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Research on Sustainable Bridge Construction Using Recycled Materials for Environmental Protection

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Abstract - Surface water contains lots of dissolved impurities by the natural mixing of sewage wastewater, industrial effluent and runoff water, whereas ground and ground water were polluted due to the salt water intrusion and percolation of leachates through waste dumping. Reports indicate that 90% of water in India is polluted; it may not be an overstatement that most of the surface water in developing countries remains suspicious in terms of quality. The rising prevalence of endemic diseases such as diarrhoea, dysentery, amoebiasis, hepatitis, typhoid, and jaundice could indicate a high level of exposure to negative human consequences. The simplest method for water treatment is coagulation with coagulants. Chemical coagulants are frequently used for the treatment of water. Long time use of chemical coagulants causes carcinogenic diseases and water pollution. The residual part of the chemical affects metabolism of aquatic creatures. Sludge disposal of chemically treated water is also a big issue because it is non-biodegradable, toxic and harmful for human health in this method. Minimization of the above problem may be possible through use of natural plant based coagulants.

The proposed study deals to investigate potential of plant based coagulants for the treatment of wastewater. The characteristics of water sample from the river will checked in the laboratory such as pH, TDS, turbidity, etc. and natural plants should be used as an organic coagulant such as Moringa oleifera (drumstick seed), Carica papaya (papaya seed), Abelmoschus esculentus (okra seed), Solanum incanum (wild brinjal seed) and Strychnos potatorum (clearing nut seed) due to presence of polymeric polyelectrolyte. They are also environmentally suitable, non toxic biodegradable, cost effective and safe for human health. Quantity of coagulant doses optimized experimentally by Jar test apparatus. Identification and characterization of functional groups present in natural coagulants will be analyzed. Removal efficiency of turbidity and TDS will be analyzed for various doses of each coagulant. among all coagulants. Change in pH value will also be observed, by adding a coagulant dose in the water sample.

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

INTRODUCTION

The rapid expansion of infrastructure development, particularly in transportation networks, has led to a substantial increase in the demand for construction materials. Among these, concrete remains the most widely used material in bridge construction due to its strength, durability, and versatility. However, conventional concrete production relies heavily on natural resources such as river sand, coarse aggregates, and cement, the extraction and processing of which have significant environmental consequences. Excessive sand mining, in particular, has emerged as a critical issue, causing riverbank erosion, loss of aquatic ecosystems, and depletion of groundwater resources.

In parallel with resource depletion, industrialization has resulted in the generation of large quantities of non-biodegradable waste materials, including glass fiber waste from industries such as fiberglass manufacturing, automotive components, and wind energy sectors. These materials are often disposed of in landfills, posing long-term environmental challenges due to their resistance to degradation. The dual problem of natural resource scarcity and waste accumulation necessitates the development of sustainable alternatives in construction practices.

Sustainable construction aims to minimize environmental impact while maintaining structural performance and economic feasibility. One of the most promising approaches in this field is the utilization of recycled materials as partial or full replacements for conventional concrete constituents. In recent years, significant attention has been directed toward incorporating waste materials such as fly ash, slag, recycled aggregates, and fibers into concrete to enhance both sustainability and performance.

Among these alternatives, recycled glass fibers have shown considerable potential due to their high tensile strength, durability, and resistance to chemical attack. When incorporated into concrete, glass fibers can improve crack resistance, tensile strength, and overall durability. While most studies have focused on the use of glass fibers as reinforcement, their application as a replacement for fine aggregate remains relatively unexplored and presents an innovative approach to material substitution.

This study focuses on the experimental investigation of using recycled waste glass fibers as a partial replacement for fine aggregate

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in M40 grade concrete, which is commonly used in bridge construction. The research evaluates the performance of concrete with varying replacement levels of 2%, 4%, 6%, 8% and 10%, and compares the results with conventional concrete to determine the optimum mix.

The significance of this study lies in its potential to address two major environmental concerns simultaneously: reducing the consumption of natural sand and promoting the reuse of industrial waste. By integrating recycled glass fibers into concrete, the study contributes to the development of eco-friendly construction materials and supports the transition toward sustainable bridge construction practices.

Overall, this research aims to provide a practical and environmentally responsible solution that aligns with modern sustainability goals while ensuring the structural integrity and performance required for bridge infrastructure.

II. LITERATURE REVIEW

1] Silva et al. (2019) conducted an extensive investigation on the performance of recycled aggregate concrete (RAC) by replacing natural aggregates with recycled aggregates obtained from construction and demolition waste. The study evaluated key properties such as compressive strength, durability, and microstructural characteristics. Their findings indicated that recycled aggregates can effectively replace natural aggregates up to a moderate percentage (typically 20–30%) without causing significant reduction in compressive strength. However, higher replacement levels were associated with increased porosity and reduced durability due to the presence of adhered mortar on recycled aggregates.

2] Tam et al. (2020) presented a comprehensive review of the use of construction and demolition (C&D) waste in concrete production, focusing on sustainability and material performance. The study highlighted that the reuse of C&D waste significantly reduces environmental impacts by minimizing landfill disposal and conserving natural resources. Experimental findings from various case studies showed that recycled aggregate concrete exhibits acceptable mechanical properties when properly designed.

3] Akhtar and Sarmah (2019) investigated the environmental and mechanical performance of concrete incorporating recycled construction waste materials. Their study focused on evaluating sustainability indicators such as carbon footprint reduction, energy consumption, and waste diversion from landfills. The results demonstrated that the use of recycled aggregates significantly reduces greenhouse gas emissions associated with raw material extraction and processing. In addition to environmental benefits, the study found that recycled aggregate concrete can achieve satisfactory compressive strength and durability when appropriate mix proportions are used. The authors emphasized that the environmental advantages are particularly significant in large-scale infrastructure projects where material consumption is high.

4] Kisku et al. (2020) conducted an experimental study to evaluate the mechanical properties of recycled aggregate concrete with varying replacement levels of natural aggregates. The research focused on compressive strength, tensile strength, and modulus of elasticity. The results indicated that recycled aggregate concrete can achieve performance comparable to conventional concrete, particularly at lower replacement levels (up to 30–40%). The study also highlighted that proper mix design adjustments, such as controlling water-cement ratio and using admixtures, can compensate for the strength of recycled aggregates, such as higher water absorption. Microstructural analysis revealed that improved interfacial transition zones contribute to better bonding and strength development.

5] Fiore et al. (2019) conducted an experimental investigation on the reuse of glass fiber reinforced polymer (GFRP) waste in concrete, focusing on its influence on mechanical properties, particularly tensile behavior. The study involved incorporating processed GFRP waste into concrete mixes and evaluating parameters such as tensile strength, crack propagation, and failure patterns. The results showed a significant improvement in tensile strength due to the fiber bridging mechanism, where glass fibers act as crack arresters and prevent sudden crack propagation.

6] Correia et al. (2021) explored the recycling of fiber-reinforced polymer (FRP) composites, including glass fibers, for use in construction materials. Their research emphasized the mechanical performance and structural behavior of concrete incorporating recycled glass fibers. The findings revealed that the addition of recycled glass fibers significantly enhances crack resistance and ductility, making the concrete more resistant to brittle failure. The study demonstrated that fibers improve the energy absorption capacity of concrete by delaying crack initiation and propagation underloading. This results in a more gradual failure mechanism compared to conventional concrete. Additionally, the authors highlighted that recycled fibers contribute to improved durability by reducing crack widths and permeability.

7] Asokan et al. (2020) investigated the feasibility of utilizing composite waste, particularly GFRP waste, as a filler material in cementitious composites. The study focused on processing techniques such as shredding and grinding to convert composite waste into usable forms. The experimental results indicated that finely processed composite waste can be successfully incorporated into concrete as a partial replacement material without significantly affecting compressive strength. However, the study emphasized that the performance of such materials is highly dependent on particle size, shape, and distribution. Improper processing can lead to poor bonding, increased voids, and reduced mechanical performance. The authors highlighted the importance of adequate size reduction and surface treatment to ensure uniform dispersion within the cement matrix.

8] Zhang et al. (2022) conducted a detailed experimental study on the performance of concrete incorporating recycled glass fibers, with particular emphasis on post-cracking behavior and energy absorption capacity. The research involved mechanical testing under flexural and tensile loading to evaluate how fibers influence crack development and failure mechanisms. The results demonstrated that recycled glass fibers significantly improve post-cracking performance, allowing concrete to sustain loads even after initial cracking. The fibers enhance energy absorption capacity by dissipating stress through fiber pull-out and bridging actions, which improves toughness and impact resistance.

Replacing fine aggregates with alternative materials has been a major area of research due to the depletion of natural sand resources. Waste glass, quarry dust, and industrial by-products have been widely studied as partial replacements.

9] Aliabdo et al. (2019) conducted an experimental investigation on the utilization of waste glass powder as a partial replacement for fine aggregate in concrete. The study focused on evaluating compressive strength, workability, and durability characteristics at different

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replacement levels. The results indicated that waste glass powder can effectively replace natural sand up to approximately 20% without causing any significant reduction in compressive strength. The improved performance at moderate replacement levels was attributed to the pozzolanic activity of finely ground glass particles, which enhances the microstructure by forming additional calcium silicate hydrate (C–S–H) gel. This leads to better particle packing and reduced porosity. However, beyond the optimum level, strength reduction was observed due to increased brittleness and potential alkali–silica reaction risks.

10] Kumar and Kumar (2021) investigated the use of various industrial waste materials as partial replacements for fine aggregate in concrete, with a focus on durability and strength characteristics. The study examined parameters such as compressive strength, water absorption, and resistance to environmental degradation. The findings revealed that partial replacement of sand with industrial waste materials can enhance durability properties, including reduced permeability and improved resistance to chemical attack, while maintaining compressive strength within acceptable limits. This improvement was attributed to better particle packing and the presence of finer particles filling the voids in the concrete matrix.

11] Oliveira et al. (2020) Oliveira et al. (2020) examined the mechanical behavior of concrete incorporating recycled glass fibers, particularly focusing on tensile strength, workability, and compressive strength. The study involved varying the content of glass fibers and analyzing their influence on concrete performance. The results showed that the inclusion of glass fibers significantly improves tensile strength and crack resistance due to the fiber bridging effect, which helps in controlling crack propagation. However, the study also identified certain limitations associated with higher fiber content. Excessive replacement levels led to reduced workability, as fibers tend to interlock and hinder the flow of the mix.

12] Sadrmomtazi et al. (2019), carried out an experimental study to evaluate the mechanical properties of glass fiber reinforced concrete, with particular emphasis on tensile and flexural behavior. The research involved incorporating different proportions of glass fibers into concrete and analyzing their influence on crack development and load-carrying capacity. The findings revealed that the inclusion of glass fibers significantly enhances split tensile and flexural strength due to the crack-bridging mechanism, where fibers act as connectors across micro-cracks and delay their propagation. This results in improved toughness and energy absorption capacity. The study also observed a more ductile failure pattern compared to conventional concrete.

13] Gencel et al. (2021) investigated the effect of fiber reinforcement on the mechanical and durability properties of concrete, focusing on parameters such as impact resistance, ductility, and energy absorption. The study included various fiber types, including glass fibers, and evaluated their performance under different loading conditions. The results showed that fiber addition significantly improves impact resistance and ductility, allowing concrete to absorb higher amounts of energy before failure. The presence of fibers helps in redistributing stresses and prevents sudden brittle failure, resulting in a more gradual and controlled fracture behavior.

14] Bashir et al. (2020) examined the influence of varying glass fiber content on the compressive strength and workability of concrete. The study involved preparing concrete mixes with different fiber percentages and evaluating their fresh and hardened properties.

15] Zhao et al. (2023) Zhao et al. (2023) conducted a comprehensive study to determine the optimum fiber content in fiber-reinforced concrete for achieving balanced mechanical performance. The research involved analyzing the effects of different fiber volume fractions on compressive strength, tensile strength, and durability.

16] Pacheco-Torgal et al. (2020) examined the influence of fiber incorporation on the fresh properties of concrete, particularly focusing on workability. The study reported that the addition of fibers significantly reduces the flowability of concrete due to increased internal friction and higher surface area of the fibers. This results in difficulty in mixing, placing, and compaction. To overcome these challenges, the authors emphasized the use of chemical admixtures such as superplasticizers, which help in improving workability without altering the water-cement ratio. The study concluded that proper mix design adjustments are essential when using fiber-reinforced concrete to ensure both workability and performance.

17] Gonçalves et al. (2021) conducted an experimental study to evaluate the effect of fiber content on the workability of concrete. The results showed a consistent decrease in slump values with increasing fiber dosage. This reduction was attributed to the interlocking behavior of fibers and their tendency to restrict the movement of aggregate particles within the mix. The study also highlighted that higher fiber content leads to poor compaction and increased risk of void formation if not properly managed. The authors concluded that controlling fiber dosage and using suitable admixtures are crucial to maintain acceptable workability in fiber-reinforced concrete. In terms of durability, glass fibers have shown promising results.

18] Fiore et al. (2019) investigated the mechanical and durability performance of concrete incorporating glass fibers. The study found that the inclusion of glass fibers significantly improves resistance to cracking by bridging micro-cracks and preventing their propagation. This crack control mechanism reduces the permeability of concrete, thereby enhancing its durability. The improved microstructure also contributes to better resistance against environmental degradation. The authors concluded that glass fibers are highly effective in improving the long-term durability of concrete, especially in applications where crack resistance is critical.

19] Zhang et al. (2022) focused on the durability characteristics of concrete reinforced with recycled glass fibers, particularly under aggressive environmental conditions. The study demonstrated that glass fiber incorporation enhances resistance to freeze–thaw cycles and chemical attack. This improvement was attributed to the reduced formation of cracks and a denser internal structure, which limits the ingress of harmful agents such as water and chemicals. The fibers also help in maintaining structural integrity under repeated loading and environmental stress. The authors concluded that glass fiber reinforced concrete is well-suited for structural applications, including bridges, where durability under harsh conditions is essential.

20] Akhtar and Sarmah (2019) conducted a comprehensive study on the environmental and mechanical implications of incorporating industrial waste materials into concrete. The research focused on sustainability indicators such as carbon emissions, energy consumption, and waste management. The findings revealed that replacing conventional materials with recycled industrial waste significantly reduces greenhouse gas emissions associated with raw material extraction, processing, and transportation. Additionally, the study showed a notable reduction in energy consumption due to

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decreased dependence on virgin resources. The authors concluded that the use of industrial waste in concrete is an effective strategy for achieving environmentally sustainable construction while maintaining acceptable 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.

FLOWCHART

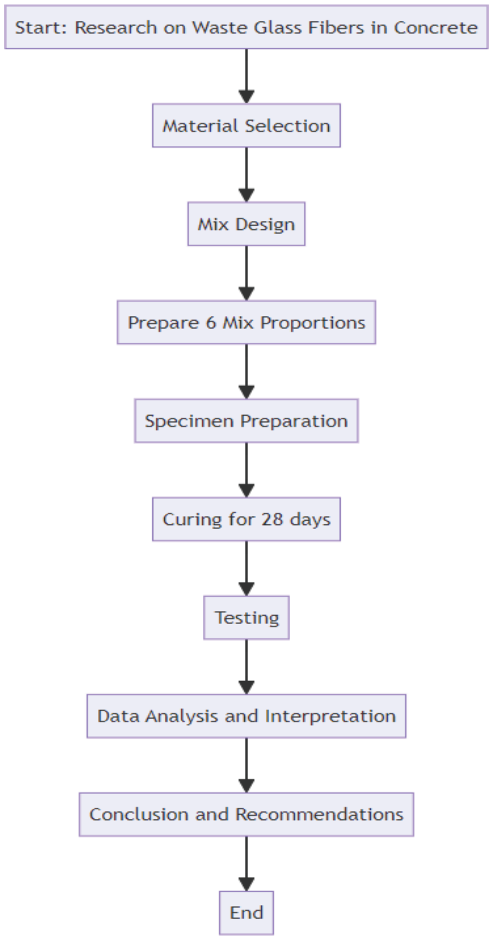

Fig. 1 shows the Flowchart of Proposed System

IV. SYSTEM REQUIREMENT

MATERIALS USED

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

V. RESULT

Overall, the study concludes that the incorporation of recycled glass fibers significantly enhances the mechanical properties of concrete up to an optimum level, beyond which performance deteriorates. The optimum replacement level is identified as approximately 4% to 6%, which provides the best balance between workability, strength, and durability. This research demonstrates that recycled glass fibers can be effectively utilized in concrete as a sustainable material,

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contributing to resource conservation and waste management while maintaining satisfactory structural performance.

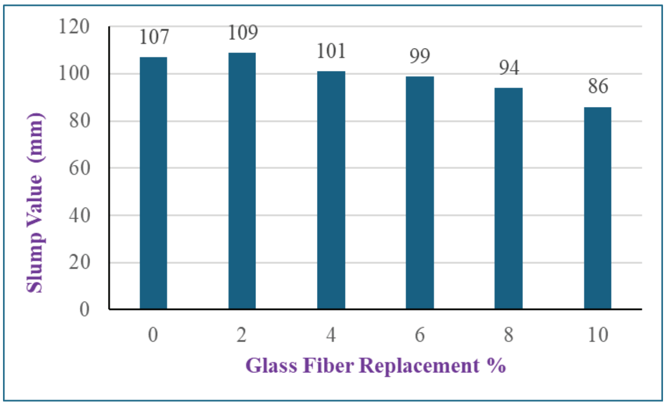

Fig. 2 shows the Slump Value of Conventional Concrete and Modified Concrete

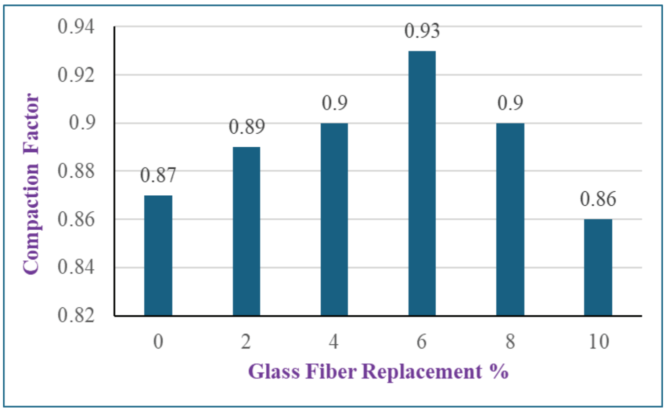

Fig. 3 shows the Compaction Factor of Concrete Mix

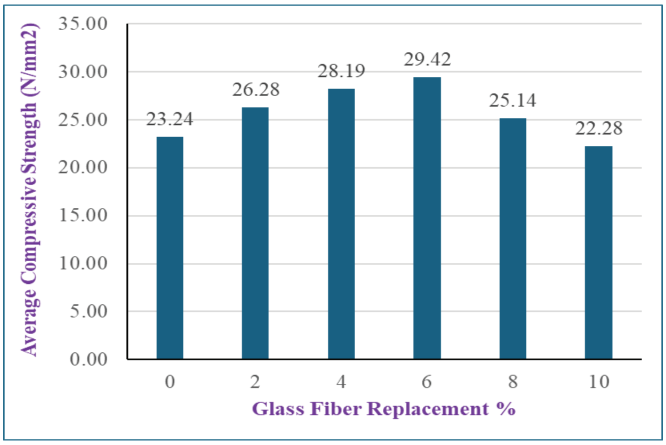

Fig. 4 shows the Representation of Compressive Strength at 7 Days Curing Period

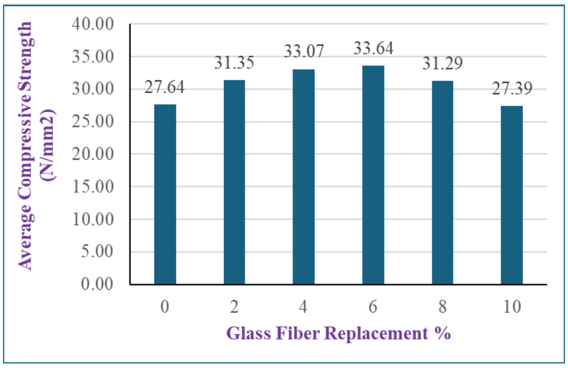

Fig. 5 shows the Representation of Compressive Strength at 14 Days Curing Period

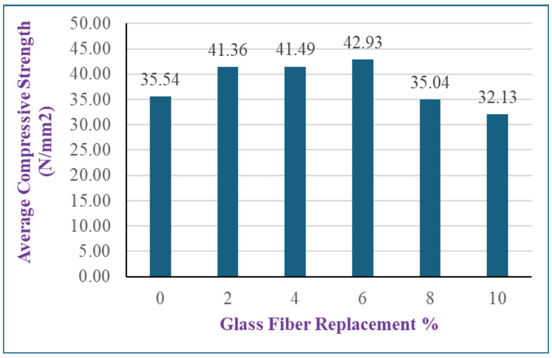

Fig. 6 shows the Representation of Compressive Strength at 28 Days Curing Period

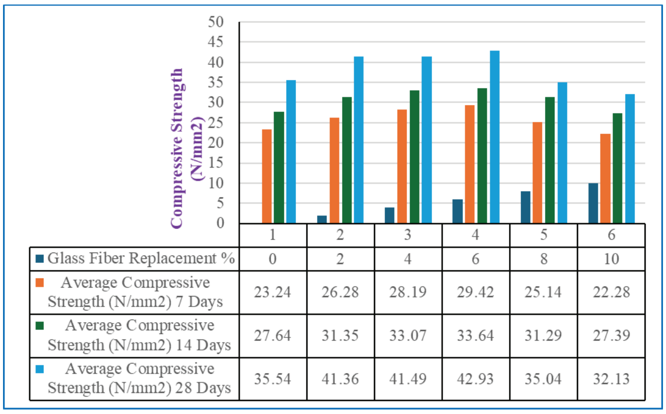

Fig. 7 shows the Representation Comparative Analysis of Compressive Strength

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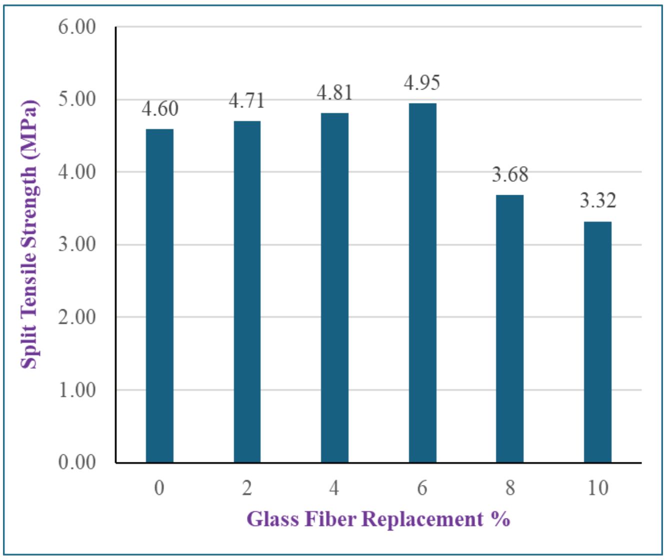


Fig. 8 shows the Representation of Split Tensile Strength at 7 Days Curing Period

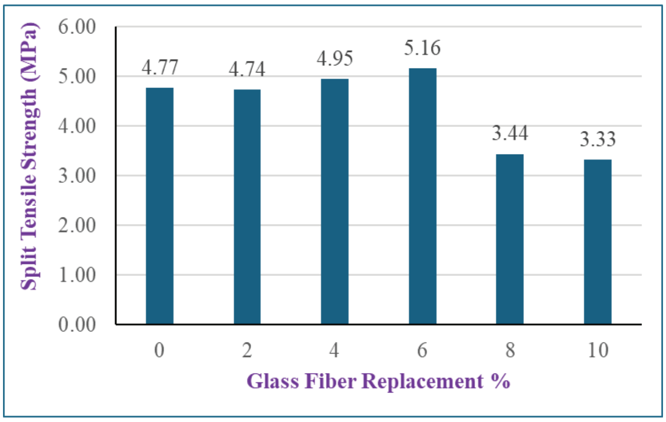


Fig. 9 shows the Representation of Split Tensile Strength at 14 Days Curing Period

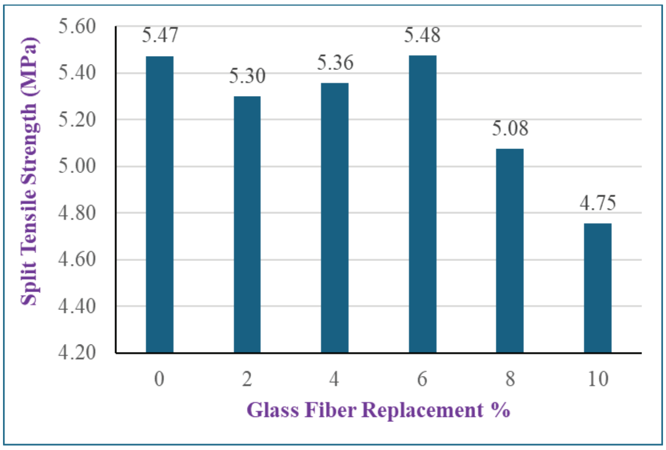
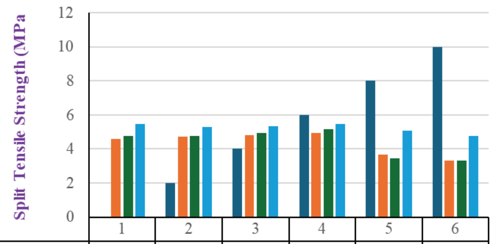


Fig. 10 shows the Representation of Split Tensile Strength at 28 Days Curing Period



	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

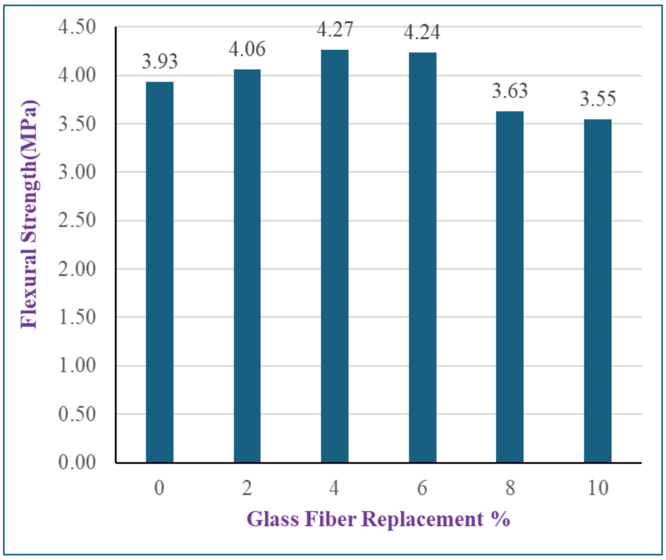


Fig. 12 shows the Representation of Flexural Strength at 7 Days Curing Period

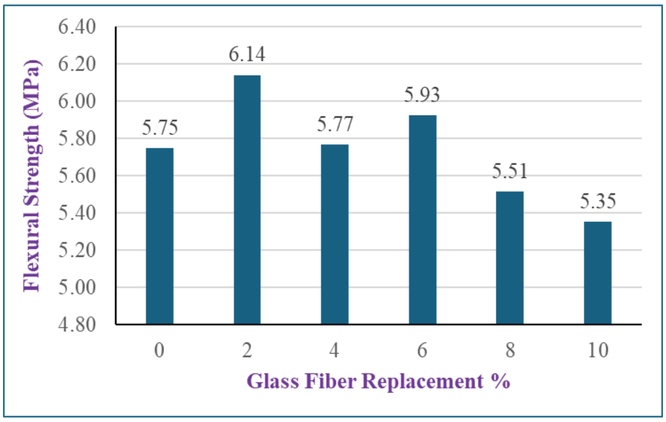


Fig. 13 shows the Representation of Flexural Strength at 14 Days Curing Period

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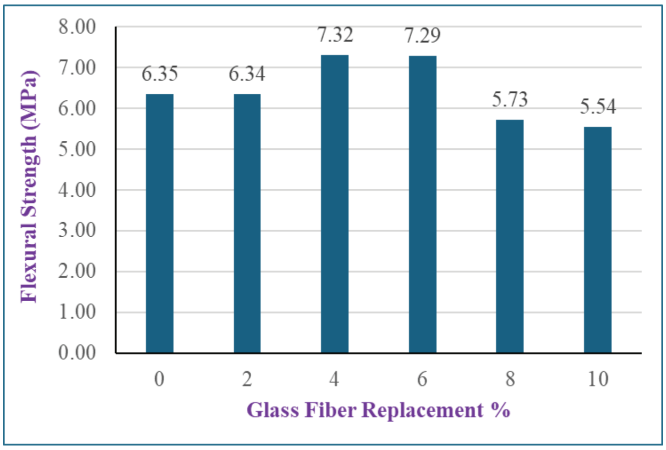
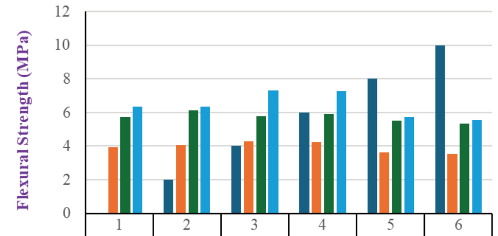


Fig. 14 shows the Representation of Flexural Strength at 28 Days Curing Period



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

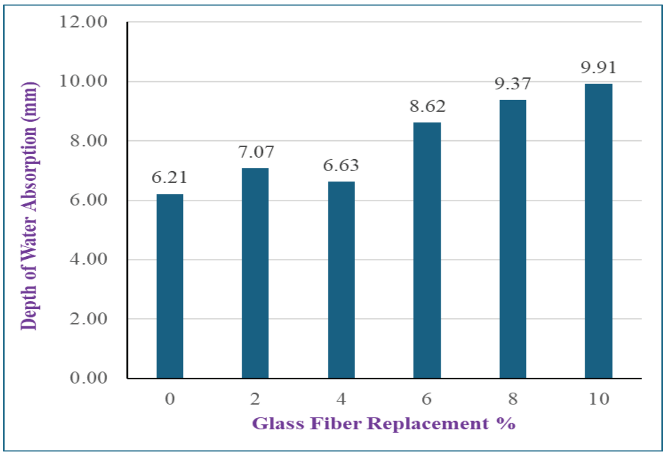


Fig. 16 shows the Representation of Depth of Water Absorption at 7 Days Curing Period

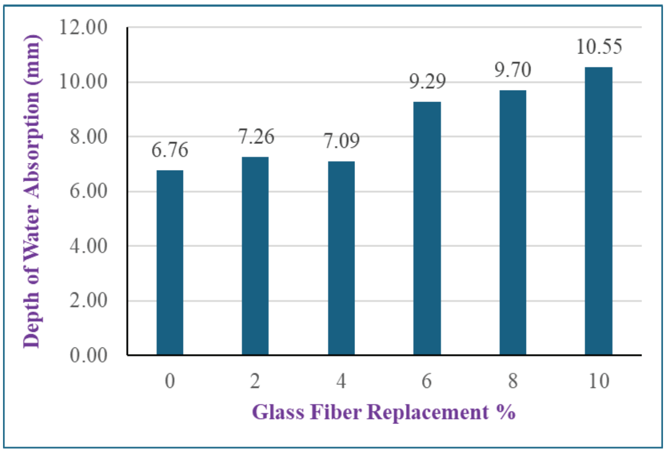


Fig. 17 shows the Representation of Depth of Water Absorption at 14 Days Curing

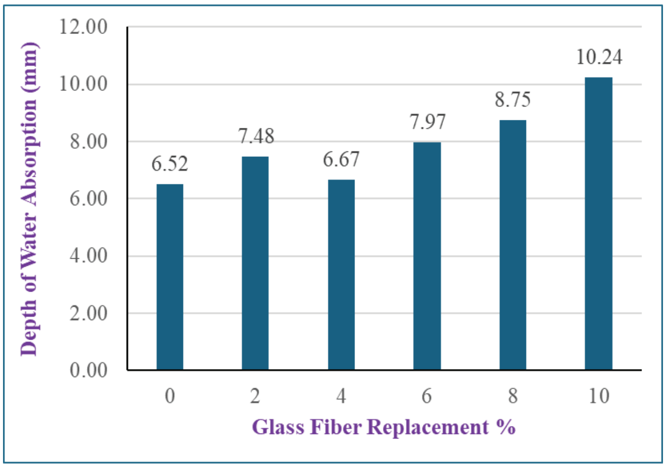
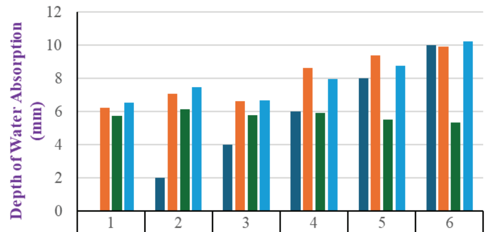


Fig. 18 shows the Representation of Depth of Water Absorption at 28 Days Curing



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

V. CONCLUSION

The present study investigated the feasibility of utilizing recycled glass fibers as a partial replacement for fine aggregate in M40 grade concrete, with replacement levels ranging from 0% to 10%. The performance of concrete was evaluated in terms of workability, mechanical properties, and durability, and the results indicate a clear influence of fiber content on overall concrete behavior.

- The workability of concrete, assessed using the slump cone test, showed an initial improvement followed by a gradual decline with increasing fiber content. The slump value increased slightly from 107 mm (0%) to 109 mm at 2% replacement, indicating enhanced flowability at lower fiber content. However, beyond this level, workability decreased progressively to 101 mm (4%), 99 mm (6%), 94 mm (8%), and 86 mm (10%), due to increased internal friction, higher surface area, and fiber interlocking. This confirms that excessive fiber addition adversely affects the consistency and ease of placement of concrete.
- The compressive strength results demonstrated a significant improvement up to an optimum replacement level. 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 an increase of approximately 20.8%. Beyond this level, strength decreased to 35.04 MPa (8%) and 32.13 MPa (10%), primarily due to poor workability, fiber clustering, and increased void content.
- The split tensile strength exhibited an increasing trend up to 6% replacement. At 28 days, the tensile strength reached a maximum of 5.48 MPa at 6%, compared to 5.47 MPa for the control mix, with notable improvements also observed at earlier curing ages. However, a significant reduction was observed at higher replacement levels, with values decreasing to 5.08 MPa (8%) and 4.75 MPa (10%), indicating reduced tensile resistance due to weak bonding and increased porosity.
- The flexural strength results further supported these findings, showing optimum performance within the range of 4% to 6% replacement. The maximum 28-day flexural strength of 7.32 MPa was recorded at 4% replacement, followed closely by 7.29 MPa at 6%, compared to 6.35 MPa for the control mix, representing an improvement of approximately 15%. Beyond this range, the strength decreased significantly to 5.73 MPa (8%) and 5.54 MPa (10%), due to reduced cohesiveness and fiber agglomeration.
- From a durability perspective, the depth of water absorption increased with higher fiber content, indicating increased permeability. The control mix showed an absorption depth of 6.52 mm at 28 days, which increased to 7.48 mm (2%) and 6.67 mm (4%), and further to 7.97 mm (6%), 8.75 mm (8%), and 10.24 mm (10%). This trend confirms that excessive fiber content leads to increased porosity and reduced resistance to water ingress, adversely affecting durability.

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