets improves strength and ductility, but the extent of improvement depends on the prior damage. High axial loads reduce ductility and energy dissipation, particularly affecting the energy dissipation capacity. CFRP retrofitting enhances seismic resistance, with square columns showing less ductility improvement than circular columns due to better confinement in the latter. The technique stabilizes hysteresis curves, reducing stiffness and strength degradation compared to un-retrofitted columns.

K. Olivova and J. Bilick (2008) conducted an experimental study on reinforced concrete columns strengthened with carbon fiber sheets and strips in pre-cut grooves. Their findings revealed that numerical analysis results were about 20% higher than theoretical predictions, and experimental results were 25-35% higher. The study demonstrated that the near-surface mounted (NSM) carbon fiber strengthening technique significantly improves the load-carrying capacity of concrete columns, particularly those failing in bending, showing promising potential for enhancing structural performance.

K.P. Jaya and Jessy Mathai (2012): found that strengthening RC beam-column specimens with GFRP jackets significantly improved their load-carrying capacity and ductility. Columns wrapped with two, four, and six layers of GFRP showed increases in load capacity by 8%, 28%, and 32%, respectively. The 6-layer GFRP jacket provided the highest strength increase. Additionally, ductility improved by 25%, 54%, and 70% for two, four, and six layers of GFRP, highlighting the effectiveness of GFRP in enhancing structural performance.

Thamer Kubat, Riadh Al-Mahaidi, and Ahmad Shayan (2016): studied the effects of CFRP confinement on circular concrete columns affected by alkali-aggregate reactions (AAR). AAR causes expansion and cracking, reducing the mechanical properties and service life of concrete structures. The study found that CFRP confinement improved the strength and strain capacity of affected columns compared to unconfined ones. Additionally, increasing the number of CFRP layers further enhanced the capacity of the columns, offering a promising solution to mitigate AAR impacts..

Pranay Ranjan and Poonam Dhiman (2016) compared three retrofitting methods for strengthening failed columns in existing buildings: RC, FRP, and SFRC Jacketing. The study included design procedures for each method, specifically Reinforced Concrete, Carbon Fiber Reinforced Polymer (CFRP), and Steel Fiber Reinforced Polymer (SFRC) Jacketing. The paper provided a comparative analysis of the effectiveness of these methods, exploring how each method impacts the strengthening process and the size adjustments needed for the column sections in RC Jacketing.

Mohammad R. Irshidat and Mohammad H. Al-Saleh (2017): studied the impact of carbon nanotubes (CNTs) on flexural strength recovery of heat-damaged RC beams reinforced with CFRP composites. The beams, heated to 500–600°C and then repaired, showed enhanced ultimate load-carrying capacity and stiffness after using epoxy resin modified with CNTs. The results revealed that CFRP confinement increased load capacity by 111% and 81%, and stiffness by 75% and 56%, compared to unheated beams, demonstrating CNT’s effectiveness in strengthening heat-damaged structures.

Mohammad T. Jameel, M. Neaz Sheikh, and Mohammad N.S. Hadi (2017) studied the behavior of circularized and CFRP-wrapped hollow concrete specimens under axial compression. The results showed that circularizing hollow specimens reduces stress concentration at corners, improving ultimate load capacity and ductility, similar to solid specimens. Circularization contributed more to increasing the ultimate axial stress than corner rounding. A simplified theoretical model was developed to predict the axial load of CFRP-confined square and circularized solid and hollow specimens.

Kavita Kene et al. conducted an experimental study on the behavior of steel and glass fiber reinforced concrete composites. The study compared fiber-reinforced concrete with 0% and 0.5% steel fiber volume fractions and alkali-resistant glass fibers (0% and 25% by weight of cement, 12 mm length), analyzing their performance differences.

G. Jyothi Kumari et al. studied concrete beams reinforced with silica-coated GFRP flats and found that beams with these flats as shear reinforcement exhibited failure at higher loads and good ductility. They noted that the strength of GFRP composites depends on fiber orientation, fiber-to-matrix ratio, and fiber content, with higher content increasing tensile strength.

Dr. P. Srinivasa Rao et al. studied the durability of glass fiber reinforced concrete (GFRC) using alkali-resistant fibers. Their findings showed that adding glass fibers improved concrete’s resistance to acid attack, reduced bleeding, and enhanced overall durability, particularly in M30, M40, and M50 grades, compared to ordinary concrete.

S. H. Alsayed et al. studied the performance of GFRP bars in reinforcing concrete structures, finding that the flexural capacity of GFRP-reinforced beams can be estimated using ultimate design theory. They also noted that due to GFRP's low modulus of elasticity, deflection criteria may control the design of intermediate and long beams.

Yogesh Murthy et al. found that incorporating glass fiber in concrete improves its properties, with a 30% increase in flexural strength for beams with 1.5% glass fiber content. Additionally, the study highlighted a reduction in slump with increased fiber content.

Avinash Gornale et al. observed that the addition of glass fibers to M20, M30, and M40 grade concrete led to a 20-30% improvement in compressive, flexural, and split tensile strength at 3, 7, and 28 days compared to plain concrete.

Amr EL-Nemra et al. studied the flexural behavior of concrete beams reinforced with sand-coated and helically- grooved GFRP bars. They found that over-reinforced GFRP-reinforced concrete beams failed due to concrete crushing, with distributed flexural cracks. Smaller diameter GFRP bars helped limit crack widths. Sand-coated GFRP bars showed better bond performance than helically-grooved bars. Additionally, the study found that ACI and ISIS codes accurately predicted crack widths and deflections, while CSA underestimated these values in multilayer GFRP-reinforced beams.

III. MANUFACTURING PROCESS

Pultrusion process is a continuous manufacturing method for producing composite materials with constant cross-sections. The process involves the following key steps,

1) Steps 1. Fiber Feeding: Continuous reinforcing fibers (rovings or mats) are pulled from a series of creels.
2) Steps 2. Guiding: The fibers are fed through a guiding system to ensure proper alignment.
3) Steps 3. Resin Impregnation: The fibers pass through a resin bath where they are thoroughly impregnated with the matrix material.
4) Steps 4. Preforming: The resin-soaked fibers are guided through a preforming system that shapes them close to the final profile
5) Steps 5. Heating and Curing: The shaped, resin-impregnated fibers enter a heated die where the curing process begins.
6) Steps 6. Pulling: A pulling system draws the cured profile through the die
7) Steps 7. Cutting: The fully cured pultruded profile is cut to the desired length using a cut-off saw.

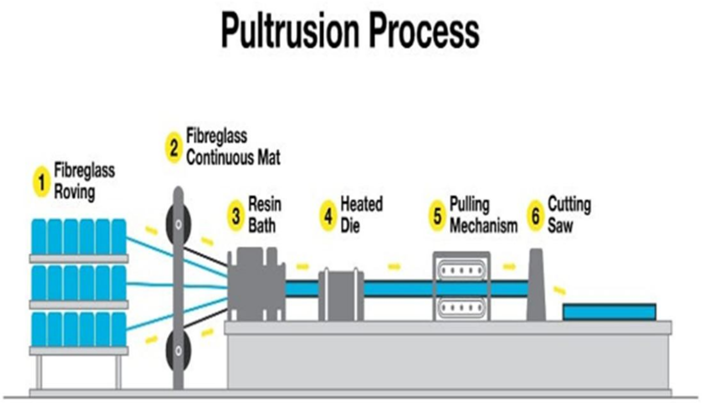

Fig. Pultrusion Process

A. *Advantages*

- The known advantage of FRP bars are as follows:
- Higher tensile strength than mild steel
- Lightweight (0.2 -0.25 of the weight of steel bar)
- Resistant to electrical and thermal conductivity (limited to GFRP bar only)
- No need for admixtures that prevent corrosion
- Endures high level fatigue
- Longer service life in corrosive environment when compared to steel bar
- Thickness of concrete cover can be reduced
- Not affected by chemical attack and chloride ion
- Better damage tolerance than steel bar coated with epoxy.

B. Disadvantages

- Fiberglass rebar is generally more expensive than steel rebar, although the cost gap is narrowing as technology advances. This can be a significant factor for large-scale projects.
- Fiberglass rebar has lower stiffness than steel rebar, meaning it deflects more under load. This can be an issue for applications where high stiffness is required, such as beams and columns.
- Fiberglass rebar has a brittle behavior, meaning it fractures suddenly without much warning. This is in contrast to steel rebar, which exhibits ductile behavior and can absorb more energy before failure.
- Fiberglass rebar is not as fire-resistant as steel rebar. When exposed to high temperatures, fiberglass rebar can lose its strength and integrity, potentially compromising the structural integrity of the concrete member.
- The long-term performance of fiberglass rebar is still being investigated. There is less data available on its behavior over time compared to steel rebar, which has a long history of use in concrete structures.

IV. SCOPE OF FUTURE

1) Mechanical Properties Evaluation: Conducting comprehensive mechanical tests to determine the tensile strength, compressive strength, flexural strength, and shear strength of GFRP compared to traditional steel reinforcement. This includes examining how GFRP performs under different loading conditions, such as static, dynamic, and fatigue.

2) Durability and Longevity Studies: Investigating the long-term durability of GFRP in various environmental conditions, including exposure to moisture, UV radiation, chemicals, and temperature variations. Longevity studies can provide insights into the material's resistance to corrosion and degradation over time.

3) Fire Performance Assessment: Investigating the fire resistance of GFRP compared to steel reinforcement. Experimental studies can include fire testing to determine the material's behavior under fire conditions, its thermal insulation properties, and the potential for fire-induced spalling.

V. CONCLUSION

1) FRP bars, including CFRP and AFRP, enhance the design and reliability of concrete structures, improving safety and failure mode prediction, especially regarding shear and bond failure.

2) Locally produced GFRP bars perform similarly to commercial ones, showing promise in terms of fiber volume fraction, tensile strength, and elastic modulus for concrete reinforcement.

3) Failure modes of GFRP reinforced concrete depend on the reinforcement ratio, with excessive reinforcement leading to compression failure, while insufficient reinforcement causes GFRP rupture.

4) Due to FRP's lower modulus of elasticity, FRP-reinforced concrete structures tend to show smaller deflections and strains compared to steel-reinforced ones.

5) For optimal performance, the reinforcement ratio should be balanced. Too high or too low a ratio can cause issues such as GFRP rupture or compression failure.

6) GFRP bars show superior mechanical properties, including higher tensile strength and yield strain compared to traditional steel rebars, offering corrosion resistance and good flexural strength.

7) GFRP rebars offer significant cost savings (up to 30%) compared to steel, while maintaining superior shear and tensile strengths, making them ideal for modern construction.

8) Using CFRP jackets for retrofitting damaged concrete columns significantly improves their strength, ductility, and seismic resistance, particularly in cases of prior damage.

9) The incorporation of alkali-resistant glass fibers enhances the durability of concrete, improving resistance to acid attacks and reducing bleeding, especially in high-grade concrete.

10) The interaction between GFRP bars and concrete can significantly impact performance, with surface coatings like sand-coating improving bond performance and crack control in GFRP-reinforced beams.

These studies highlight the growing importance and application of advanced composite materials like GFRP and CFRP in enhancing the performance and durability of reinforced concrete structures.

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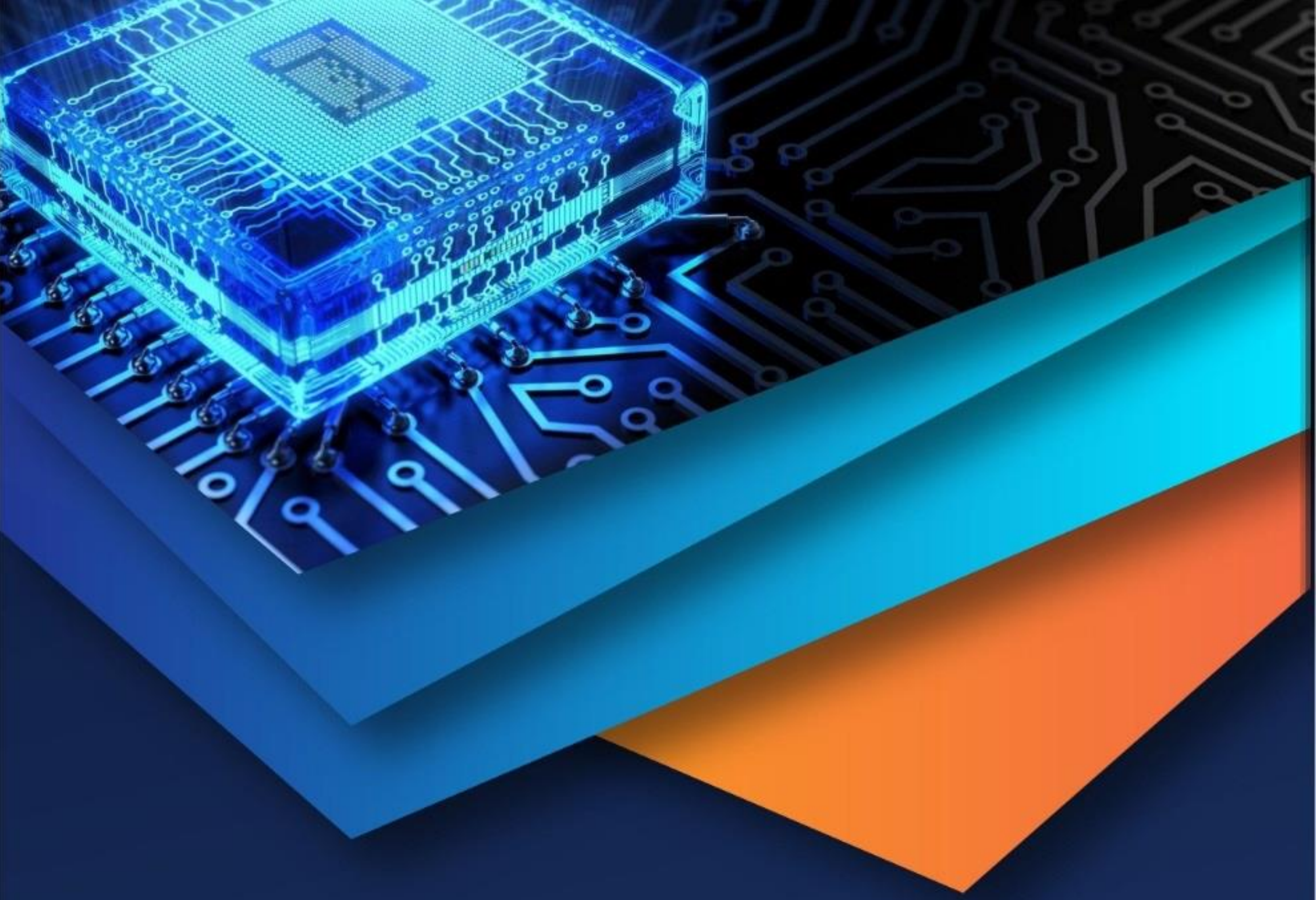

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