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An Optimized Design of Concrete with Manufactured Sand and Alkali-resistant Glass Fibres

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ABSTRACT

In light of the depletion of natural river sand (RS) and the detrimental impact on the environment of sand mining, manufactured sand has become an appealing and sustainable substitute for concrete manufacturing. In India, RS remains the highest source of fine aggregate for all construction activities. Uncontrolled sand mining removes the flora and fauna from the river system triggering the ground water table and even causing floods during rainy seasons. Using alternate sand can reduce the dependency on RS to promote sustainability goals. This study focuses on the development of sustainable Alkali-resistant Glass Fibre-reinforced Concrete incorporating partial replacement of RS with manufactured sand. Experimental results demonstrated that the partial replacement of R sand by 60% with manufactured sand mix M60R40 enhances compressive strength, flexural strength and split tensile strength after 56 days by 11.7%, 23.5% and 22.19% with respect to control mix (M0R100), while maintaining acceptable workability. The inclusion of alkali-resistant glass fibres by 0.3% fibre content mix M60GF3 further improves compressive strength, flexural strength and split tensile strength by 9.36%, 38.8%, and 19.1% with respect to M60R40 after 56 days. The findings suggest that the inclusion of 0.3% Alkali-resistant Glass Fibre offers a sustainable, eco-friendly alternative to conventional concrete.

Keywords: Alkali-resistant glass fibre, Manufactured sand, Fibre-reinforced concrete, River sand, Workability, Strength.

INTRODUCTION

The rapid change in the field of construction has led to advancements and shown the importance of sustainability in India (Roberts, 1972). The infrastructure sector is one of the crucial aspects in India's economy, such that the government now focuses more on initiating necessary policies for world standard developments while keeping the point of conserving resources that are limited (Mallick & Mahalik, 2010; Wang et al., 2018). MoEFCC (Ministry of Environment, Forest and Climate Change) 2020 Act focuses on the management of sand mining in the country states, where illegal and uncontrolled mining leads to loss of revenue and degradation of the environment (*MoEFCC*, n.d.). SSMMG (Sustainable Sand Mining Management Guidelines) 2016 suggest that sources of sand in India are River beds, Flood pain, Lakes, Reservoirs, Agricultural fields, Marine sand, and Paleo-channels (Aishwarya, 2025). In recent past times, there has been surge in illegal mining cases in the country, which depicts the loss of biodiversity, ecological damage, and vulnerability to natural calamities in the upcoming years (Kumar et al., 2022). Due to the substantial reliance on fine aggregates, such as river sand, in concrete production, excessive extraction has occurred to satisfy the construction industry's high demand. The environmental consequences of natural river sand mining, especially on riverbanks, have led to its prohibition in many countries. Hence, alternate options are essential to maintain natural resources (Asim et al., 2023).

The use of Manufactured sand (M-sand) has been adopted mainly to reduce and replace the use of natural River sand (R-sand), which is used as fine aggregate in all civil applications (Borigarla et al., 2022). Fine aggregate constitutes from 25% to 35% volume in concrete and more than 50% volume in mortar, so the need of R-sand as a fine aggregate is never ending to be said (John & Dharmar, 2021). Studies have set forth that even 100% replacement is suitable with benefits and drawbacks, where hard properties display acceptable rise, but stiffening the fresh properties (Arulmoly et al., 2021). However, it is evident that in industries and on-site construction, R sand is used and wherever it is scarce M sand is completely replaced (Noufal E. & Manju, 2016). Among the drawbacks, concrete produced with full replacement of M sand experiences higher shrinkage cracks than R sand, due to its finer particles, stone powder content, and angular shapes, potentially leading to higher water demand (Lee et al., 2016; Zhang et al., 2024).

Studies also depict that proportioning the M sand to R sand ratio is beneficial to control water demand, and adding fibres to concrete can reduce the shrinkage and cracks (Gokulnath et al., 2020; Veerappan et al., 2024). The main advantage of adding fibres to concrete is the reduction in post-cracking state and failure strain, where toughness increases through fibres bridging the cracks (Afroughsabet et al., 2016). Compared to natural fibres, such as jute, coir, and bagasse, synthetic fibres, such as glass, polypropylene, and nylon, are becoming more preferable for their ductility, effect on fatigue strength, tensile strength and flexural strength (Hamada et al., 2023; Richardson et al., 2016). The challenge is the increasing amounts of agricultural fibres generated by different production processes resulting in enormous environmental liabilities (Afonso et al., 2022). Industrial waste includes glass waste which can be recycled. Glass fibre is widely available in all sizes and fragments with high potential of recycling and reusability (Bartos, 2017). Fibre volume added to the mix affects the action that it has on mechanical properties, and in the case of orientation, some researchers suggest that fibres aligned perpendicular to the load applied can resist cracks more effectively than fibres in the path of load (Anandaraj et al., 2019). Fibre distribution plays another role, as it impacts fresh and hardened properties of concrete, while heterogeneous distribution can potentially lead to local structural failure of concrete (Simões et al., 2017; Hussain, S. & Yadav, J.S., 2023). Thus, adding glass fibres that are industrial by-products not only helps in improving durability and strength, but also becomes a suitable cause for sustainable construction (Tahir et al., 2023). Microscopic studies showed that mixtures with WG had less micro-cracks and a better transition zone between the geopolymer paste and the fine aggregate (A M Tahwia et al., 2022). The growing interest in finding partial substitutes for cement and other constituents of concrete is the result of the desire to reduce air pollution caused by the cement industry (Ibrahim et al., 2022).

This study aims to improve the concrete mix by replacing R sand, thus decreasing the negative environmental impacts resulting from dredging and extraction. The incorporation of glass fibres at an optimal amount will help improve the durability of the mixture. At different percentages (0%-100%), M sand will be substituted for R sand so as to find an optimum of M sand that will yield the best results for hard and fresh properties. Once the percentage of M sand is ideally fixed, we will be able to add Alkali-resistant Glass Fibres (ARGFs) at the percentage of (0.1%-0.5%), so as to find the optimum concentration of fibres that can yield the best results. Currently, few studies have examined the potential for influencing the strength and durability of concrete by using glass fibres at the proper fraction with partially substituted M-sand concrete as per literature survey.

Materials Used

This study utilizes OPC grade-43 cement, having a specific gravity of 3.14, in accordance with IS 269:2015 criteria. The initial and final setting times were recorded as 45 minutes and 360 minutes, respectively, with a fineness modulus of 2.36%, all in accordance with IS 4031 standards. Locally sourced M sand and R sand corresponded to the specifications of IS 2386-3, both classified as Zone II, with specific gravities of 2.5 and

2.68, respectively. Figure 1 shows the particle size distribution for M sand and river sand. The water absorption rates for R sand and M sand were 0.89% and 1.56%, respectively. A 20-mm coarse aggregate with a specific gravity of 2.7, a fineness modulus of 6.8, and a water absorption rate of 1.2% was employed. Ordinary tap water was utilized for the preparation and curing of concrete. In addition, locally sourced alkali-resistant glass fibres from AKS Build, Ludhiana had a filament length of 12 mm, a filament diameter of 13 µm, a density of 2.7 g/cm^3 and a modulus of elasticity of 72 GPa.

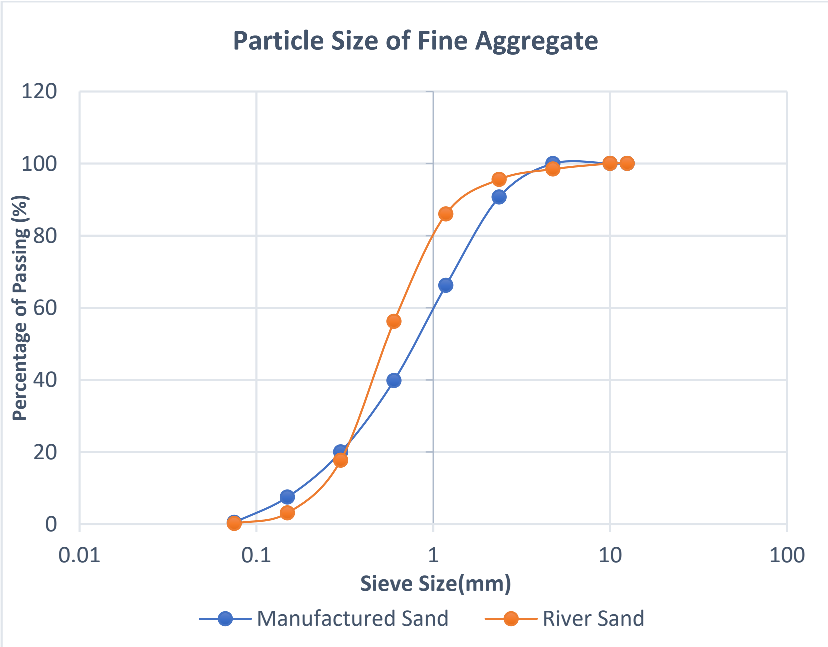


Figure 1. Particle size distribution of fine aggregate

Design for Control Mix for Achieving Grade M25

The mix design seeks to improve the replacement of river sand with M sand while incorporating ARGF to create a successful Glass Fibre-reinforced Concrete (GFRC). The procedure meets the standards stipulated in IS 10262:2019 for concrete mix design. Table 1 shows the mix proportions for control mix M0R100. Table 2 refers to mix proportions for M sand substituted with 10 different percentages (0-100%), and the resulting mixtures are tested for their effects on strength and workability. The replacement level that maximizes strength performance while meeting workability conditions will be selected for further addition of AR-GFRC with % varying as 0.1%, 0.2%, 0.3%, 0.4% and 0.5% of the concrete volume. All the materials have been procured from local areas of Jalandhar and Phagwara.

Table 1. Mix proportions for control mix

Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water(kg/m^3)
421.6	409.11	754.15	189.7
1	0.98	1.8	0.44

Table 2. Mix proportions of all mixes

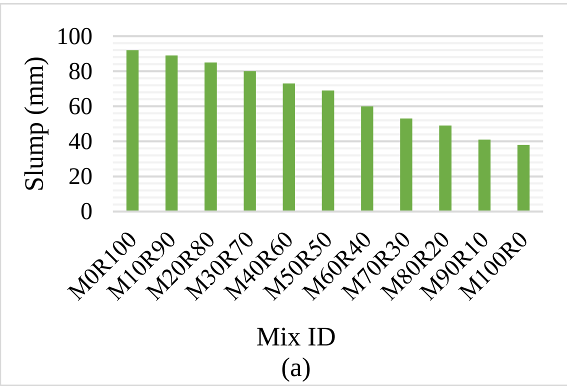
MIX ID	Cement (kg /m^3)	R sand (kg /m^3)	M sand (kg /m^3)	Coarse Aggregate (kg /m^3)	Fibre content (%)
M0R100	421.6	0.00	409.11	754.15	-
M10R90	421.6	40.91	368.20	754.15	-
M20R80	421.6	81.82	327.29	754.15	-
M30R70	421.6	122.73	286.38	754.15	-
M40R60	421.6	163.64	245.47	754.15	-
M50R50	421.6	204.56	204.56	754.15	-
M60R40	421.6	245.47	163.64	754.15	-
M70R30	421.6	286.38	122.73	754.15	-
M80R20	421.6	327.29	81.82	754.15	-
M90R10	421.6	368.20	40.91	754.15	-
M100R0	421.6	409.11	0.00	754.15	-
M60GF1	421.60	245.47	163.64	754.15	1.77
M60GF2	421.60	245.47	163.64	754.15	3.55
M60GF3	421.60	245.47	163.64	754.15	5.32
M60GF4	421.60	245.47	163.64	754.15	7.10
M60GF5	421.60	245.47	163.64	754.15	8.87

The concrete specimen is denoted as M0R100, with M0 indicating 0% M-sand and R100 signifying 100% river sand. Upon calculating the ideal R sand to M sand ratio, glass fibres are added at increasing volumetric percentages: 0.1%, 0.2%, 0.3%, 0.4%, and 0.5% of the total concrete volume. The terminology for specimens involving glass fibres is M60GF0.1, with M60 denoting 60% replacement of M sand and GF0.1 indicating the inclusion of 0.1% glass fibre based on the concrete's weight.

EXPERIMENT AND RESULTS

Fresh Properties

The slump test to evaluate concrete workability is carried out in accordance with IS 1199. A slump cone, with a base diameter of 200 mm, a top diameter of 100 mm, and a height of 300 mm, is utilized to determine the slump depth. Concrete is poured into the cone and compacted prior to measuring the slump. The slump values for conventional concrete without any fibres are within the permissible range for satisfactory workability. M sand's particle size and higher fineness lead to higher water absorption, thus increasing the demand for more water compared to R sand. If, furthermore, glass fibres are added to a fully replaced M sand based concrete, it is sure to reduce the workability due to internal friction and cohesion that fibres cause. In this scenario, optimized M-sand substitution M60R40 has enabled the slump depth within the permissible range, so that the addition of admixtures, such as superplasticizers, can be avoided.



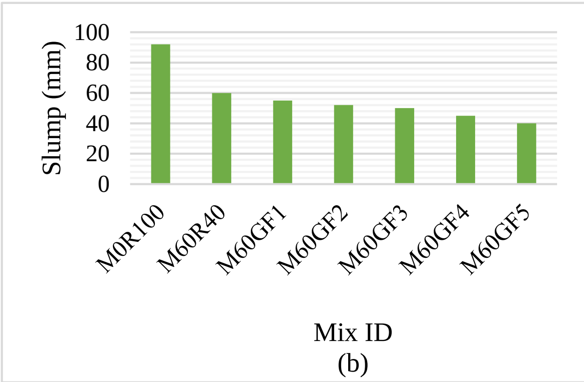


Figure 2. Workability of (a) M sand replaced concrete (b) Alkali-resistant fibre-reinforced concrete

Figure 2 shows that as the M sand is substituted from M0R100 to M100R0, workability diminishes due to water demand. In the case of addition of ARGF to the optimized mix, it is observed that the workability further decreases due to factors, like cohesion of fibres in the concrete matrix and water absorbed due to surface area absorption of fibres.

Table 3. Mechanical strength of tested concrete specimens

	Compressive Strength (Mpa)			Flexural Strength (Mpa)			Split Tensile Strength(Mpa)		
MIX ID	**7-day**	**28-day**	**56-day**	**7-day**	**28-day**	**56-day**	**7-day**	**28-day**	**56-day**
M0R100	21.93	30.15	33.17	2.20	4.10	4.55	1.89	2.94	3.47
M10R90	21.60	28.78	31.66	2.56	4.03	4.47	1.95	2.89	3.41
M20R80	21.10	28.08	30.89	2.96	3.86	4.28	2.11	2.85	3.36
M30R70	21.50	28.95	31.85	3.09	4.05	4.50	2.15	2.91	3.43
M40R60	22.41	29.32	32.25	3.20	4.15	4.61	2.19	2.97	3.50
M50R50	24.23	31.59	34.75	3.50	4.42	4.91	2.68	3.20	3.78
M60R40	27.40	33.69	37.06	3.85	5.06	5.62	2.83	3.59	4.24
M70R30	26.66	33.45	36.80	3.80	4.80	5.33	2.68	3.33	3.93
M80R20	25.85	32.98	36.28	3.62	4.74	5.26	2.61	3.19	3.76
M90R10	23.65	32.80	36.08	3.36	4.59	5.10	2.45	3.20	3.78
M100R0	22.63	32.54	35.79	2.98	4.57	5.07	2.10	3.15	3.72
M60GF1	29.04	32.33	37.00	4.13	5.23	5.88	2.87	3.78	4.54
M60GF2	30.55	33.82	37.20	4.27	5.78	6.50	2.95	3.83	4.60
M60GF3	31.85	36.13	40.53	4.45	6.58	7.40	3.02	4.21	5.05
M60GF4	29.11	33.11	36.42	4.26	6.19	6.96	3.05	3.68	4.42
M60GF5	28.22	31.59	34.70	3.94	5.57	6.27	2.93	3.06	3.67

Hardened samples, which were cured for 7, 28, and 56 days, were tested for compressive strength, flexural strength, and split tensile strength. The results of these tests are displayed in Table 3 for average strength of 3 samples tested corresponding to each mix type for a specific curing age. In all, 144 cube, 144 cylinder and 144 beam specimens were casted.

Compressive Strength

Cube specimen of size 150 × 150 x150 mm was cast and analyzed for the compressive strength of concrete as per IS 516: Part 1: Sec. 1: 2021, in which M-sand substitution exhibited notable changes across mix amounts. On the contrary, M100R0 indicated a small improvement of nearly 3% in compressive strength, revealing that the total substitution yields not much gain. The optimized mix (M60R40), including 60% M sand and 40% R sand, showcased a 19.9% improvement compared to the control mix.

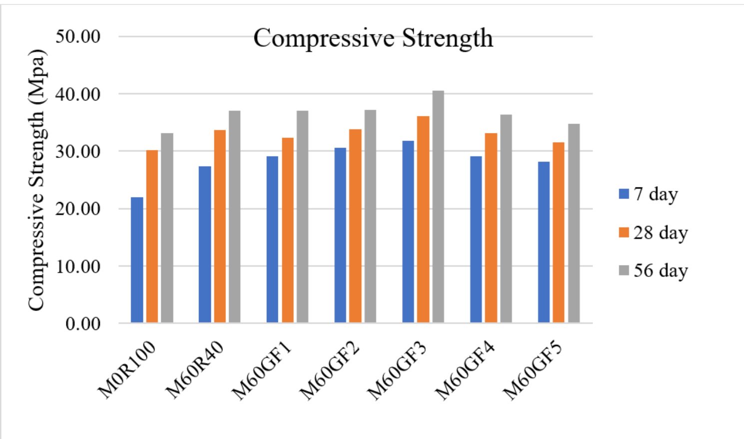


Figure 3. Compressive strength of ARGFC

Table 3 clearly depicts how M60R40 is better than the 100% replacement of M sand, while Figure 3 shows that the pattern of compressive strength increases initially when glass fibre percentages are increased, where peak strength is achieved at the inclusion of 0.3% of ARGF. Addition of glass fibre after 0.3% leads to a decrease in the compressive strength value, and this pattern is similar in both 7-day and 28-day results.

Flexural Strength

A concrete specimen of 100 x 100 x 500 mm was cast and subjected to two-point loading utilizing a flexural testing machine to determine its flexural strength. Testing was performed as per IS 516: Part 1: Sec. 1: 2021. Figure 4 illustrates the increase in flexural strength that results from substituting river sand with M sand and adding glass fibres into the concrete mixture.

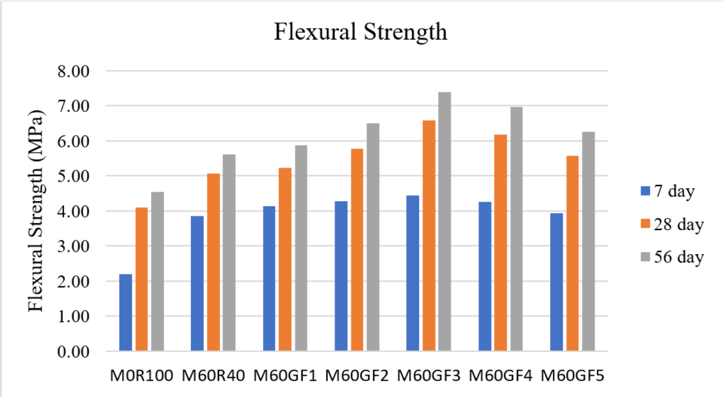


Figure 4. Flexural strength of ARGFC

As per Figure 4, the results indicate that flexural strength of concrete gradually increases with the inclusion of fibres, and upon further increase after 0.3% addition, flexural strength gradually decreases. The flexural strength of AR-GFRC (M60GF3) is double that of conventional concrete.

Split Tensile Strength

The split tensile strength of concrete was assessed under load in accordance with the parameters stated in IS 516: Part 1: Sec. 1: 2021. A cylindrical specimen with a depth of 300 mm and a diameter of 150 mm was fabricated and cast for loading tests. All combinations with M-sand replacement showed improved split tensile strength in comparison to conventional concrete, with M60R40 displaying the greatest splitting strength among all M-sand replacement ratios as per Figure 5.

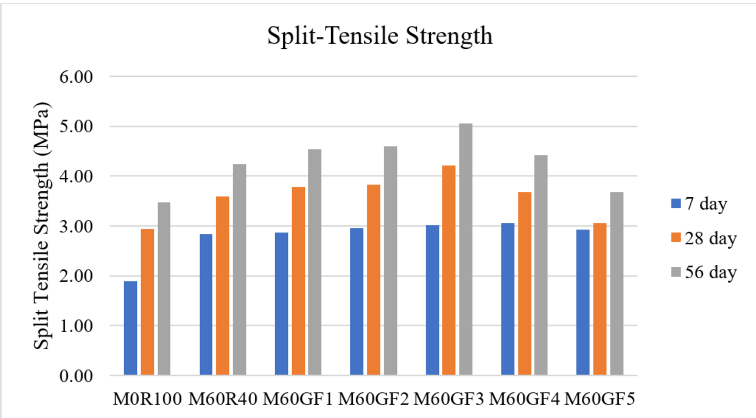


Figure 5. Split tensile strength of ARGFC

When tensile stress develops, micro-cracks are prone to form, counter-acted by the bridging mechanism of AGFRC which is visible at the inclusion of fibres into concrete. Incorporating fibres up to 0.3% increases the split tensile strength and further addition can cause balling effect and stress concentration in concrete which is visible in 0.4% and 0.5% additions.

Water Penetration Test

Concrete samples of 150mm x 150mm x 150mm are cast and cured for 28 days as per test requirements in IS 3085. The test sample is placed in the testing chamber and it is ensured that there is no leakage of water. Pressure is gradually applied from 0.5 to 0.7 MPa for 72 hours. Once the time period of 72 hours is completed, the specimen is split into two halves to observe and mark the depth of water penetrated using a scale.

Table 4. Water penetration test comparisons

MIX ID	Water Penetration Depth (mm)
M0R100 (Normal Concrete)	18
M60R40 (Optimized Mix)	20
M100R0 (M sand 100% concrete)	25
M60GF1	22
M60GF2	21.2
M60GF3 (Optimized AR-GFRC)	15
M60GF4	14.2
M60GF5	13.4

Table 4 represents the depth of water penetrated for the tested mix samples. Conventional concrete has a better water penetration depth as M sand contains more fines, whereas M60R40, the optimized mix of R sand of angular shapes filling up voids and irregularities in M sand, making it a much better approach that fully replaced M-sand concrete. Further, when ARGF is introduced into the concrete, it bridges the micro-cracks and improves the internal bonding, resulting in a much denser mix and reducing water penetration.

Water Absorption Test

Concrete samples of 150mm x 150mm x 150mm, cured for 28 days, are initially oven dried. The dry weights of the samples for various mixes are obtained and then, prior to cooling, they are immersed in water for 48 hours. After immersion, the samples are removed and surface dried to obtain the saturated weight, through which the water absorption percentages are calculated by comparing dry weight to saturated weight.

Table 5. Water absorption test

MIX ID	Dry Weight of Concrete Cube (kg)	Wet Weight of Concrete Cube (kg)	Water Absorption (%)
M0R100	7.47	7.7	3.08
M60R40	7.64	7.79	1.96
M60GF1	7.63	7.8	2.23
M60GF2	8.03	8.17	1.74
M60GF3	7.87	8	1.65
M60GF4	7.83	7.96	1.66
M60GF5	7.93	8.17	3.03

Table 5 indicates that M60GF3 mix showed the lowest water absorption rate of 1.65%, confirming that adding glass fibres at an optimal percentage can decrease the micro-cracks and improve the internal bonding, whereas M60GF4 and M60GF5 are vulnerable to fibre clustering, which induces localized voids, which are later places for water to accumulate.

Rapid Chloride Penetration Test

A 100-mm diameter × 50-mm thickness saturated specimen is placed between two cells, one containing 3% NaCl at the anode and the other 0.3M NaOH at the cathode. A specified voltage is applied for 6 hours, and the current is recorded at intervals. Based on Coulombs passed, permeability is rated under: High (>4000), Moderate (4000-2000), Low (2000-1000), and Very Low (less than 1000).

Table 6. Rapid chloride penetration test

Mix ID	$I_{average}$
MOR100	2932.2
M60R40	2567.7
M60GF1	2437.6
M60GF1	2421.5
M60GF2	2289.3
M60GF3	2107.8
M60GF4	2219.2
M60GF5	2499.3

Table 6 shows that the conventional concrete M0R100 displayed the highest charge passage, with 2932.2 Coulombs, indicating relatively higher chloride permeability and showing poor resistance against chloride attacks. The M60R40 mix is able to resist better compared to M0R100, as it even proves the same in water absorption rates. Compared to both, in M60GF3 with the addition of glass fibres, it exhibits better particle packing and reduced porosity, resulting in lower charges passed with an average of 2107.8 Coulombs.

Scanning Electron Microscopy

The procedure involves cutting a small sample from the concrete cube, drying it thoroughly, and coating it with a conductive material, like gold or carbon, to prevent charging under the electron beam. The sample is then placed in the SEM chamber, where a focused electron beam scans the surface, generating 2D or 3D images with magnification. The dominant phase observed is C-S-H gel, appearing as dense, foamy, clusters that form the primary binding framework which is critical in strength development. Pores and micro-cracks are visible are dark, irregular voids likely arising from capillary water evaporation during curing or mechanical stresses, as shown in Figure 6. Micro-cracks that were observed in M60R40, depicted as in Figure 7, were shorter and tortuous cracks. Tortuous cracks provide better resistance against further crack propagation. Unlike M60R40, in AR-GFRC (M60GF3), it is clearly visible from Figure 8, how fibres reduce cracks and increase interlocking between cement paste, aggregate and fibres. Yazan Issa Abu Aisheh et al. (2022) and Hou, L. et al. (2023) have observed similar results for micro-structural analysis for fibre-reinforced concrete. It has been observed that concrete reinforced with GF and SF exhibits superior mechanical properties and durability in acidic environments, making it a promising material for use in harsh conditions. (Stefania et al., 2025).

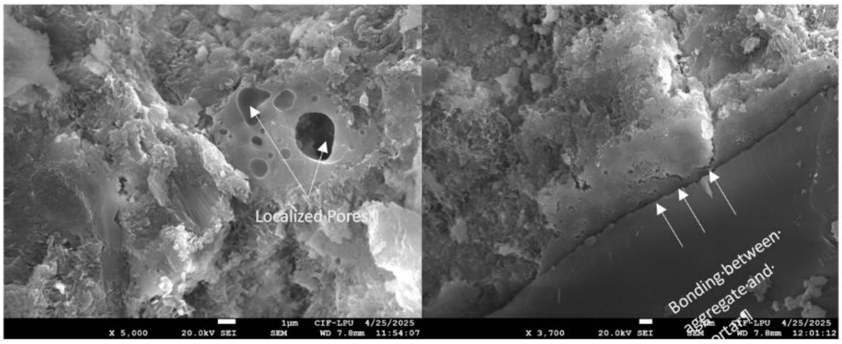


Figure 6. SEM image of conventional concrete (M0R100)

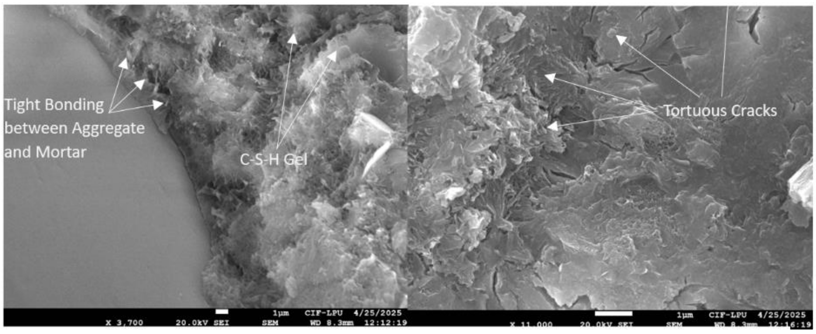


Figure 7. SEM image of M60R40 mix concrete

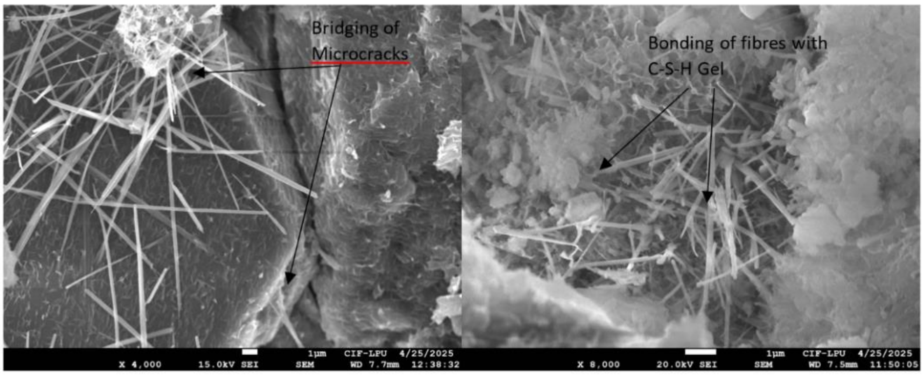


Figure 8. ARGF binding at the ITZ in M60GF3

RESULTS AND CONCLUSIONS

This research has conclusively demonstrated that through careful material selection and proportioning, ARGFRC represents a significant advancement in concrete technology that can address many limitations of conventional reinforced concrete systems while meeting the evolving demands of modern infrastructure. The drawn conclusions can be listed as follows:

1. Concrete developed incorporating partial replacement of natural river sand (R sand) with manufactured sand (M sand) has been identified M60R40 as the optimized mix (60% M sand and 40% river sand) as per 28-day and 56-day strength behaviour. Complete replacement (M100R0) significantly increased the water demand and reduced slump values, the optimized mix (M60R40) achieved a balance in workability with better strength.
2. M60R40 showed increase in compressive strength, flexural strength and split tensile strength after 56-days by 11.7%, 23.5% and 22.19% with respect to the control mix M0R100, while maintaining acceptable workability.
3. Further, blending of concrete mix with AR-GFRC has been studied with addition of 0.1%, 0.2%, 0.3%, 0.4%, 0.5% glass fibre. M60GF3 with the addition of 0.3% of glass fibre showed further improvement in compressive strength, flexural strength and split tensile strength by 9.36%, 38.8%, and 19.1% with respect to M60R40 after 56 days. Moderate reduction in workability, but remained within the acceptable ranges.
4. Durability behaviour studied through water permeability and RCPT also shows satisfactory behaviour for M60GF3. It may suggest reduced risk of reinforcement corrosion.

It is observed through the SEM images of concrete with fibres that there is a reduction in cracks and increase in interlocking between cement paste, aggregate and fibres.

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