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A Review on Sustainable Bridge Construction Using Recycled Materials for Environmental Protection

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ABSTRACT: The rapid growth of industrialization, urbanization, and technological advancement has resulted in the large-scale generation of plastic and fiber-based waste materials, creating serious environmental challenges across the world. Fiber plastics, including fiberglass and reinforced plastic materials used in industries such as automotive manufacturing, construction, aerospace, and packaging, are non-biodegradable in nature and remain in the environment for long periods without decomposition. Improper disposal of these waste materials through landfilling or open dumping leads to soil contamination, water pollution, and ecological imbalance. In addition, the continuous extraction and consumption of natural resources for construction activities have further increased environmental degradation and resource depletion. Therefore, the effective reuse and recycling of fiber plastic waste have become essential for achieving sustainable environmental protection and waste management practices.

The construction industry offers significant potential for the utilization of recycled fiber plastic waste as an alternative material in concrete production and other civil engineering applications. The incorporation of recycled fiber plastics into concrete can reduce the excessive consumption of natural aggregates while simultaneously minimizing the environmental burden caused by plastic waste accumulation. Moreover, recycled fiber materials possess desirable engineering properties such as lightweight characteristics, chemical resistance, durability, and tensile strength, which can enhance the performance of construction materials when used in optimum proportions.

The present study aims to investigate the feasibility of reusing recycled fiber plastic waste in concrete for sustainable construction and environmental protection. Different percentages of recycled fiber plastic material will be incorporated as a partial replacement for conventional fine aggregate, and the performance of concrete will be evaluated through various mechanical and durability tests. Parameters such as workability, compressive strength, split tensile strength, flexural strength, and water absorption will be analyzed to determine the influence of fiber plastic content on concrete behavior. The study also focuses on identifying the optimum replacement percentage that provides improved structural performance while maintaining durability characteristics.

The reuse of fiber plastic waste in construction materials can significantly reduce environmental pollution, decrease landfill disposal, conserve natural resources, and promote sustainable waste management practices. Furthermore, the adoption of recycled fiber plastic materials in civil engineering applications supports the development of eco-friendly and economical construction techniques. Overall, the study is expected to contribute toward environmental protection by encouraging the effective utilization of non-biodegradable fiber plastic waste in sustainable infrastructure development.

Keywords: Coagulation, Natural coagulants, Moringa oleifera, Carica papaya, Solanum incanum, Acacia catechu, Strychnos potatorum, Abelmoschus esculentus, Surface water treatment.

I. INTRODUCTION

The continuous advancement of infrastructure projects, particularly in transportation facilities such as bridges, highways, and flyovers, has considerably increased the requirement for construction materials worldwide. Concrete is one of the most commonly utilized materials in bridge construction because of its superior strength, durability, workability, and ability to withstand heavy loads over long periods. As infrastructure development continues to expand, the consumption of conventional concrete materials has also increased rapidly. However, the manufacturing of traditional concrete largely depends on natural resources including river sand, cement, and coarse aggregates. The excessive extraction and processing of these resources have created serious environmental concerns and have negatively affected ecological balance.

Among these concerns, uncontrolled river sand mining has become a significant environmental issue in many regions. River sand is extensively used as fine aggregate in concrete, but its overexploitation leads to severe environmental problems such as riverbank erosion, depletion of groundwater levels, destruction of aquatic habitats, and disturbance of river ecosystems. In addition, excessive mining activities can alter the natural flow of rivers and increase the chances of flooding in nearby areas. Similarly, cement production releases a large amount of carbon dioxide into the atmosphere, which contributes to global warming and environmental pollution. These challenges have highlighted the urgent need for sustainable and environmentally responsible alternatives in the construction industry.

At the same time, rapid industrial growth and technological development have resulted in the generation of huge quantities of industrial waste materials that are non-biodegradable in nature. One such waste material is glass fiber waste, which is produced from industries related to fiberglass products, automobile manufacturing, aerospace components, and wind energy systems. Since glass fibers do not decompose naturally, their disposal in landfills creates long-term environmental and waste management problems. The increasing accumulation of industrial waste has encouraged researchers to identify effective methods for recycling and reusing such materials in construction applications.

The concept of sustainable construction focuses on minimizing environmental impacts while maintaining structural performance, durability, and economic efficiency. In recent years, researchers have paid significant attention to the use of recycled and waste materials in concrete production as substitutes for conventional ingredients. Materials such as fly ash, silica fume, blast furnace slag, recycled aggregates, and waste fibers have been widely studied for their potential to improve sustainability in the construction sector. The use of these materials not only reduces environmental pollution but also helps conserve valuable natural resources.

Among the various recycled materials available, waste glass fibers have emerged as a promising alternative because of their high tensile strength, durability, lightweight properties, and resistance to chemical attack. The inclusion of glass fibers in concrete has been found to enhance tensile strength, reduce cracking, and improve the overall durability of concrete structures. Although many studies have investigated glass fibers as reinforcing materials, limited research has been conducted on their use as a partial replacement for fine aggregate. Therefore, utilizing recycled glass fibers in place of natural sand represents an innovative and sustainable approach in concrete technology.

The present research investigates the feasibility of using recycled waste glass fibers as a partial replacement for fine aggregate in M40 grade concrete, which is widely used in bridge construction due to its high strength requirements. The study examines different replacement percentages of 2%, 4%, 6%, 8%, and 10% to evaluate their effects on the mechanical and durability properties of concrete. The results obtained from these mixes are compared with conventional concrete to determine the optimum replacement level that provides the best performance.

The significance of this study lies in its potential to solve two major environmental problems simultaneously by reducing the excessive use of natural river sand and promoting the utilization of industrial glass fiber waste. The incorporation of recycled glass fibers into concrete contributes to sustainable waste management practices and supports the development of environmentally friendly construction materials. Furthermore, the adoption of such sustainable materials in bridge construction can help reduce the overall environmental impact of infrastructure projects.

In conclusion, this research aims to develop an eco-friendly, economical, and practical solution for sustainable bridge construction. The findings of the study are expected to encourage the use of recycled industrial waste materials in the construction industry while ensuring adequate structural strength, durability, and long-term performance of bridge infrastructure.

II. LITERATURE REVIEW

1] Silva et al. (2019) demonstrate that replacing natural aggregates with construction and demolition waste offers a viable path for sustainable concrete production. Their investigation reveals that concrete maintains stable compressive strength at moderate replacement levels of 20% to 30%. However, exceeding this optimum range increases material porosity and water absorption while reducing overall durability. The study identifies the porous adhered old mortar on the recycled aggregates as the primary cause of this structural decline. Ultimately, the research establishes clear boundary limits for recycled aggregate concrete, proving that precise replacement ratios are essential to balance environmental benefits with structural integrity.

2] Tam et al. (2020) critical review demonstrates that incorporating construction and demolition (C&D) waste into concrete production offers a viable pathway toward sustainable construction. By diverting debris from landfills and reducing the consumption of virgin gravel, this practice substantially lowers the carbon footprint of structural projects. Although recycled aggregates inherently possess higher porosity and water absorption, the study confirms that proper mix proportioning mitigates these deficiencies.

Consequently, the resulting recycled aggregate concrete achieves satisfactory compressive and tensile strength. This foundational research validates eco-friendly concrete alternatives, proving that strategic engineering can successfully balance environmental preservation with rigorous structural performance standards.

3] Akhtar and Sarmah (2019) highlights how utilizing recycled construction waste in concrete production boosts environmental and mechanical performance. Focusing on sustainability indicators, the study reveals that this practice significantly minimizes energy consumption, lowers carbon footprints, and diverts debris from landfills. By reducing raw material extraction and processing, the use of recycled aggregates substantially cuts greenhouse gas emissions. Furthermore, the authors prove that carefully optimized mix proportions allow recycled aggregate concrete to maintain satisfactory durability and compressive strength. These environmental and structural advantages become exceptionally impactful when implemented in high-volume, large-scale infrastructure projects

4] Kisku et al. (2020) conducted experimental assessments on sustainable concrete to determine the impact of varying substitution levels on its physical properties. Findings demonstrate that integrity in terms of elasticity, tension, and compression is maintained when traditional ingredients are replaced at rates between 30% and 40%. Because recycled elements often possess high porosity, the researchers suggest adjusting liquid-to-binder proportions and utilizing specific chemical admixtures. Micro-level analysis confirms that these technical adjustments improve the interfacial transition zones. Such refinements strengthen the bond between aggregates, ensuring the environmentally friendly composite achieves the durability required to satisfy established engineering standards.

5] Fiore et al. (2019) examines how integrating recycled glass fiber reinforced polymer (GFRP) scraps alters the structural performance of concrete mixtures. This laboratory assessment focuses heavily on tensile capabilities, fracturing characteristics, and ultimate failure modes. The data indicates that adding this processed industrial byproduct substantially enhances tensile resistance. This upgrade stems from an internal bridging mechanism where the embedded glass filaments intercept micro-cracks, effectively stopping rapid fracture development. Ultimately, the paper proves that repurposing composite waste serves as an internal reinforcing agent, increasing fracture toughness while offering a sustainable disposal strategy for manufacturing debris.

6] Correia et al. (2021) investigate how utilizing salvaged fiber-reinforced polymer (FRP) composites, particularly glass filaments, enhances the structural behavior of building materials. Their evaluation centers on energy dissipation, fracturing characteristics, and deformation capacity under mechanical stress. The data reveals that integrating these recycled fibers substantially increases ductile performance and fracture toughness, mitigating sudden, brittle collapse. By intercepting internal fissures, the embedded fibers postpone crack development, ensuring a gradual failure mechanism. Additionally, the authors note that this reinforcement restricts crack widening and minimizes fluid permeability, which significantly improves the long-term durability of the concrete matrix.

7] Asokan et al. (2020) evaluate the viability of repurposing industrial glass fiber reinforced polymer scraps as filler components within cement-based mixtures. Their research highlights specific mechanical processing operations, including grinding and shredding, required to transform these composite residues into viable additives. The laboratory outcomes demonstrate that finely milled byproduct powder can partially substitute standard ingredients without compromising overall compressive capabilities. Nevertheless, the authors emphasize that structural success relies heavily on particle geometry, sizing, and distribution. Inadequate refining causes high porosity and weak internal adhesion, meaning thorough size reduction and surface modifications are vital for achieving uniform matrix dispersion.

8] Zhang et al. (2022) examine the post-fracture durability and energy dissipation of concrete containing salvaged glass filaments through tensile and flexural testing. Their investigation demonstrates that these recycled fibers significantly boost structural performance after initial cracking, enabling the material to sustain stress post-splitting. This toughness and impact resistance stem from fiber bridging and pull-out mechanisms that effectively absorb mechanical energy. Simultaneously, growing concerns over depleted natural sand resources have shifted scholarly attention toward fine aggregate alternatives. Researchers are widely evaluating options like quarry dust, industrial byproducts, and waste glass as partial substitutes to mitigate this environmental shortage.

9] Aliabdo et al. (2019) assess how substituting natural sand with waste glass powder alters concrete performance, specifically analyzing workability, durability, and compressive properties. Their findings reveal that a 20% substitution effectively preserves structural integrity. This optimal performance relies on the pozzolanic reactivity of fine glass, which yields extra calcium silicate hydrate (C–S–H) gel to densify particle packing and minimize porosity. However, surpassing this threshold causes strength degradation. The researchers attribute this decline to heightened material brittleness and an elevated risk of destructive alkali-silica reactions, establishing clear operational limits for glass powder integration.

10] Kumar and Kumar (2021) evaluate how substituting natural sand with diverse industrial manufacturing byproducts affects the longevity and mechanical integrity of concrete composites. Their research assesses crucial performance parameters, including fluid absorption, compressive thresholds, and resistance to environmental weathering.

The empirical data reveals that partial fine aggregate replacement successfully limits matrix permeability and elevates protection against chemical degradation while preserving acceptable compressive capacities. The authors attribute these structural enhancements to optimized particle packing, wherein the ultra-fine waste particulates efficiently seal internal voids. Consequently, their study confirms that repurposing factory residues densifies concrete microstructures, bolstering resistance to harsh conditions.

11] Oliveira et al. (2020) analyze how adding salvaged glass filaments modifies concrete performance, focusing heavily on fluid consistency, tensile resistance, and compressive thresholds. By testing diverse fiber volumes, their research determines how these composites change material behavior. The empirical data reveals that fiber integration significantly boosts tensile capacity and fracture resistance, because the internal bridging action restricts crack expansion. Nevertheless, the study highlights critical operational drawbacks at higher dosing levels. Elevating the fiber content drastically reduces fresh mix workability, as the dense filaments mechanically interlock and obstruct fluid flow, establishing distinct limits for optimal mixture design.

12] Sadrmomtazi et al. (2019) assess how varying glass filament proportions modify concrete's structural behavior, focusing on split-tensile and flexural properties. Their testing reveals that fiber integration significantly boosts bending and tensile capabilities. This improvement relies on an internal bridging effect, where filaments span micro-fissures to stall fracture growth, enhancing overall toughness and energy dissipation. Additionally, the researchers note a shift toward a ductile failure pattern, confirming that fiber-reinforced matrices resist sudden, brittle collapse far better than standard mixtures.

13] Gencel et al. (2021) analyze how diverse fiber additions, notably glass filaments, modify concrete's longevity and structural response under varied stress conditions. Their research tracks parameters like impact toughness, energy dissipation, and deformation capacity. Results show that fiber integration significantly elevates impact resistance and ductility, allowing the composite to absorb greater mechanical energy before collapsing. By dispersing internal stress uniformly, the fibers prevent sudden, catastrophic breaking. Consequently, the study validates that this internal reinforcement results in a highly controlled, gradual fracture progression.

14] Bashir et al. (2020) evaluate how altering glass filament concentrations modifies both the fresh consistency and hardened compressive capabilities of concrete mixtures. Their laboratory work involved casting diverse batches with distinct fiber percentages to systematically measure changes in material behavior. By tracking these specific variations, the study establishes clear correlations between fiber dosing and structural outcomes, helping engineers optimize mixture designs. This empirical data serves to balance fluid performance during pouring with ultimate load-bearing capacities in cured structural applications.

15] Zhao et al. (2023) execute an exhaustive analysis targeting the ideal volumetric proportions of fibers within reinforced concrete to secure balanced mechanical properties. Their investigation systematically checks how varying fiber volume fractions alter fundamental parameters, specifically examining split-tensile capacity, durability, and compressive strength. By mapping these specific variables, the researchers isolate the exact threshold where fiber additions provide maximum reinforcement benefits without triggering material degradation. Consequently, this study establishes a vital engineering blueprint for balancing fluid mixture workability with robust hardened properties in structural concrete.

16] Pacheco-Torgal et al. (2020) investigated how embedding fibers impacts fresh concrete, focusing heavily on workability. Their research demonstrated that fiber integration severely restricts flowability by raising internal friction and total surface area. Consequently, construction teams face major obstacles during mixing, placement, and consolidation. To mitigate these issues, the researchers recommended utilizing chemical agents like superplasticizers. These additives enhance fluid movement without disrupting the critical water-to-cement ratio. Ultimately, precise adjustments to the mix proportions remain vital to guarantee optimal installation ease and structural integrity.

17] Gonçalves et al. (2021) examined how varying fiber volumes alter wet concrete characteristics. Their experimental data proved that slump values decrease steadily as fiber content increases. This trend happens because interlocking fibers create an internal network that restricts aggregate movement. Consequently, excessive fiber dosages hinder proper compaction, raising the risk of internal void formation. The authors concluded that strictly regulating fiber amounts and utilizing proper chemical admixtures are vital steps. Additionally, integrating glass fibers offers a promising solution for enhancing long-term material durability.

18] Fiore et al. (2019) analyzed the mechanical durability of concrete enhanced with glass fibers. Their findings revealed that adding these fibers markedly increases cracking resistance by bridging internal micro-cracks and halting their expansion. This structural control drastically lowers concrete permeability, which directly boosts its overall service life. Additionally, the refined microstructure provides superior defense against harsh environmental degradation. The researchers determined that glass fibers offer exceptional efficiency in extending concrete durability, particularly for engineering projects where preventing structural cracks is a major priority.

19] Zhang et al. (2022) evaluated the durability of concrete enhanced with recycled glass fibers, specifically targeting performance in hostile environments. The investigations revealed that fiber integration significantly fortifies the matrix against chemical degradation and freeze-thaw cycles. This enhanced resistance stems from a highly densified internal microstructure and mitigated micro-cracking, which collectively obstruct the permeation of aggressive moisture and deleterious agents. Furthermore, the reinforcing fibers preserve overall structural stability when subjected to cyclic loading and environmental fatigue. Consequently, the researchers concluded that this sustainable material is exceptionally viable for critical infrastructure projects, such as bridges, requiring long-term resilience.

20] evaluated the mechanical and environmental ramifications of integrating industrial waste byproducts into cementitious matrices. By analyzing key sustainability parameters—including carbon emissions, energy footprints, and waste diversion—the researchers determined that substituting conventional constituents with recycled industrial waste substantially mitigates greenhouse gases. This ecological benefit arises from reducing the necessity for raw material extraction, processing, and transportation. Furthermore, diminishing the reliance on virgin resources markedly lowers production energy requirements. The authors concluded that incorporating industrial waste serves as a potent strategy for achieving sustainable infrastructure development without compromising essential mechanical performance.

21] Kisku et al. (2020) investigated the environmental and structural performance of recycled aggregate concrete by analyzing parameters such as resource conservation, energy efficiency, and mechanical properties. The study demonstrated that the use of recycled materials in concrete production substantially lowers the environmental footprint of construction activities by reducing the demand for natural aggregates and minimizing waste disposal. Furthermore, the research indicated that with proper mix design, recycled aggregate concrete can achieve comparable strength and durability to conventional concrete. The authors concluded that recycled material usage not only supports sustainable construction practices but also contributes to long-term environmental conservation.

22] Correia et al. (2021) explored the recycling potential of glass fiber reinforced polymer (GFRP) waste and its application in construction materials. The study highlighted the growing concern of GFRP waste accumulation in landfills due to its non-biodegradable nature. By incorporating recycled GFRP waste into concrete and other construction materials, the research demonstrated a significant reduction in landfill burden. The authors emphasized that such recycling practices support the principles of the circular economy, where waste materials are reused as valuable resources. The study concluded that recycling GFRP waste not only mitigates environmental pollution but also promotes sustainable material management in the construction industry.

III. METHODOLOGY

This section presents the detailed experimental methodology adopted to evaluate the performance of M40 grade concrete incorporating recycled waste glass fibers as a partial replacement for fine aggregate. The methodology includes material selection, processing of recycled glass fibers, mix design procedure, specimen preparation, curing, and testing methods. The experimental program was designed in accordance with relevant Indian Standards to ensure reliability and reproducibility of results.

This section is systematically divided into several sections, each addressing a specific component of the research methodology. The initial section describes the materials used in the study, including cement, aggregates, water, and recycled waste glass fibers. Then it outlines the mix design proportions and details the experimental procedures followed for specimen preparation, casting, curing, and testing.

Subsequently, the section presents a detailed description of the various experimental tests conducted to evaluate the performance of the concrete mixes in terms of mechanical properties, durability, and environmental aspects. Finally, the methods adopted for data analysis and interpretation of results are explained, providing a clear basis for understanding the experimental outcomes.

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FLOWCHART

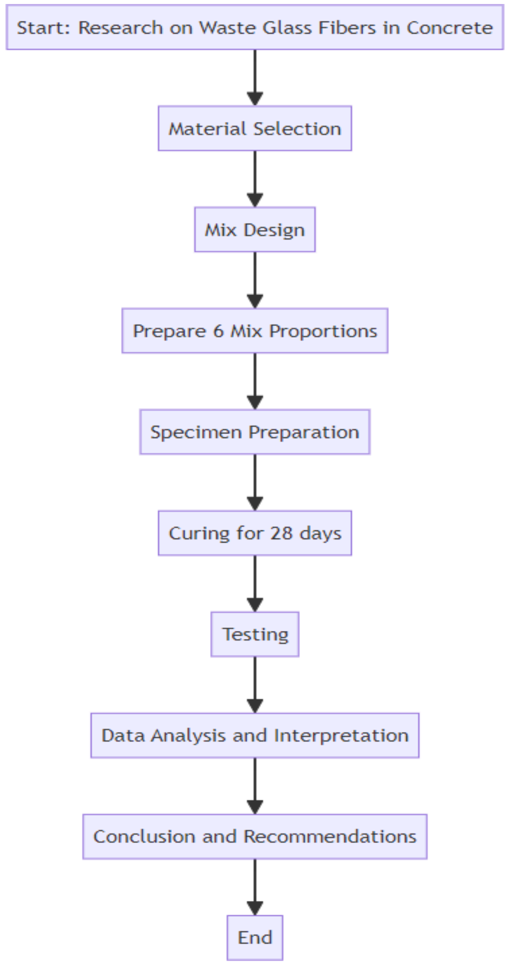

Fig. 1 shows the Flowchart of Proposed System

IV. SYSTEM REQUIREMENT

MATERIALS USED
1] Cement
2] Fine Aggregate (Sand)
3] Coarse Aggregate
4] Recycled Waste Glass Fibers
5] Water

V. RESULT

The mechanical characteristics of concrete improve significantly when supplemented with recycled glass fibers up to a specific limit, after which structural integrity declines. Investigations indicate that an optimal substitution threshold of approximately 4% to 6% establishes a superior equilibrium among compound workability, material strength, and long-term durability. This data substantiates that post-consumer glass fibers can serve as an efficient, sustainable component within concrete mixtures. Consequently, this engineering approach advances industrial resource preservation and landfill diversion efforts without reducing the expected load-bearing capacity of the cured structural elements

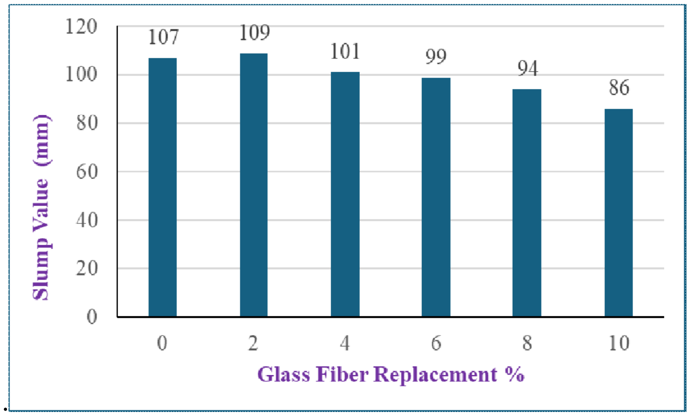

Fig. 2 shows the Slump Value of Conventional Concrete and Modified Concrete

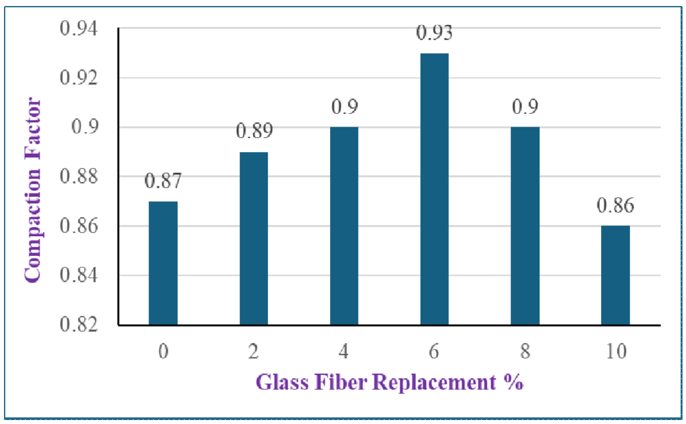

Fig. 3 shows the Compaction Factor of Concrete Mix

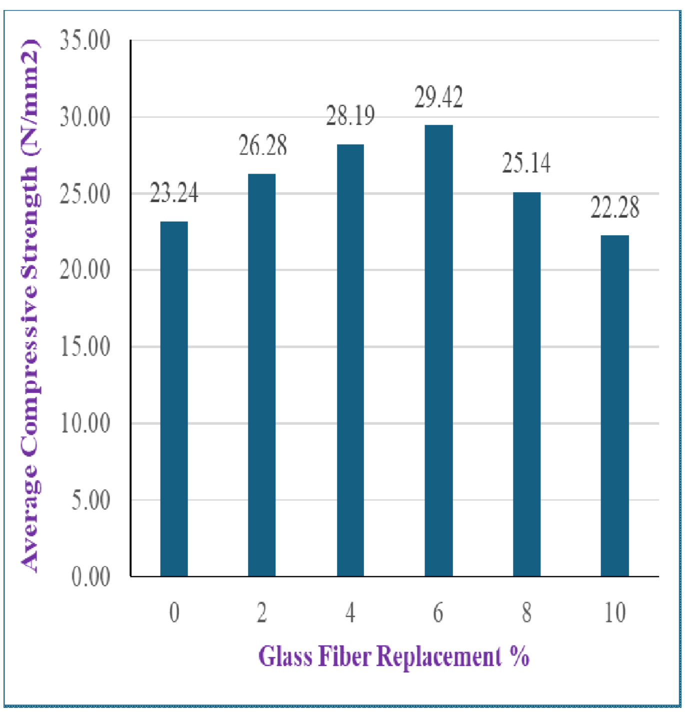

Fig. 4 shows the Representation of Compressive Strength at 7 Days Curing Period

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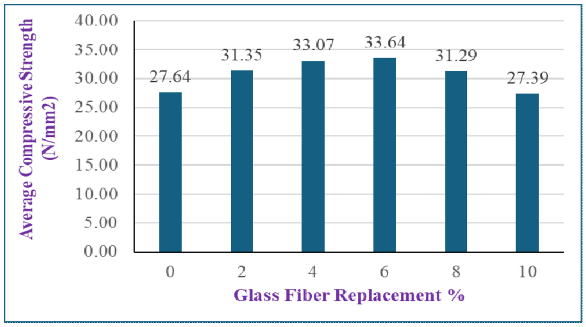


Fig. 5 shows the Representation of Compressive Strength at 14 Days Curing Period

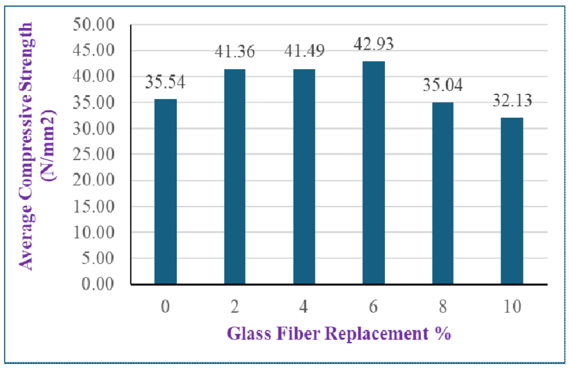
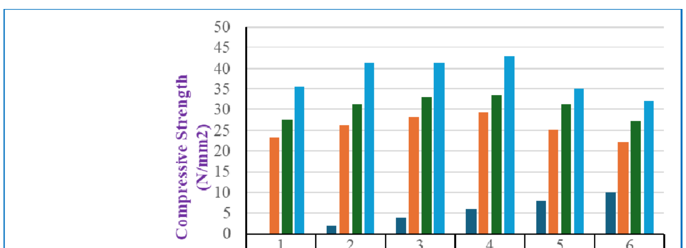


Fig. 6 shows the Representation of Compressive Strength at 28 Days Curing Period



	1	2	3	4	5	6
Glass Fiber Replacement %	0	2	4	6	8	10
Average Compressive Strength (N/mm2) 7 Days	23.24	26.28	28.19	29.42	25.14	22.28
Average Compressive Strength (N/mm2) 14 Days	27.64	31.35	33.07	33.64	31.29	27.39
Average Compressive Strength (N/mm2) 28 Days	35.54	41.36	41.49	42.93	35.04	32.13

Fig. 7 shows the Representation Comparative Analysis of Compressive Strength

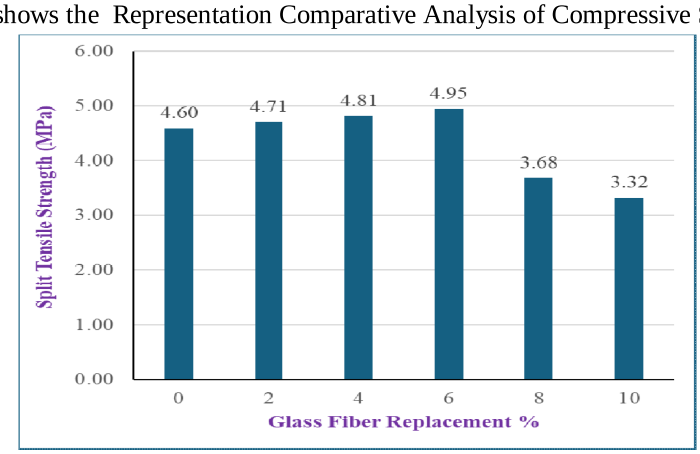


Fig. 8 shows the Representation of Split Tensile Strength at 7 Days Curing Period

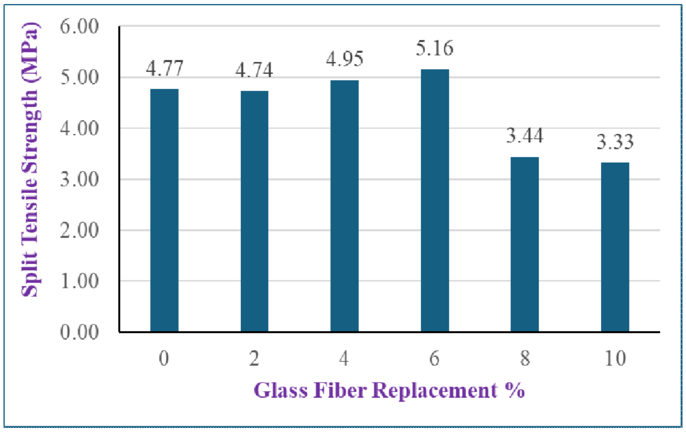


Fig. 9 shows the Representation of Split Tensile Strength at 14 Days Curing Period

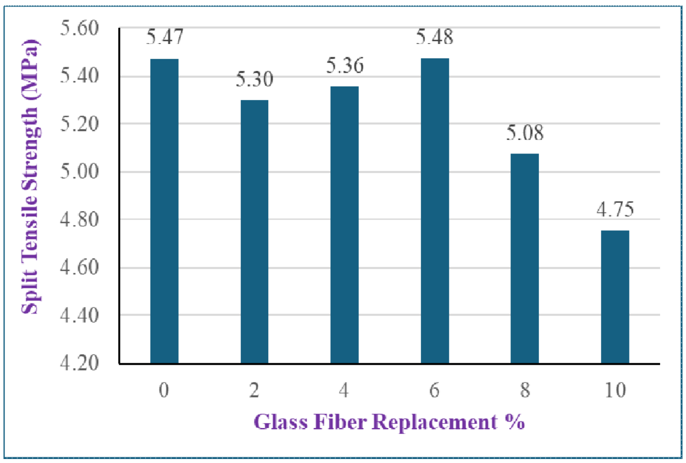
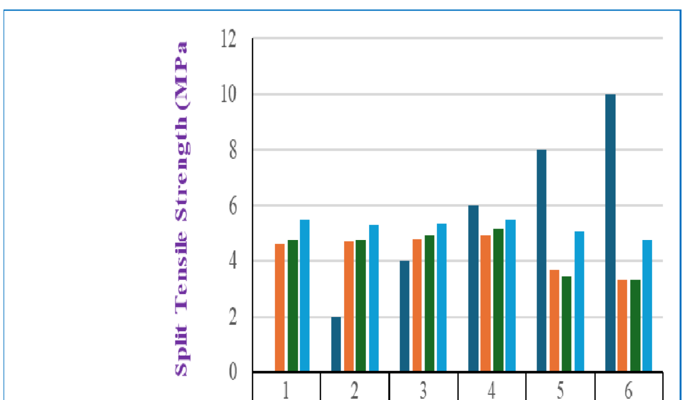


Fig. 10 shows the Representation of Split Tensile Strength at 28 Days Curing Period



	1	2	3	4	5	6
Glass Fiber Replacement %	0	2	4	6	8	10
Split Tensile Strength (MPa) 7 Days	4.60	4.71	4.81	4.95	3.68	3.32
Split Tensile Strength (MPa) 14 Days	4.77	4.74	4.95	5.16	3.44	3.33
Split Tensile Strength (MPa) 28 Days	5.47	5.30	5.36	5.48	5.08	4.75

Fig. 11 shows the Representation of Comparative Analysis of Split Tensile Strength

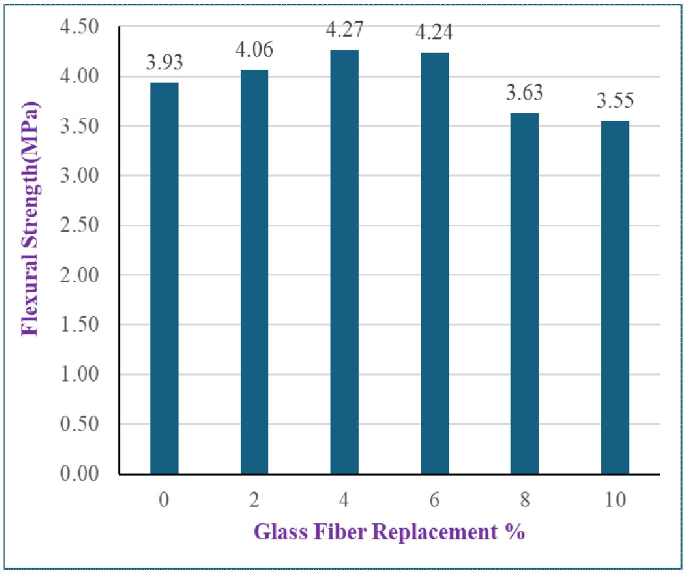


Fig. 12 shows the Representation of Flexural Strength at 7 Days Curing Period

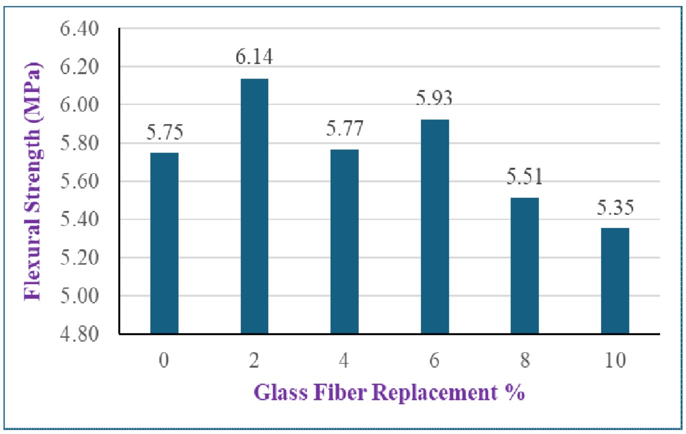


Fig. 13 shows the Representation of Flexural Strength at 14 Days Curing Period

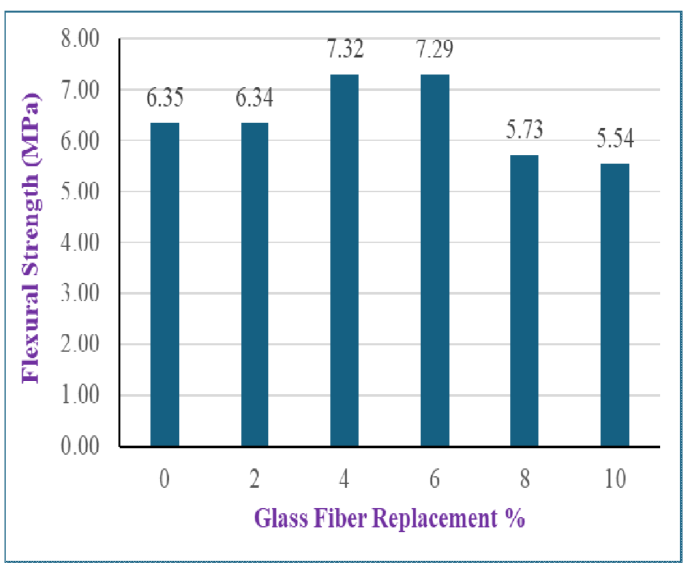


Fig. 14 shows the Representation of Flexural Strength at 28 Days Curing Period

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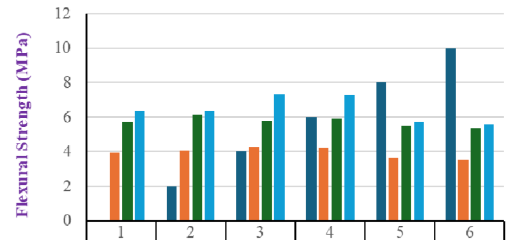

	1	2	3	4	5	6
Glass Fiber Replacement %	0	2	4	6	8	10
Flexural Strength (MPa) 7 Days	3.93	4.06	4.27	4.24	3.63	3.55
Flexural Strength (MPa) 14 Days	5.75	6.14	5.77	5.93	5.51	5.35
Flexural Strength (MPa) 28 Days	6.35	6.34	7.32	7.29	5.73	5.54

Fig. 15 shows the Representation of Comparative Analysis of Flexural Strength

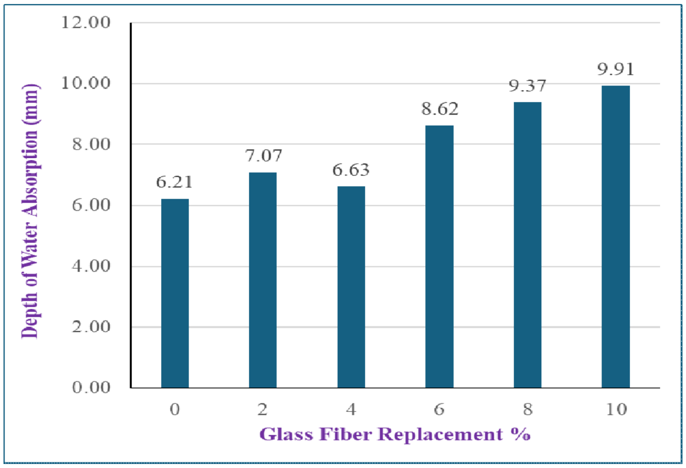

Fig. 16 shows the Representation of Depth of Water Absorption at 7 Days Curing Period

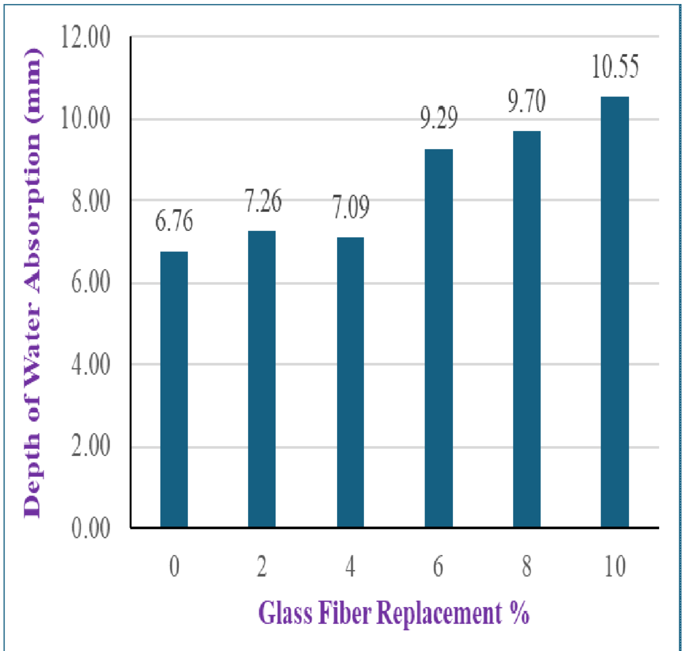

Fig. 17 shows the Representation of Depth of Water Absorption at 14 Days Curing

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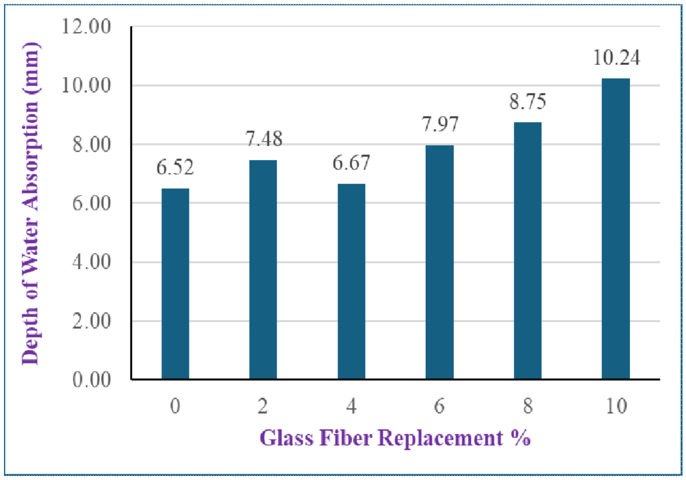
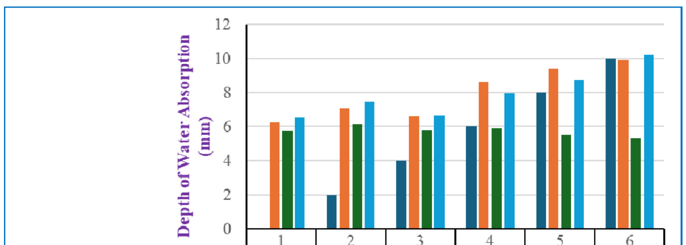


Fig. 18 shows the Representation of Depth of Water Absorption at 28 Days Curing



	1	2	3	4	5	6
Glass Fiber Replacement %	0	2	4	6	8	10
Depth of Water Absorption (mm) 7 Days	6.21	7.07	6.63	8.62	9.37	9.91
Depth of Water Absorption (mm) 14 Days	5.75	6.14	5.77	5.93	5.51	5.35
Depth of Water Absorption (mm) 28 Days	6.52	7.48	6.67	7.97	8.75	10.24

Fig. 19 shows the Representation of Comparative Analysis of Depth of Water Absorption

VI. CONCLUSION

The present investigation focused on evaluating the feasibility and effectiveness of utilizing recycled glass fibers as a partial replacement for fine aggregate in M40 grade concrete at varying replacement levels ranging from 0% to 10%. The study primarily aimed to examine the influence of recycled glass fibers on the fresh, mechanical, and durability properties of concrete in order to determine the optimum replacement percentage suitable for sustainable bridge construction applications. Experimental observations indicated that the incorporation of recycled glass fibers had a significant impact on the overall performance characteristics of concrete, with both beneficial and adverse effects depending upon the percentage of replacement adopted.

The workability characteristics of concrete were assessed through the slump cone test, and the results demonstrated that a lower percentage of recycled glass fiber replacement slightly enhanced the flowability of the concrete mix. The slump value increased marginally from 107 mm for conventional concrete to 109 mm at 2% replacement, indicating improved particle distribution and better consistency at lower fiber content. However, as the replacement percentage increased beyond this level, a continuous reduction in workability was observed. The slump values gradually decreased to 101 mm at 4%, 99 mm at 6%, 94 mm at 8%, and 86 mm at 10% replacement. This decline in workability was mainly attributed to the increased surface area of fibers, higher internal friction among particles, and fiber interlocking effects, which reduced the ease of mixing, handling, and placement of concrete.

The mechanical performance of concrete exhibited notable improvement up to an optimum replacement range of approximately 4%–6%. The maximum 28-day compressive strength of 42.93 MPa was achieved at 6% replacement compared to 35.54 MPa for the control mix, representing a significant increase in strength. Similarly, split tensile and flexural strength values also demonstrated considerable enhancement within the same replacement range due to the crack-bridging mechanism and improved bonding characteristics provided by the glass fibers. The highest flexural strength of 7.32 MPa was recorded at 4% replacement, while optimum split tensile performance was observed at 6% replacement.

Nevertheless, replacement levels exceeding the optimum limit resulted in a noticeable reduction in strength properties because of poor workability, non-uniform fiber dispersion, increased void formation, and fiber agglomeration within the concrete matrix.
From a durability perspective, the study revealed that the depth of water absorption increased progressively with higher glass fiber content, indicating greater permeability and porosity in the concrete. Excessive fiber incorporation adversely affected the resistance of concrete against water ingress, thereby reducing its long-term durability characteristics. Based on the overall experimental findings, the study concluded that recycled glass fibers can be effectively utilized as a sustainable partial replacement for fine aggregate in M40 grade concrete up to an optimum replacement level of 4%–6%, where improved mechanical performance and acceptable durability characteristics can be achieved simultaneously.

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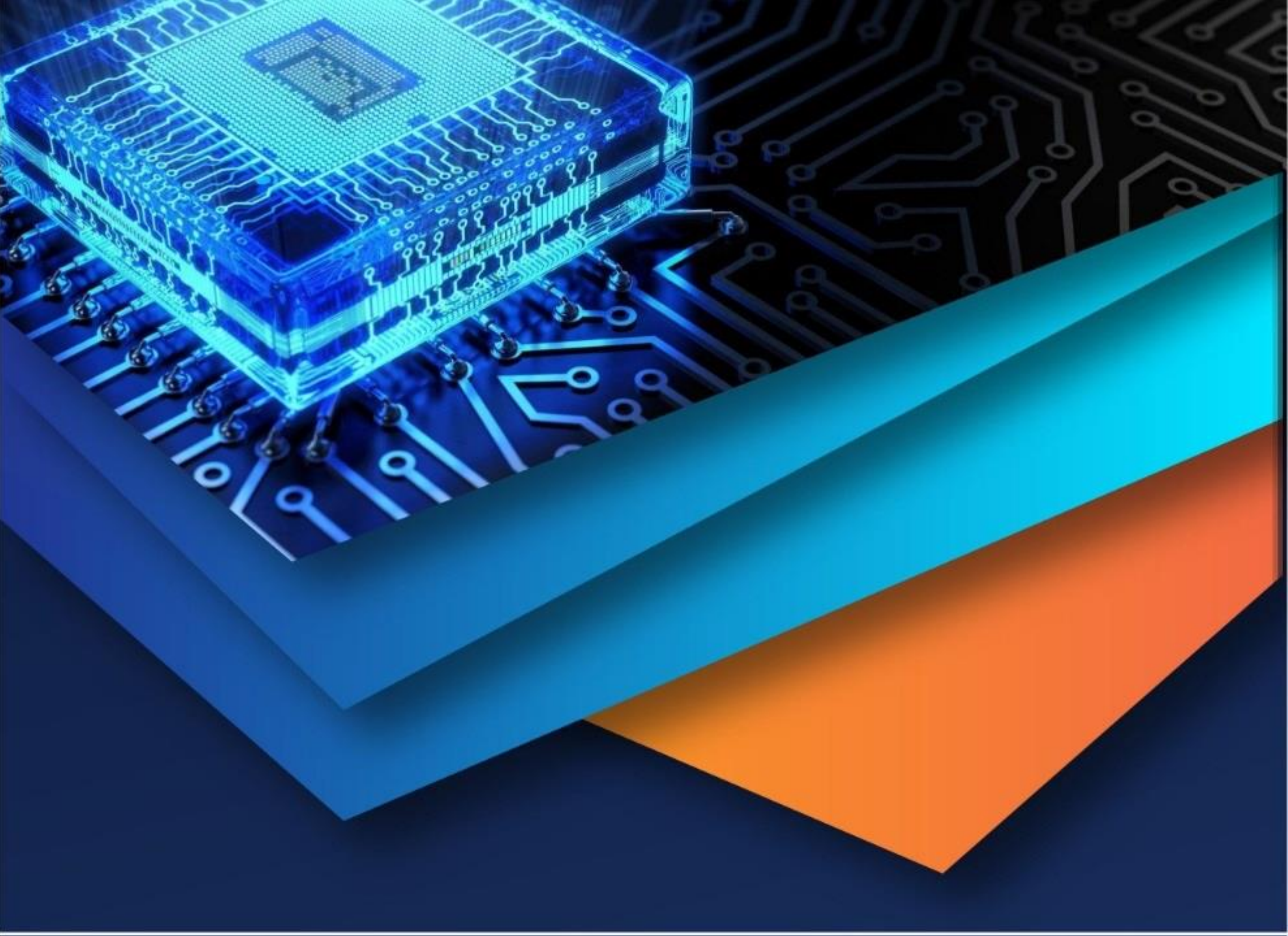

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