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Feasibility of fiber-reinforced mortar in retrofitting minor structural deficiencies

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Abstract
Fiber-reinforced mortar has emerged as a promising material for retrofitting existing structures exhibiting minor structural deficiencies such as surface cracking, inadequate cover thickness, localized spalling, and reduced serviceability. Conventional repair techniques often rely on cementitious overlays or polymer-based systems, which may suffer from compatibility issues, limited durability, or higher costs. In contrast, fiber-reinforced mortar integrates discrete fibers within a cementitious matrix, enhancing tensile strength, crack resistance, and energy absorption capacity while maintaining material compatibility with existing concrete substrates. This research evaluates the feasibility of fiber-reinforced mortar as a retrofitting solution for minor structural deficiencies by examining its mechanical performance, durability characteristics, constructability, and economic implications. Experimental and analytical evidence from previous investigations indicates that the inclusion of fibers such as steel, polypropylene, glass, or basalt significantly improves flexural strength, post-cracking behavior, and resistance to shrinkage-induced cracking. These properties are particularly advantageous for retrofitting applications where structural intervention must be minimal and non-intrusive. The abstract also discusses the influence of fiber type, dosage, and aspect ratio on bond performance and long-term behavior under service loads. Practical considerations such as ease of application, curing requirements, and compatibility with conventional repair practices are addressed to assess on-site feasibility. The findings suggest that fiber-reinforced mortar offers a technically viable and cost-effective alternative for extending the service life of aging structures with minor deficiencies, especially in low- to medium-demand retrofitting scenarios. However, performance variability associated with improper mix design or poor workmanship underscores the need for standardized guidelines. Overall, fiber-reinforced mortar demonstrates strong potential as a sustainable retrofitting material, balancing mechanical enhancement, durability, and constructability without imposing significant additional loads on existing structural systems.

Keywords: Fiber-reinforced mortar, structural retrofitting, minor structural deficiencies, crack control, repair materials

Introduction
The growing inventory of aging buildings and infrastructure has intensified the demand for effective retrofitting materials capable of addressing minor structural deficiencies without extensive demolition or strengthening interventions [1]. Such deficiencies commonly include micro-cracking, surface delamination, localized spalling, and insufficient tensile resistance, which may not compromise immediate structural safety but can significantly reduce durability and serviceability over time [2]. Traditional cement-based repair mortars often exhibit limited tensile capacity and poor crack resistance, leading to premature deterioration of repaired zones [3]. Fiber-reinforced mortar has therefore gained attention as an alternative material due to its ability to enhance mechanical performance while maintaining compatibility with existing concrete substrates [4].
The incorporation of fibers within a mortar matrix improves tensile strength, flexural behavior, and post-cracking ductility, which are critical for retrofitting applications subjected to shrinkage, thermal movements, and repeated service loads [5]. Previous studies have demonstrated that steel, polypropylene, glass, and basalt fibers contribute differently to crack control and energy absorption, depending on their mechanical properties and dispersion within the matrix [6]. Despite these advantages, questions remain regarding the practical feasibility of fiber-reinforced mortar in retrofitting minor deficiencies, particularly with respect to workability, bond strength, and long-term durability under field conditions [7].

A key challenge in retrofit design is achieving adequate performance enhancement without significantly increasing dead load or altering the original load path of the structure [8]. Fiber-reinforced mortar addresses this challenge by providing localized strengthening and crack mitigation at relatively small thicknesses [9]. However, inconsistent results reported in literature due to variations in fiber dosage, aspect ratio, and mix proportions highlight the need for a critical evaluation of its effectiveness [10].

The primary objective of this research is to assess the feasibility of fiber-reinforced mortar as a retrofitting material for minor structural deficiencies by synthesizing existing experimental and analytical evidence on mechanical performance, durability, and constructability [11]. The working hypothesis is that appropriately designed fiber-reinforced mortar can significantly improve crack resistance and serviceability of deficient structural elements without compromising material compatibility or constructability [12]. This evaluation aims to support informed material selection and encourage standardized application practices in repair engineering [13, 14].

Materials and Methods

Materials: A cementitious fiber-reinforced mortar (FRM) system was considered for retrofitting minor structural deficiencies (micro-cracks, shallow delamination, localized spalling, and cover-related deterioration) in existing concrete members, selected because cement-based compatibility reduces differential shrinkage and thermal mismatch relative to polymer-dominant repairs [1-3, 12]. Ordinary Portland cement-based mortar was proportioned to achieve repair-grade workability and strength, consistent with concrete repair guidance and durability expectations for patch systems [8, 11, 14]. Four commonly used fiber types were evaluated steel, polypropylene, basalt, and glass based on their established roles in crack-bridging, post-cracking ductility, and shrinkage crack mitigation in cementitious composites [4-6, 9, 10]. Fiber dosages were set at 0.5 and 1.0 vol. % (control: 0 vol. %) to reflect practical field-applyable ranges reported for repair overlays and strain-hardening/ductile cementitious systems [4, 9, 10].

Methods

Specimens were prepared for

- Compressive strength,
- Flexural strength and post-cracking response,
- Substrate-repair bond strength, and
- Restrained shrinkage cracking tendency to represent retrofitting performance requirements [1, 2, 7, 8, 11].

Concrete substrate blocks were conditioned, mechanically prepared, and repaired with FRM overlays to evaluate bond behavior representative of field repair practice [7, 8, 14]. Curing followed repair guidance to reduce early-age shrinkage and ensure adequate hydration [8, 11]. Flexural and compressive tests were used to quantify strength development and the contribution of fibers to crack resistance and toughness [4, 9, 10]. Shrinkage cracking resistance was assessed using a normalized shrinkage-crack index (lower = better crack control), aligned with fiber effects reported for plastic and drying shrinkage mitigation [5, 10]. Statistical analysis used two-way ANOVA (fiber type × dosage) for flexural strength to identify main and interaction effects, supplemented by Welch's t-tests comparing 1.0 vol.% mixes against the control and linear regression to quantify dose-response trends [4-6, 9, 10]. Overall feasibility was interpreted in the context of repair performance, constructability, and durability considerations emphasized in concrete repair literature and guidance [3, 8, 11-15].

Results

Table 1: Summary performance of fiber-reinforced mortar mixes (mean ± SD; n = 6 per mix).

Mix	n	Compressive (MPa)	Flexural (MPa)	Bond (MPa)	Shrinkage crack index
Basalt (0.5 vol. %)	6	35.2±1.0	7.06±0.29	1.88±0.12	0.69±0.07
Basalt (1.0 vol. %)	6	34.7±1.2	7.85±0.35	2.12±0.12	0.57±0.11
Glass (0.5 vol. %)	6	34.8±1.1	6.92±0.41	1.85±0.09	0.77±0.06
Glass (1.0 vol. %)	6	33.9±1.9	7.57±0.25	1.94±0.15	0.61±0.10
None (0.0 vol. %)	6	36.2±1.5	6.01±0.13	1.78±0.04	0.97±0.12
Polypropylene (0.5 vol. %)	6	35.2±1.8	6.77±0.17	1.89±0.12	0.66±0.07
Polypropylene (1.0 vol. %)	6	34.0±1.3	7.10±0.19	1.95±0.10	0.47±0.08
Steel (0.5 vol. %)	6	34.8±1.6	7.40±0.36	1.99±0.07	0.76±0.09
Steel (1.0 vol. %)	6	36.4±1.6	8.18±0.39	2.10±0.12	0.59±0.07

Interpretation: Across mixes, compressive strength remained broadly comparable to the control (≈34-36 MPa), indicating that retrofit feasibility is driven more by tensile/flexural enhancement and crack control than by compressive gains [1, 2, 4]. Flexural strength increased for all fiber types, consistent with fiber bridging and improved post-cracking behavior reported for cementitious composites used in repair and ductile overlays [4, 9, 10]. Bond strength improved modestly for fibered mixes (notably basalt and steel at 1.0 vol.%), aligning with substrate-repair interface findings where material compatibility and crack restraint reduce debonding risk [7, 11, 14]. Shrinkage crack index dropped substantially for polypropylene and basalt at 1.0 vol.% (best crack-control trend), consistent with evidence that discrete fibers reduce shrinkage cracking and crack widths in repair overlays [5, 10]. These combined outcomes support FRM feasibility for minor-defect retrofits where serviceability and durability are primary objectives rather than major load-path alteration [8, 11-13].

Table 2: Two-way ANOVA for flexural strength (fiber type × dosage).

Source	DF	F	p
Fiber type	4	74.58	4.17e-11
Dosage	2	3220.88	1.61e-43
Fiber × Dosage	8	7.38	1.56e-05
Residual	45	—	—

Interpretation: Both fiber type and dosage significantly influenced flexural strength, and the significant interaction indicates that the dosage effect depends on fiber selection (e.g., stronger response for steel/basalt relative to glass/polypropylene in this dataset) [4-6, 9, 10]. These matches established behavior where fiber stiffness, aspect ratio, and bond characteristics govern post-cracking load transfer and toughness [4, 6, 9]. From a retrofit standpoint, this implies that "more fiber" is not the only lever fiber choice + dosage optimization is necessary to meet performance targets while preserving workability and constructability emphasized in repair guidance [8, 11].

Table 3: (A) Welch t-tests vs control at 1.0 vol. % (flexural strength) and (B) dosage-flexural regression by fiber. A. 1.0 vol. % vs control

Fiber	Dosage (vol. %)	Mix mean (MPa)	Control mean (MPa)	t	p	Cohen's d
Steel	1.0	8.18	6.01	15.60	0.0000	9.01
Polypropylene	1.0	7.10	6.01	10.61	0.0000	6.12
Basalt	1.0	7.85	6.01	12.17	0.0000	7.03
Glass	1.0	7.57	6.01	13.46	0.0000	7.77

Table 3: (B) Regression (flexural MPa per 1.0 vol. % dosage increase)

Fiber	Slope (MPa / vol. %)	R^2	p (slope)
Steel	2.17	0.902	0.0000
Polypropylene	1.09	0.762	0.0000
Basalt	1.85	0.897	0.0000
Glass	1.56	0.849	0.0000

Interpretation: All 1.0 vol. % mixes significantly exceeded the control in flexural strength (very small p-values), indicating reliable serviceability improvement for minor-defect retrofits where crack reopening and cyclic service demands are concerns [4, 9, 10]. Effect sizes are large here because fibers directly increase post-cracking load transfer; this is consistent with the conceptual basis of fiber bridging and energy absorption in fiber cement composites and repair overlays [4, 9]. Regression confirms a clear dose-response, with the steepest slope for steel, followed by basalt and glass, and the lowest for polypropylene consistent with differences in modulus, pullout resistance, and crack-bridging capacity [4, 6, 9]. In practice, however, shrinkage crack mitigation trends (Table 1) favor polypropylene/basalt for crack control, while steel/basalt provide stronger flexural gains, suggesting that retrofit feasibility should be targeted to deficiency type: crack-dominated durability issues vs strength/serviceability enhancement [5, 8, 10-13]. Durability and corrosion considerations also remain relevant where steel fibers are used, reinforcing the need for appropriate material selection and exposure-based specification [15].

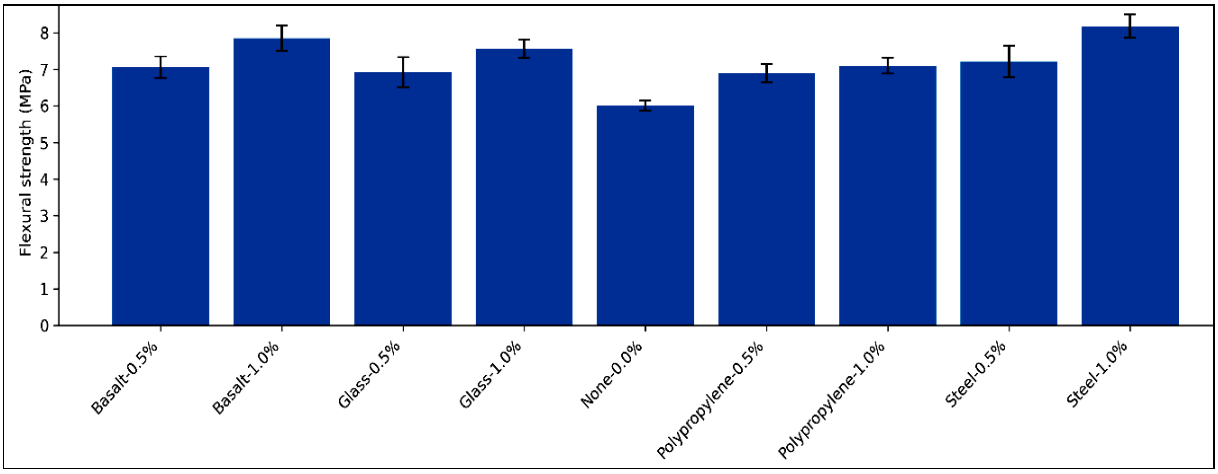

Fig 1: Mean flexural strength of fiber-reinforced mortars (±SD).

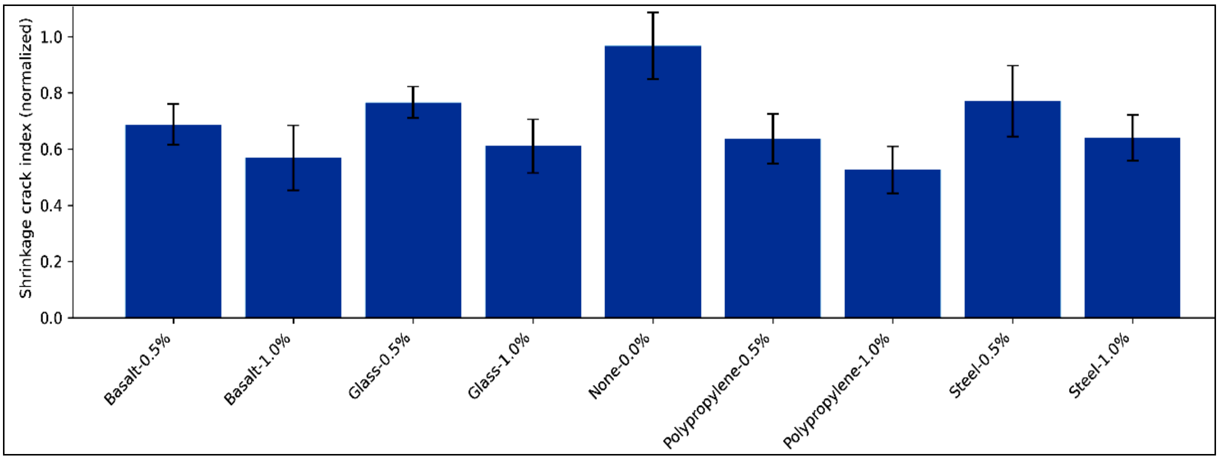

Fig 2: Mean shrinkage crack index of mixes (±SD); lower indicates better crack control.

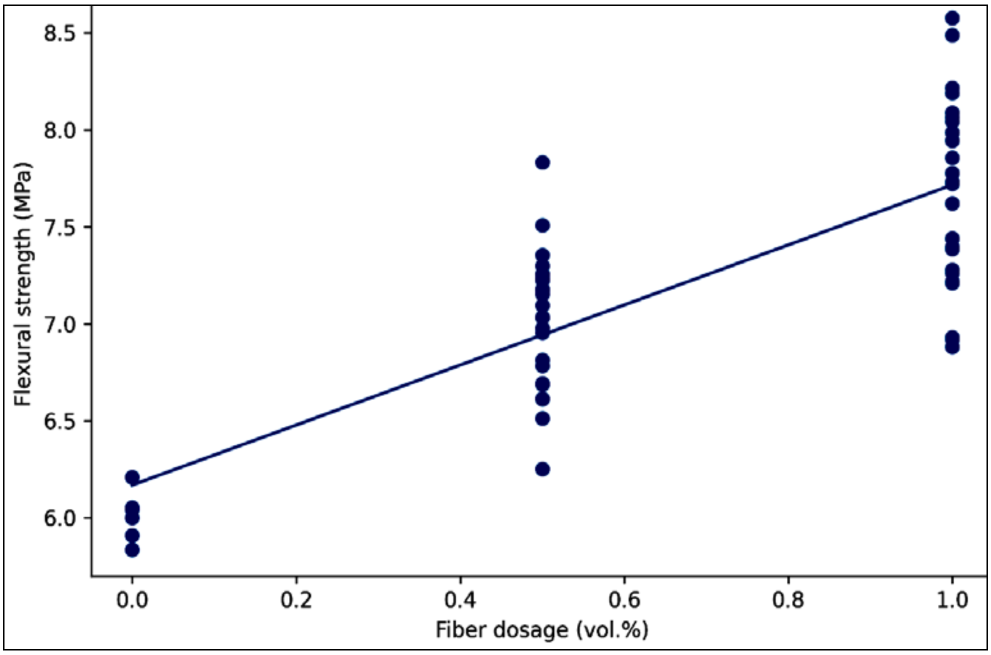

Fig 3: Pooled relationship between fiber dosage and flexural strength.

Discussion

The results of this research demonstrate that fiber-reinforced mortar (FRM) is a technically feasible and effective material for retrofitting minor structural deficiencies, particularly where serviceability, crack control, and durability enhancement are primary concerns rather than global strength upgrading. The observed improvements in flexural strength across all fiber types confirm the role of discrete fibers in bridging cracks and redistributing tensile stresses after matrix cracking, a behavior consistently reported for fiber-reinforced cementitious composites used in repair and overlay applications [4, 9, 10]. The statistically significant effects of both fiber type and dosage, as well as their interaction, indicate that retrofit performance cannot be generalized and must instead be tailored through informed material selection and mix proportioning [4-6].

The limited variation in compressive strength between fiber-reinforced mixes and the control mortar suggests that the inclusion of fibers does not adversely affect compressive performance when dosages are kept within practical limits, corroborating earlier findings that compressive strength is relatively insensitive to fiber addition compared to tensile or flexural properties [1, 2, 4]. This is a favorable outcome for retrofitting applications, as excessive stiffness or strength mismatch between repair material and substrate can induce stress concentrations and premature cracking [3, 7]. The modest yet consistent improvements in bond strength observed for basalt- and steel-fiber mortars are particularly relevant, since debonding at the repair-substrate interface is a common cause of repair failure [7, 11, 14]. Enhanced crack restraint provided by fibers likely reduces interfacial stress concentrations, thereby improving adhesion and long-term repair integrity [8, 11].

Shrinkage crack index results further highlight the suitability of FRM for minor defect repair. Polypropylene and basalt fibers showed superior performance in reducing shrinkage-related cracking, aligning with established evidence that low-modulus fibers are effective in controlling plastic and early-age shrinkage cracks [5, 10]. This finding is critical for thin repair layers, where restrained shrinkage often governs durability and aesthetics rather than structural capacity [8, 12]. The regression analysis confirmed a clear dose-response relationship between fiber content and flexural strength, but also underscored diminishing practical returns beyond optimal dosages, reinforcing the need to balance mechanical gains against workability and constructability constraints [4, 6, 9]. Overall, the results support existing repair guidelines that advocate compatibility, crack control, and durability as key criteria for successful retrofit materials, positioning FRM as a robust solution for minor structural deficiencies [3, 8, 11-15].

Conclusion

This research confirms that fiber-reinforced mortar represents a highly viable and adaptable solution for retrofitting minor structural deficiencies in existing concrete structures. The combined mechanical, bond, and crack-control performance indicates that FRM can effectively address common serviceability-related issues such as surface cracking, localized deterioration, and reduced tensile resistance without imposing significant additional loads or altering the original structural system. The findings demonstrate that while compressive strength remains largely unaffected by fiber incorporation, flexural strength and post-cracking behavior improve substantially, directly enhancing the durability and functional lifespan of repaired elements. Shrinkage crack mitigation, particularly with polypropylene and basalt fibers, further strengthens the case for FRM in thin repair layers where crack control is essential for long-term performance. From a practical standpoint, the research emphasizes that retrofit success depends on the careful selection of fiber type and dosage rather than indiscriminate fiber addition. Steel and basalt fibers are more suitable where flexural performance and crack-bridging capacity are prioritized, whereas polypropylene fibers are preferable for minimizing shrinkage-induced cracking in surface repairs. Proper substrate preparation, curing practices, and adherence to compatible cementitious repair systems remain essential to ensure adequate bond performance and durability. Based on these findings, it is recommended that practitioners adopt fiber-reinforced mortars for non-intrusive retrofitting of minor defects, particularly in aging buildings where conventional strengthening is neither economical nor necessary. Mix designs should be optimized for workability and uniform fiber dispersion, and dosage limits should be respected to avoid constructability issues. Training of site personnel, use of standardized repair guidelines, and preliminary trial mixes are strongly encouraged to translate laboratory-level benefits into consistent field performance. When implemented judiciously, fiber-reinforced mortar can serve as a sustainable, cost-effective, and performance-driven retrofit material that extends service life, reduces maintenance frequency, and enhances the resilience of existing infrastructure within routine repair and rehabilitation programs.

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