Performance Evaluation of Glass Fiber Reinforced Concrete using Manufactured Sand: A Systematic Literature Review

Siddharth C. Patel [1], Dr. Kamal Singh[2], Achyut Kumar Singh[3]

[1]*M.Tech Transportation Engg., Dept. of Civil Engineering, MANIT Bhopal, India*
[2]*Associate Professor, Dept. of Civil Engineering, MANIT Bhopal, India*
[3]*M.Tech Transportation Engg., Dept. of Civil Engineering, MANIT Bhopal, India*

---***---

Abstract *– Glass Fiber Reinforced Concrete (GFRC) has emerged as a high-performance material in construction with improved mechanical properties in terms of strength, crack resistance, and durability. At the same time, Manufactured Sand (M-Sand) has gained popularity as a sustainable material in the construction sector with the implementation of environmental regulations and scarcity of river sand. Pavement Quality Concrete (PQC) for highways and airfields demands high strength, durability, and resistance to environmental effects. This study is a systematic literature review of existing experimental research aimed at evaluating the mechanical properties, durability, and pavement properties of glass fiber reinforced concrete when M-Sand is used as a fine aggregate. The results show that an optimal glass fiber content of 0.5% to 1.5% by weight of cement gives the best results. M-Sand also gives better strength results compared to conventional river sand. Application of M-Sand and GFRC together shows immense potential for the construction of sustainable rigid pavements. However, research needs to be focused on Pavement Quality Concrete using OPC and PPC cement, 100% M-Sand, and optimized glass fibers to develop design guidelines for Indian pavement design codes.*

Key Words: **Glass Fiber Reinforced Concrete (GFRC), Manufactured Sand (M-Sand), Pavement Quality Concrete, Compressive Strength, Flexural Strength, Durability, Skid Resistance, Rigid Pavement, Fiber Reinforced Concrete.**

1. INTRODUCTION

Rigid pavements are largely adopted in highway and airport infrastructure owing to their long service life and ability to sustain heavy traffic loads. Cement concrete is the most extensively used construction material worldwide [6], valued for its compressive strength, durability, and versatility.

However, plain cement concrete inherently suffers from low tensile strength, brittleness, low ductility, limited fatigue life, and low impact resistance [3]. Pavement Quality Concrete (PQC), intended to resist flexural and fatigue failures, is increasingly threatened by environmental issues, material availability, and premature cracking.

The over-exploitation of river sand for construction has major environmental concerns, prompting bans and the search for viable alternatives such as Manufactured Sand [17]. M-Sand, produced by crushing hard granite rock through controlled processes, offers consistent gradation, angular particle shape, and improved surface texture, translating into better bonding with cement paste and superior mechanical performance compared to river sand [3][8]. Borigarla et al. [8] demonstrated that 100% M-Sand replacement in M40 concrete yielded compressive strength 12.54% higher than conventional river sand concrete [16].

Fiber Reinforced Concrete (FRC) is intended to overcome these deficiencies by using discrete fibers that bridge cracks, arrest their propagation, and enhance post-cracking behavior. Glass Fiber Reinforced Concrete (GFRC) has attracted considerable research attention due to its high tensile strength (approximately 1020 to 4080 MPa), corrosion resistance, light weight, and ease of mixing [17]. Alkali-resistant glass fibers are mostly used in concrete as reinforcement due to their resistance against alkali attacks caused by Portland cement [14,15].

This systematic literature review evaluates published experimental evidence on: (i) The effect of glass fiber content on mechanical strength parameters [1 to 7]; (ii) Durability properties including UPV, acid resistance, chloride penetration, and shrinkage [1,2,4,5]; and (iii) Pavement-specific properties such as skid resistance, temperature differential, and fatigue life [3,8], with particular attention to the role of M-Sand as fine aggregate.

2. OBJECTIVES OF THE REVIEW

The primary objectives of this systematic literature review are:

- To compile and critically analyze published experimental data on the effect of varying glass fiber content on the compressive, tensile, and flexural strength of concrete.
- To assess the durability performance of GFRC, including UPV, rebound hammer results, chloride penetration resistance, sorptivity, acid resistance, and drying shrinkage [1,2,4,5].

- To evaluate the pavement-specific performance of M-Sand modified concrete, including skid resistance, temperature differential, and fatigue behavior [3,8].
- To identify the optimum glass fiber content for mechanical and durability performance based on a synthesis of reviewed studies.
- To highlight the combined advantages of using M-Sand as fine aggregate in GFRC systems for pavement quality concrete applications.

3. REVIEW METHODOLOGY

This review follows a systematic literature review (SLR) methodology adapted for civil engineering research papers. Papers were identified from IRJET, Elsevier, ResearchGate, and Indian Roads Congress databases.

3.1 Inclusion Criteria

- Experimental studies on glass fiber reinforced concrete (GFRC).
- Studies investigating M-Sand as full or partial replacement of natural river sand [1,2,3,8].
- Papers covering at least one of compressive strength, split tensile strength, flexural strength, UPV, durability, or pavement performance characteristics.
- Peer-reviewed journal articles, conference papers, and indexed publications from 2015 to 2025.

3.2 Data Extraction

For each included study, the following data were extracted: authors and year, concrete grade, cement type, fine aggregate type, glass fiber type and content (% by weight of cement), water-cement ratio, superplasticizer usage, test results at 7 and 28 days, and key conclusions regarding optimal fiber content [1,2,3,4,5,6,7,8].

3.3 Proposed Testing Program

The following experimental research methodology is proposed for investigating Glass Fiber Reinforced M-Sand Based Pavement Quality Concrete:

- Material Selection & Characterization: Testing cement (PPC), M-Sand, glass fibers, and admixtures for consistency, gradation, and strength properties.
- Mix Design of Concrete as per IS 10262:2019 with OPC/PPC cement, Manufactured Sand, coarse aggregate, glass fiber, and water-cement ratio of 0.36–0.40.
- Casting & Curing: Cubes (150×150×150 mm), cylinders (150 Dia×300 mm), beams (100×100×500 mm), and slabs (500×500×150 mm) cured at 7, 14, and 28 days.
- Mechanical Testing: Compressive strength (IS 516), Split tensile strength (IS 5816), Flexural strength (IS 516/IRC:44).
- Durability Studies: Water absorption (ASTM C642), skid resistance (British Pendulum), abrasion resistance (ASTM C944), shrinkage cracking (ASTM C157).
- Data Analysis: Optimization of fiber dosage and comparison of mixes using statistical analysis.

Table-I: Proposed Testing Program

Test Category	Test Conducted	Standard / Reference	Age / Condition
Fresh Properties	Slump test	IS 1199	Fresh concrete
Fresh Properties	Density & air content	IS 1199	Fresh concrete
Mechanical	Compressive strength	IS 516	7 & 28 days
Mechanical	Flexural strength (MOR)	IS 516 / IRC:44	28 days

4. MATERIALS USED IN VARIOUS STUDIES

4.1 Cement

Most reviewed studies used OPC 53 grade cement conforming to IS 12269:2013. Portland Pozzolana Cement (PPC) conforming to IS 1489:1991 was used in studies involving supplementary cementitious materials (SCMs). Studies by Gayathri et al. [2] and Partheeban et al. [1] incorporated ternary blends with PPC, fly ash, and Alccofine (specific gravity 2.88).

4.2 Fine Aggregate

River sand (Zone I and Zone II per IS 383:1970) was used as conventional fine aggregate in most early studies [4,5,6,7]. M-Sand by crushed granite with controlled gradation was used as 100% replacement of river sand by Gayathri et al. [2], Rage Meenakshi & Rajesh [3], and Borigarla et al. [8]. The physical properties of M-Sand (specific gravity: 2.62–2.71; fineness modulus: 2.71) are comparable to river sand, while its angular morphology increases bond strength with cement paste.

4.3 Coarse Aggregate

Locally available crushed granite aggregates of 20 mm nominal maximum size (IS 383:1970) were used consistently in all reviewed studies [1,2,3,4,5,6,7,8]. Specific gravities ranged from 2.68 to 2.82.

4.4 Glass Fibers

The most used glass fiber across all reviewed studies was Alkali Resistant (AR) Cem-FIL glass fiber, featuring a filament diameter of 14 microns, length of 12 mm, aspect ratio of 857:1, tensile strength of 2500 MPa, modulus of elasticity of 70 GPa, and specific gravity of 2.68 to 2.78. Fibers were added by weight of cement at dosages ranging from 0.25% to 2.5% across the reviewed literature.

4.5 Admixtures

Superplasticizers were used in all studies involving M-Sand and higher fiber contents to maintain workability. Conplast SP430 (1% by cement weight) was used by Rage Meenakshi & Rajesh [3], a Sicca-based superplasticizer by Sharma et al. [4], and naphthalene sulfonate formaldehyde (Tec mix 550) at 1.5% by Borigarla et al. [8].

5. PERFORMANCE EVALUATION: MECHANICAL STRENGTH

5.1 Compressive Strength

Compressive strength is the primary mechanical parameter for concrete design (IS 516:1959) and was evaluated in all reviewed studies. The common trend indicates an increase in Compressive Strength with glass fiber content up to an optimum value, beyond which strength is constant or reduced due to fiber balling, poor workability, and incomplete compaction.

Key observations: Rage Meenakshi & Rajesh [3] reported the highest CS at 1.5% GF in M-Sand-based M30 concrete (62.42 MPa) — a 21.06% improvement over the control. Sharma et al. [4] found optimal CS of 40.62 MPa at 0.7% GF in M20 concrete, representing a 20% increase. Vamsi Krishna et al. [6] reported 72 MPa at 1% GF in M80 HSC. Hemalatha & Rose [5] confirmed that CS increased at 1% GF (48.88 MPa) in M40 concrete and declined beyond this threshold.

5.2 Split Tensile Strength

Split tensile strength (STS) is evaluated per IS 5816 and was investigated in most reviewed studies [4,5,6,7,8]. Glass fibers contribute significantly to tensile performance through crack-bridging. Sharma et al. [4] demonstrated STS improvements of up to 55.4% at 0.7% GF (5.05 MPa vs. 3.60 MPa for control) in M20 concrete. Hemalatha & Rose [5] reported STS of 7.96 MPa at 1.0% GF in M40 concrete — a 37.9% improvement over control. Borigarla et al. [8] recorded STS of 5.41 MPa in M-Sand M40 concrete (no GF), demonstrating the inherent benefit of angular M-Sand particles.

5.3 Flexural Strength

Flexural strength (Modulus of Rupture) is the most critical parameter for rigid pavement design per IRC 44:2017 and IS 516. Satpute et al. [7] reported the highest FS of 9.93 MPa at 2.0% hybrid GF + steel fiber in M30 concrete — a 36.8% improvement due to combined crack-bridging effects. Gayathri et al. [2] and Partheeban et al. [1] reported FS of 3.89 MPa at 0.5% GF in M-Sand M30 concrete, satisfying IRC:SP:62-2014 requirements for low-volume roads. Borigarla et al. [8] reported FS of 7.55 MPa in M-Sand M40

Table-II: Mechanical Characteristics Strength Summary

Author(s) & Year [Ref.]	Grade	Fine Aggregate & Cement	GF %	CS 28d (MPa)	STS 28d (MPa)	FS 28d (MPa)
Sharma et al. (2017) [4]	M25	River Sand, PPC	0	33.85	3.25	5.70
Sharma et al. (2017) [4]	M25	River Sand, PPC	0.3	35.96	3.81	6.58
Sharma et al. (2017) [4]	M25	River Sand, PPC	0.5	38.69	4.53	7.27
Sharma et al. (2017) [4]	M25	River Sand, PPC	0.7	40.62	5.05	7.80
Hemalatha & Rose (2016) [5]	M40	River Sand, OPC	0	45.33	6.36	6.37
Hemalatha & Rose (2016) [5]	M40	River Sand, OPC	1.0	48.88	7.96	6.86
Hemalatha & Rose (2016) [5]	M40	River Sand, OPC	2.0	44.88	4.77	4.90
Rage Meenakshi & Rajesh (2023) [3]	M30	M-Sand, OPC	1.5	62.42	—	—
Vamsi Krishna et al. (2015) [6]	M80	River Sand, OPC	1.0	72.00	9.00	8.50
Gayathri et al. (2025) [2]	M30	M-Sand, PPC B0	0	41.58	—	4.30
Kamble et al. (2024) [16]	M40	M-Sand, OPC	0.5	54.75	—	6.56
Partheeban et al. (2021) [1]	M30	M-Sand,90 Flyash+ 10 GGBFS	0.5	39.74	3.50	5.00
Borigarla et al. (2022) [8]	M40	M-Sand (MS-100% & No GF)	—	56.78	5.41	7.55
Satpute et al. (2016) [7]	M30	River Sand, PPC	0	37.52	4.80	7.51

concrete without glass fiber, confirming M-Sand itself contributes to improved flexural performance.

6. DURABILITY STUDIES

Durability investigations have shown reduced permeability, controlled microcracking, and improved resistance of GFRC to harsh environments.

Table-III: Durability Performance Summary of Reviewed Studies

Author(s) [Ref.]	Durability Test	Key Finding	Optimal GF	Grade
Sharma et al. [4]	UPV	3983–4586 m/s (Good to Excellent as per IS 13311)	0.70%	M20
Sharma et al. [4]	Rebound Hammer	Values 22.46–25.91; max diff. -0.70%	0.70%	M20
Hemalatha & Rose [5]	Acid Attack (HCl)	Weight loss of 0.34 kg (control mix) to 0.47 kg (1% GF) at 28d	1.00%	M40
Gayathri et al. [2]	RCPT & Sorptivity	Reduced chloride penetration with 0.5% GF and Alccofine	0.50%	M30
Gayathri et al. [2]	Drying Shrinkage	Improved with fiber inclusion	0.50%	M30
Appadurai, A. S. et al. [17]	RCPT & Alkalinity	Reduced chloride penetration high alkalinity	-	M30
Partheeban et al. [1]	RCPT	Improved chloride penetration resistance with 0.5% GF	0.50%	M30
Borigarla et al. [8]	Skid Resistance	M-Sand: 88 mm (dry) / 64 mm (wet) — best performance	N/A	M40
Borigarla et al. [8]	Temp. Differential	M-Sand slab: 11.1°C is lowest within IRC 58:2011 limit	N/A	M40
Borigarla et al. [8]	Fatigue Life	M-Sand: 42,749 cycles at SR 0.65 highest among mixes	N/A	M40

6.1 Rebound Hammer Test

Sharma et al. [4] performed rebound hammer testing, finding close correlation between rebound numbers and destructive compressive strength values (maximum difference of 0.70%). Rebound values increased from 22.46 (0% GF) to 25.91 (0.7% GF), indicating increased surface hardness with fiber addition, validating the rebound hammer as a viable non-destructive evaluation technique for GFRC.

6.2 Chloride Penetration and Durability (RCPT & Sorptivity)

Gayathri et al. [2] and Partheeban et al. [1] employed the Rapid Chloride Penetration Test (RCPT) and sorptivity measurements to assess durability of ternary blend concrete with M-Sand, RCA, and 0.5% GF. The combination of 10% Alccofine with glass fibers produced the most significant improvement in chloride penetration resistance. Ultrafine Alccofine particles fill capillary pores and form dense C-S-H gel (confirmed by SEM), while glass fibers limit crack width and reduce pore network connectivity.

6.3 Acid Attack Resistance

Hemalatha et al. [5] investigated immersion in 5% hydrochloric acid (HCl) solution for 28 and 60 days, measuring weight loss as a durability index. Weight loss increased progressively with GF content (0.47 kg at 1% GF vs. 0.34 kg for control at 28 days). However, the best 1% GF mix showed adequate acid resistance for most structural uses.

7. PAVEMENT SPECIFIC PERFORMANCE EVALUATION

7.1 Skid Resistance

Skid resistance is an important pavement safety parameter. Borigarla et al. [8] investigated skid resistance of M40 grade concrete using a British Pendulum Skid Resistance Tester. M-Sand modified concrete achieved 88 mm on dry surfaces and 64 mm on wet surfaces, compared to 74 mm (dry) and 55 mm (wet) for conventional river sand concrete — an increase of 18.9% on dry and 16.4% on wet surfaces. The better skid resistance is attributed to the angular shape of M-Sand particles, resulting in better macro-texture on pavement surfaces.

7.2 Temperature Differential

Temperature differential is the temperature difference between the two surfaces of a pavement section causing warping and cracking. Borigarla et al. [8] monitored temperature differentials across 500×500×150 mm slabs over four months. The maximum temperature difference was highest in conventional concrete slabs (12.1°C) and lowest in M-Sand concrete slabs (11.1°C). All values remained within the IRC 58:2011 permissible limit of 17.3°C. Kamble et al. [16] also investigated temperature effects on M40 PQC using single-layer and composite sections incorporating steel fibers, glass fibers, and GGBS, confirming SF+GF composite sections exhibited better flexural strengths and temperature differentials compared to plain PQC.

7.3 Fatigue Behavior

Fatigue life is a fundamental design parameter for rigid pavements. Borigarla et al. [8] conducted fatigue testing under repeated flexural loading at stress ratios of 0.65, 0.75, and 0.85. M-Sand modified concrete exhibited the highest fatigue life at all stress ratios: 42,749 cycles at SR 0.65, 16,550 at SR 0.75, and 747 at SR 0.85 — consistently outperforming Quarry dust concrete (33,960; 11,750; 570 cycles) and conventional concrete (24,974; 8,000; 340 cycles).induced distress under heavy traffic.

TABLE IV: COMPREHENSIVE SUMMARY OF REVIEWED LITERATURE OF GFRC AND M-SAND STUDIES

Author (s) and Year	M-Grade	Fine Aggregate	GF %	CS (MPa)	Durability Tests	Optimal GF %	Remarks
Partheeban et al. [1] 2021	30	M-Sand + RCA	0.5	39.74	RCPT, Sorptivity, Shrinkage	0.5	Alccofine, Geopolymer
Gayathri et al. [2] 2025	30	M-Sand + RCA	0.25 - 0.75	39.74	RCPT, Sorptivity, Shrinkage	0.5	RSM, SEM, Ternary blend
Rage Meenakshi & Rajesh [3] 2023	30	M-Sand (Zone I)	0 – 2.5	62.42	—	1.5	CS peak at 1.5%
Sharma, Kumar & Sharma [4] 2017	20	River Sand	0 – 0.7	40.62	UPV, Rebound Hammer	0.7	UPV: 3983–4586 m/s
Hemalatha & Leema Rose [5] 2016	40	River Sand	0.33 – 2	48.88	Acid attack (HCl)	1	Cem-FIL AR glass fiber
Vamsi Krishna & Rao [6] 2015	80	River Sand	0, 0.25	72.00	—	1	Compared with steel fiber
Satpute, Kulkarni et al. [7] 2016	30	River Sand	0–3 hybrid	42.28	—	2	Hybrid GF + steel fiber
Borigarla et al. [8] 2022	40	M-Sand 100%	—	56.78	Skid, Fatigue, Temp. Diff.	N/A	Pavement focus, no GF
Kamble et al. [16] 2024	40	PQC Composite	SF+GF	Improved	Fatigue (Temp)	SF+GF Composite	PQC single & composite
Appadurai et al. [17] 2024	20 and30	M-Sand & River Sand	—	Comparable	Chloride permeability	Partial replacement	Sustainable alternative

8. DISCUSSION

8.1 Optimal Glass Fiber Content

Collective findings of all reviewed studies indicate that optimal glass fiber content falls in the range of 0.5% to 1.5% by weight of cement, depending on concrete grade and aggregate type:

- For lower-grade concrete (M20 to M30) with river sand: 0.7%–1.0% GF [4,5].
- For M30 concrete with M-Sand: 1.5% GF for maximum CS [3], while 0.5% GF is optimal for combined strength-durability in ternary blends [1,2].
- For high-strength concrete (M80): 1.0% GF for mechanical properties [6].
- For hybrid fiber systems (GF + steel): 2.0% total fiber [7].

Beyond the optimal dosage, a consistent reduction in workability leads to incomplete compaction and reduced strength [4,5,7]. Use of superplasticizers (1 to 1.5% by cement weight) is essential to maintain adequate workability at higher fiber contents.

8.2 Role of M-Sand

The reviewed literature [1,2,3,8] proves that M-Sand consistently improves the mechanical properties of concrete compared to river sand. Benefits include: (i) increased compressive strength due to interlocking properties [3,8]; (ii) better skid resistance due to rough micro-texture [8]; (iii) lower temperature differential in pavement slabs [8]; and (iv) increased fatigue life [8]. Appadurai et al. [17] showed that M-Sand concrete for M20 to M30 grade exhibited very low chloride permeability and high alkalinity, proving M-Sand is a sustainable best option as a replacement for river sand.

8.3 Implications for Pavement Engineering

From a transportation engineering perspective, the use of M-Sand and GFRC is a promising approach for pavement quality concrete. Flexural strength of 3.89 MPa at 0.5% GF in M30 concrete with M-Sand [1,2] meets IRC:SP:62-2014 requirements for low-volume roads. The better skid resistance of M-Sand concrete (88 mm) vs. conventional concrete (74 mm) on dry surfaces [8] translates directly into improved road safety. The lower temperature differential (11.1°C vs. 12.1°C) results in lower warping stresses per IRC 58:2011 design provisions. The superior fatigue resistance (42,749 cycles vs. 24,974 at SR 0.65) allows longer pavement life or thinner slabs.

9. RESEARCH GAPS IDENTIFIED

Based on the comprehensive review of existing studies, the following significant research gaps have been identified:

- Existing studies rarely address pavement-specific performance indicators such as fatigue life, temperature gradient-induced stresses, warping behavior, and abrasion resistance simultaneously.

- All existing studies are based on short-term laboratory tests. Long-term tests considering thermal cycling, moisture variations, and seasonal temperature gradients are needed.
- Further research is needed to incorporate fatigue damage models, mechanistic-empirical design approaches, and performance-based specifications for fiber-reinforced PQC under real traffic loading conditions.
- The combined effects of chloride attack, freeze-thaw cycles, sulfate exposure, and carbonation on M-Sand and fiber-reinforced concrete require detailed investigation.
- Current Indian pavement design codes (IRC 58:2011, IRC 44:2017) do not explicitly incorporate provisions for fiber-reinforced PQC using alternative fine aggregates like M-Sand.
- No existing study has simultaneously measured skid resistance, temperature differential, and fatigue in M-Sand GFRC for PQC applications.

10. FUTURE RESEARCH SCOPE

Based on the reviewed literature and identified gaps, the following future research directions are recommended:

- Experimental investigation of M-Sand-GFRC (0.5 to 1.5% GF) mix in M30 Grade PQC with PPC cement, along with skid resistance, temperature differential, and fatigue properties.
- Investigation of long-term durability tests of M-Sand GFRC beyond 90 days under simulated pavement exposure conditions (freeze-thaw cycles, wet/dry cycles, sulfate solutions).
- Life cycle assessment (LCA) and cost-benefit analysis of M-Sand GFRC pavements compared to conventional river sand PQC.
- Optimization studies using Response Surface Methodology (RSM) or machine learning techniques to predict optimal GF content for combined mechanical-pavement performance.
- Field trials of GFRC with M-Sand on actual pavement sections to validate laboratory performance under real traffic and environmental conditions per IRC design provisions.
- Development of updated design guidelines and incorporation of fiber-reinforced PQC provisions into Indian Standards (IS) and Indian Roads Congress (IRC) codes.

11. CONCLUSIONS

Based on the systematic review of experimental studies on Glass Fiber Reinforced Concrete with Manufactured Sand, the following conclusions are drawn:

- Optimal glass fiber content: The optimum GF dosage is 0.5%–1.5% by weight of cement. For M-Sand-based M30 concrete, 1.5% GF is optimal for pure compressive strength [3], while 0.5% GF with supplementary cementitious materials offers the best combined strength-durability performance [1,2].
- Compressive strength: Glass fiber additions at optimal dosages improve 28-day Compressive Strength by 4.3% to 21.1% over control mixes [4,5,6,7], with M-Sand-based concrete exhibiting higher values (up to 62.42 MPa in M30 with 1.5% GF [3]).
- Tensile and flexural strength: Glass fibers contribute disproportionately to tensile performance, with STS improvements of up to 55.4% [4] and FS improvements of up to 36.8% [7] at optimal dosages.
- Durability: GFRC exhibits improved UPV values (3983–4586 m/s, Good to Excellent per IS 13311) [4], reduced chloride penetration and sorptivity with Alccofine supplementation [1,2], and good rebound hammer correlation with destructive strength [4].
- Pavement performance: M-Sand modified concrete demonstrates superior skid resistance (88 mm dry / 64 mm wet), lower temperature differential (11.1°C vs. 12.1°C conventional), and significantly higher fatigue life (42,749 cycles at SR 0.65 vs. 24,974 conventional) [8].
- Sustainable suitability: M-Sand provides a sustainable alternative to river sand, and glass fibers improve tensile strength, flexural behavior, and crack resistance. The combination satisfies IRC:SP:62-2014 flexural strength requirements and offers measurable advantages in skid resistance, thermal behavior, and fatigue resistance [1,2,3,8].
- Research gaps exist: Further studies on M30 grade PQC with PPC cement, 100% M-Sand, and optimized glass fiber content are necessary to provide design recommendations for Indian pavement design codes.

REFERENCES

[1] Partheeban, P., et al. (2021). "Performance evaluation of geopolymer concrete using E-waste and M-sand." Research on Engineering Structures & Materials, 7(2), 183–198.

[2] Gayathri, R., et al. (2025). "Performance assessment of ternary blended fiber-reinforced recycled aggregate concrete." Research on Engineering Structures & Materials.

[3] Rage Meenakshi, K., & Rajesh, G. (2023). "A study on reinforced concrete with glass fibers." Journal of Engineering Sciences, 14(01).

[4] Sharma, A., Kumar, P., & Sharma, J. (2017). "Experimental study on strength of concrete with addition of chopped glass

fiber." International Research Journal of Engineering and Technology (IRJET), 4(12), 837–842.

[5] Hemalatha, S., & Leema Rose, A. (2016). "An experimental study on glass fibre reinforced concrete." International Research Journal of Engineering and Technology (IRJET), 3(4), 2285–2289.

[6] Vamsi Krishna, B., & Kameswara Rao, M. (2015). "A comparative and experimental study on the mechanical properties of various steel and glass fiber reinforced high strength concrete." ResearchGate Conference Paper.

[7] Satpute, P.C., Kulkarni, V.P., Mehetre, A.J., & Kokate, M.D. (2016). "Experimental study on properties of concrete by using glass and steel fibers." IJLERA, 1(5), 16–28.

[8] Borigarla, B., Buddaha, T., Sai Kiran, G., & Hait, P. (2022). "Experimental study on replacing sand by M-Sand and quarry dust in rigid pavements." Materials Today: Proceedings, 60, 658–667.

[9] Ghugal, Y.M., & Deshmukh, S.B. (2006). "Performance of Alkali-Resistant Glass Fiber Reinforced Concrete." Journal of Reinforced Plastics and Composites, 25(6), 617–630.

[10] Chaitanya, J.D., Abhilash, G.V.S., Khan, P.K. & Sai, G.M. (2016). "Experimental Studies on Glass Fiber Concrete." American Journal of Engineering, 5(5), 100–104.

[11] Wu, Z., Shi, C., Khayat, K.H., & Xie, L. (2022). "Effect of Fiber Content on Mechanical Properties of Alkali-Resistant Glass Fiber Reinforced Concrete." Materials, 15(15), 5111.

[12] Ruben, N., Venkatesh, C., Durga, C.S.S., & Chand, M.S.R. (2021). "Comprehensive study on performance of glass fibers-based concrete." Innovative Infrastructure Solutions, 6(2).

[13] Ragi, S. (2015). "A Comparative and Experimental Study on the Mechanical Properties of Various Steel and Glass Fiber Reinforced High Strength Concrete."

[14] Abbas, S.N., et al. (2022). "An Investigation of Mechanical Properties of Fly Ash Based Geopolymer and Glass Fibers Concrete." Sustainability, 14, 10489.

[15] Xiaochun, Q., Xiaoming, L., & Xiaopei, C. (2017). "The applicability of alkaline-resistant glass fiber in cement mortar of road pavement." Int. J. Pavement Res. Technol., 10, 536–544.

[16] Kamble, S.Y., Jagadeesh, H.S., & Raghavendra, C.R. "Study on influence of temperature in Pavement Quality Concrete for single and composite sections with admixed concrete of M-40 Grade."

[17] Appadurai, A.S., Sundaresan, A.A., & Nammalvar, A. (2024). "Mechanical characterization and durability studies on concrete developed with M-Sand and River Sand." Matéria (Rio De Janeiro), 29(4).

[18] IS 10262:2019 – Concrete Mix Proportioning – Guidelines. Bureau of Indian Standards, New Delhi.

[19] IS 456:2000 – Plain and Reinforced Concrete – Code of Practice. Bureau of Indian Standards, New Delhi.

[20] IRC 15:2017 – Code of Practice for Construction of Jointed Plain Concrete Pavements. Indian Roads Congress, New Delhi.

[21] IRC 44:2017 – Guidelines for Cement Concrete Mix Design for Pavements. Indian Roads Congress, New Delhi.

[22] IRC 58:2011 – Guidelines for the Design of Plain Jointed Rigid Pavements for Highways. Indian Roads Congress, New Delhi.

[23] IS 383:2016 – Coarse and Fine Aggregate for Concrete. Bureau of Indian Standards, New Delhi.

[24] IS 1489 (Part 1):2015 – Portland Pozzolana Cement (Fly Ash Based). Bureau of Indian Standards, New Delhi.

[25] IS 13311 (Part 1):1992 – Non-Destructive Testing of Concrete – Ultrasonic Pulse Velocity. Bureau of Indian Standards, New Delhi.