

COMPARATIVE STUDY OF STEEL, BASALT, AND POLYPROPYLENE FIBRES IN CONCRETE FOR LOW VOLUME ROAD PAVEMENTS: A REVIEW STUDY

Tripti Saxena¹, Mr. Ushendra Kumar²

¹Master of Technology, Civil Engineering, Lucknow Institute of Technology, Lucknow, India

²Head of Department, Department of Civil Engineering, Lucknow Institute of Technology, Lucknow, India

Abstract - Fibre-reinforced concrete offers improved crack control and, for appropriately designed macrofibre systems, residual flexural resistance that may benefit low-volume concrete road pavements. This narrative review critically compares steel, chopped basalt and polypropylene fibres across crack-bridging mechanisms, fresh-state behaviour, mechanical properties, fatigue, durability, design acceptance, constructability and life-cycle considerations. Special attention is paid to the distinction between polypropylene microfibres used mainly for early-age shrinkage mitigation and structural polypropylene macrofibres used for post-crack load transfer. The literature indicates that steel fibres possess the strongest established connection to pavement residual-strength and fatigue design, whereas basalt fibres show promising tensile and flexural responses but heterogeneous durability findings and fewer validated pavement-scale long-term studies. Polypropylene microfibres offer well-supported plastic-shrinkage control; qualified macro-polypropylene systems can provide residual flexural toughness but depend markedly on geometry, dosage and matrix interaction. Variations in experimental materials and test procedures prevent a universal numerical ranking. The paper proposes a performance-based decision framework for low-volume roads anchored in Indian Roads Congress guidance and standardized residual-flexure testing. It concludes that fibre selection should be governed by the expected failure mechanism, equivalent functional performance, construction control and verified life-cycle benefit rather than fibre identity alone.

Key Words: Low-volume road pavement; fibre-reinforced concrete; steel fibres; basalt fibres; polypropylene microfibres; macro-synthetic fibres; residual flexural strength; fatigue; cracking; durability.

1. INTRODUCTION

Low-volume road (LVR) networks provide first- and last-mile access to villages, agricultural markets, health services and small industrial areas. Although their traffic is lower than that on highways, they are not necessarily lightly stressed: occasional overloaded vehicles, concentrated wheel paths, seasonal saturation and weak shoulders can produce severe local slab responses. Cement-concrete pavements can be attractive where long service intervals are valued, provided the subgrade, drainage, slab thickness,

jointing, workmanship and curing are appropriate. IRC:SP:62-2014 specifically addresses the design and construction of cement-concrete pavements for low-volume roads, while ACI guidance on local streets places similar emphasis on the interaction of thickness, support and drainage [1], [2].

Plain concrete performs well in compression but its limited tensile strain capacity makes it vulnerable to microcracking, temperature and moisture gradients, restrained shrinkage and repetitive flexural stress. Short discontinuous fibres distributed through the matrix can restrain crack opening and, for suitable fibre geometries and dosages, transmit load after matrix cracking. Indian guidance for fibre-reinforced concrete (FRC) pavements and ACI design guidance recognize fibre reinforcement as a performance modifier rather than a universal substitute for proper pavement design [3], [4]. The relevant question for LVRs is therefore not simply which fibre produces the highest 28-day compressive strength, but which fibre system most efficiently addresses the governing deterioration mechanism under realistic construction and exposure conditions.

Steel, basalt and polypropylene (PP) fibres represent different reinforcement strategies. Steel typically supplies relatively stiff, mechanically anchored macrobridges; chopped basalt forms numerous mineral filaments with strong initial tensile properties; and PP spans two distinct categories, fine microfibres aimed principally at early-age crack control and engineered macrofibres capable of residual flexural load transfer. The comparison is easily distorted when micro-PP and macro-PP are combined into one category, when dosage is reported by mass without accounting for density, or when strength results from dissimilar concrete matrices are pooled. This review critically synthesizes the available literature and establishes a pavement-oriented, performance-based basis for comparison [4], [5].

2. SCOPE AND APPROACH OF THE LITERATURE REVIEW

This paper is a narrative, critical literature review, not a report of new laboratory or field experiments. It combines peer-reviewed studies on fibre-matrix interaction, fresh and hardened behaviour, shrinkage, fatigue and durability with

Indian pavement guidance and internationally recognized FRC testing documents. The evidence includes foundational work, material-specific reviews, primary comparative experiments and pavement-focused fatigue investigations. Sources have been selected for relevance, identifiable bibliographic information and engineering transferability; the search is not claimed to be exhaustive or a registered systematic review.

The synthesis uses four explicit comparison rules. First, distinguish fibre material from the form of the supplied product (diameter, shape, aspect ratio, surface treatment and tensile properties). Second, distinguish direct observations in concrete or pavement tests from plausible mechanisms and design extrapolations. Third, evaluate post-crack performance using compatible flexural methods, rather than assuming that increased compressive or splitting tensile strength alone establishes structural utility. Fourth, interpret results in the context of slab support, jointing, curing and the total-life cost of an LVR. Because study matrices, fibre dosages, specimen sizes and loading histories vary widely, no pooled percentage improvement or universal optimum dosage is asserted. Numerical ranges reported from individual publications are clearly identified as study-specific and not adopted as design values.

3. PAVEMENT DEMANDS AND FIBRE-REINFORCEMENT MECHANISMS

An LVR concrete slab behaves as a plate supported by a non-uniform foundation. Wheel loads cause tensile bending stresses at critical positions, including slab edges and corners; temperature and moisture differences create warping or curling; and frictional restraint produces shrinkage-related stress. Where the base loses support, increasing slab strength alone cannot fully prevent cracking or faulting. IRC:SP:62 explicitly treats slab thickness, joints and construction controls, while ACI pavement recommendations emphasize foundation and drainage effects [1], [2]. Fibres should thus be viewed as one part of a system designed to limit crack initiation, subsequent crack opening, spalling and fatigue deterioration.

The crack-bridging action begins when a discontinuity intercepts a fibre and transfers force across the faces through interfacial bond, friction and possibly mechanical anchorage. The contribution depends on the number of effectively oriented fibres crossing the crack, embedment lengths on both sides, tensile stiffness, pull-out resistance and the strength of the surrounding cement paste. A large nominal tensile strength of an isolated fibre cannot guarantee a high residual strength of its composite. Fibre clustering, poor orientation, inadequate anchorage or matrix crushing can prevent that potential from being realized [5]. Conversely, a fibre with lower intrinsic modulus may dissipate energy through elongation and controlled pull-out when its geometry and volume are adequate.

In pavement evaluation, three distinct functions should not be conflated: (i) reduction of early-age plastic shrinkage and settlement cracking, (ii) improvement in uncracked tensile or flexural response, and (iii) retained load-bearing capacity, ductility and fatigue resistance after cracking. The third function is particularly important when fibre contribution is incorporated into a slab design model. Figure 1 illustrates these contrasting fibre-scale mechanisms as an original schematic; it does not claim that every commercial fibre of a given material behaves identically. Material classes and flexural acceptance metrics are respectively codified in ASTM C1116, ASTM C1609 and EN 14651 [6]–[8].

4. STEEL FIBRE-REINFORCED CONCRETE

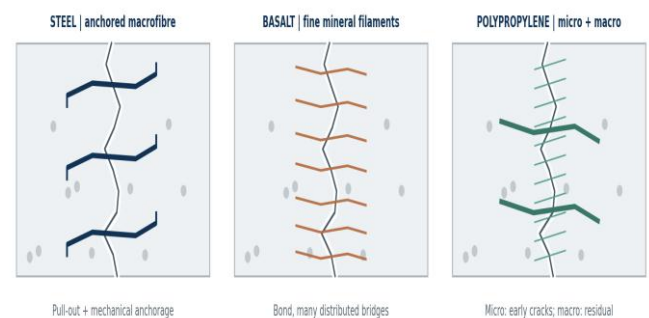


Fig. 1. Idealized fibre bridging across a concrete crack.

Steel fibres are available in straight, crimped, deformed and hooked-end configurations. Their high elastic modulus and tensile capacity support stress transfer across widening cracks; hooked or other deformed ends mobilize additional pull-out resistance. ASTM C1116 distinguishes steel FRC from synthetic and other classes, while ACI 544.4R-18 links design to fibre geometry, dosage and measured post-cracking response rather than material label alone [4], [6]. Steel can therefore be an effective option where repetitive axle loading and residual flexural capacity are central to performance.

Johnston's early overview already identified toughness, fatigue and impact behaviour as reasons for adopting steel-fibre concrete in pavements, while noting fabrication and long-term durability limitations [9]. More recent work by Koorikkattil, Nayar and Venudharan examined generalized fatigue models within different SFRC pavement-design approaches, including IRC:SP:46, and found that design efficiency and predicted response depended materially on the selected fatigue formulation [10]. This is relevant to rural roads because a claimed reduction in slab thickness based solely on cube compressive strength or nominal fibre content cannot be justified without a validated flexural-fatigue framework.

Common disadvantages include loss of workability at higher fibre counts, balling during addition, variability in orientation during vibration, greater mixture mass and cost,

and exposed-fibre corrosion or aesthetic staining. Steel fibres are not necessarily uniformly distributed through the slab depth after placing. Corrosion assessment must be exposure-specific: long-term fibre contribution in wet, cracked concrete is more uncertain than behaviour inside an intact matrix [4]. On rural pavements subject to alternating wet-dry exposure, a wet crack at the surface cannot be assumed to behave like a well-embedded fibre in intact, alkaline concrete. Cover conditions, crack width, exposure and the type of steel must be considered before specifying its long-term contribution.

5. BASALT FIBRE-REINFORCED CONCRETE

Basalt fibres are formed by drawing molten basalt into filaments and are generally supplied for concrete as short chopped strands. Their relatively high tensile strength and modulus, mineral origin and resistance to high temperature attract interest as potential alternatives to metal and petroleum-based reinforcement. Jiang et al. tested chopped basalt fibres of different lengths and volume fractions and found improvements in several mechanical indicators, but also documented higher porosity in the examined fibre concretes [11]. These results demonstrate the central tension in basalt FRC: fibre bridging can aid crack resistance while processing-induced changes in fresh-state dispersion and pore structure may counteract some benefits.

Two broad literature reviews underscore that the optimum basalt dosage is not invariant. Zheng et al. synthesized extensive data on mechanical behaviour and durability and described favourable performance under selected fibre sizes and fractions; Al-Rousan, Khalid and Rahman, however, reported conflicting findings on compressive strength and durability, including cases where strength or transport performance deteriorated [12], [13]. The apparent disagreement is not necessarily experimental error. It reflects differing aggregate grading, admixtures, water-binder ratios, fibre lengths, surface conditions and definitions of 'optimum'. A basalt proportion giving the greatest splitting tensile strength in a small cube campaign need not maximize residual bending capacity in a slab.

The durability argument needs similar nuance. A review of basalt FRC under aggressive environments identified potential improvements against permeability-related damage, frost action and chemical attack, but acknowledged the importance of exposure and fibre-matrix interaction [14]. Basalt is not susceptible to electrochemical rusting like carbon steel, yet the absence of rust is not proof of long-term invariance: mineral fibres can change under highly alkaline pore solutions, and fibre protection depends on composition and manufacturing. For LVRs, basalt appears promising for distributed microcrack management and selected tensile/flexural improvements, but field-scale evidence for retained residual strength after traffic fatigue and environmental ageing is substantially less mature than for

established steel applications. Claims of blanket superiority on sustainability grounds also require route-specific production, transport and service-life inventories.

6. POLYPROPYLENE FIBRE-REINFORCED CONCRETE

Polypropylene is light, chemically non-corroding and widely available, but the label 'PP fibre' is too broad for a technically valid pavement comparison. Micro-polypropylene fibres are relatively fine and numerous at modest addition rates. Their principal function is to control plastic shrinkage and settlement cracking during setting, when evaporation, restraint and an immature cementitious skeleton combine to produce shallow cracks. Banthia and Gupta demonstrated that fibre geometry influenced plastic-shrinkage performance, with fine and longer or fibrillated fibres outperforming less suitable configurations under their tested conditions [15]. Earlier experimental work by Soroushian, Mirza and Alhozaimy likewise documented reductions in surface crack measures at low PP volume fractions [16]. Neither result establishes that low-dose PP microfibres can replace conventional reinforcement or supply design-significant post-crack slab capacity.

Macro-polypropylene fibres are mechanically engineered, longer and usually larger in cross-section. Unlike microfibres, they can engage an opened crack and supply measurable residual flexural stress if their dosage, aspect ratio and fibre-matrix bond are adequate. Lee et al. investigated high-strength macro-PP fibres using concrete of different strengths and fractions from 0.25 to 1.00% by volume, showing that the flexural contribution depended strongly on both matrix strength and dosage [17]. Accordingly, any statement that PP is intrinsically inferior to basalt or steel in toughness is oversimplified; the comparison must specify whether it concerns microfibres or structural macrofibres and which deflection criterion is being considered.

Liu et al. reviewed PP-related shrinkage and durability indicators, observing beneficial tendencies in several studies but also limitations associated with poor dispersion and weak interfacial bonding [18]. PP's hydrophobic surface may restrict stress transfer, and its low elastic modulus relative to steel can reduce its efficiency at very small crack openings. Under high temperature, PP softening and melting can generate pressure-release channels relevant to fire spalling; however, fire behaviour is not normally the governing LVR pavement selection criterion. For wet rural environments, the absence of steel corrosion is an advantage, but this must be weighed against potential long-term creep or relaxation of load-carrying fibres, workmanship sensitivity and the residual strength actually achieved in the specified mix. In contrast, the durability contribution of steel in pre-cracked, chloride-exposed concrete remains more contested than that of intact material [19].

7. FRESH CONCRETE, DOSING AND CONSTRUCTABILITY

Fresh-state behaviour may determine whether the predicted hardened properties can be delivered on a rural road site. Every fibre class increases the internal solid-matrix interface and may reduce measured slump at higher dosage. Length, aspect ratio, dispersion aids, mixing sequence and aggregate size influence balling and the ability to consolidate concrete without voids. Steel macrofibres can entangle if introduced too rapidly; basalt filaments can agglomerate or increase water demand; and dense PP microfibres can reduce apparent mobility or interfere with surface finishing. These are process-dependent outcomes, not fixed material rankings [6], [11], [13], [18].

Comparing a steel dosage expressed in kg/m^3 with a PP dosage in kg/m^3 is particularly misleading because steel is much denser. For equal mass, a PP mixture contains a much larger fibre volume, and its number of filaments depends additionally on length and diameter. The appropriate comparative descriptors are volume fraction, approximate fibre count per unit volume, geometry, mechanical properties and the observed distribution of fibres after mixing. Increasing water to recover slump is generally an unsafe shortcut: the additional water may alter matrix strength, permeability and shrinkage, invalidating the apparent fibre benefit. Mix re-proportioning and approved admixture adjustments should be evaluated instead.

Practical site control must address available mixer capacity, batch time, fibre addition rate, uniformity of supply, paving method, consolidation, surface texture, sawing and curing. Short LVR construction windows and small-batch work may amplify operator variability. IRC:SP:46 provides a dedicated context for fibre dosing, balling and FRC pavement construction, but its provisions should be checked alongside the LVR-specific site requirements of IRC:SP:62 [1], [3]. A field trial strip is particularly valuable because laboratory specimens cannot fully reproduce an actual lane's paving direction, fibre orientation, finishing and saw-cut joint execution.

8. MECHANICAL PERFORMANCE: WHAT THE EVIDENCE SUPPORTS

The literature broadly agrees that suitable fibres can increase energy absorption and reduce the abruptness of failure, but effects on compressive strength are far less consistent. Fibres mainly act in tension or across cracks, so a modest gain in cube strength should be interpreted cautiously. Basalt studies include positive, negative and near-neutral compressive-strength outcomes; macro-PP studies show dosage- and matrix-specific flexural effects; and steel fibre pavement literature emphasizes residual bending and fatigue rather than a universal compressive uplift [10]–[13], [17]. Because compressive strength, first-

crack flexural strength, residual flexural strength and fracture energy describe different mechanical processes, they should never be substituted for one another without a defensible constitutive relationship.

ASTM C1609/C1609M-24 specifies third-point loading of fibre-concrete beams and derives first-peak and residual flexural strengths together with toughness descriptors [7]. EN 14651 uses notched beams to obtain the limit of proportionality and residual flexural tensile strengths at prescribed crack mouth opening displacements; its metallic-fibre scope and the comparability limits for other materials must be respected [8]. Figure 2 highlights the conceptual difference between plain-concrete post-peak softening and a structural FRC response retaining load after cracking. It is not an experimentally observed stress-deflection plot and intentionally avoids assigning performance curves to individual fibre materials.

These tests are especially useful for separating low-dose micro-PP mixtures, which may suppress early shrinkage cracking but provide little residual bending capacity, from structural steel or macro-PP mixtures that satisfy a design-specified residual target. Basalt mixtures should be tested on the same basis before being credited with similar structural contribution. A fair three-way investigation must therefore use comparable workability, curing and concrete grades and report both pre-cracking and post-cracking responses, not just the maximum peak load.

9. FATIGUE, REPEATED LOADING AND PAVEMENT STRUCTURAL DESIGN

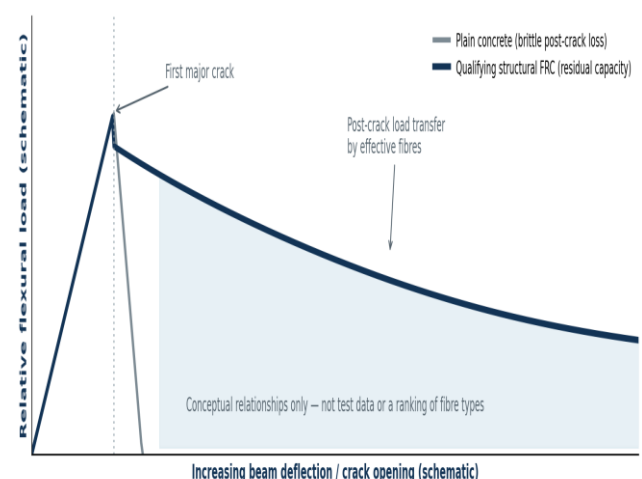


Fig. 2. Schematic distinction between brittle post-crack loss and residual load capacity in qualifying structural FRC (illustrative, nonexperimental curves).

For many LVRs, low cumulative traffic does not eliminate fatigue concerns because wheel positions repeat on a narrow slab and some vehicles carry unusually large loads. Crack

propagation under cyclic loading depends on tensile stress ratio, fibre bridging degradation, foundation support and environmental conditioning. Rooholamini, Karimi and Safari studied fibre-reinforced roller-compacted concrete with steel and macro-synthetic fibres and identified stress level, fracture energy and fibre content as influential variables in a statistical fatigue-life formulation [20]. Although roller-compacted concrete is not interchangeable with conventional cast pavement concrete, the work reinforces the conclusion that fatigue predictions should contain more information than fibre dosage alone. Del Savio et al. similarly associated flexural toughness in synthetic FRC with fibre volume, slenderness ratio and elastic modulus [21].

The pavement-specific comparison by Koorikkattil et al. is notable because it relates generalized flexural fatigue models to alternative SFRC slab design methods [10]. Its implications are methodological: a claimed reduction in thickness must be tied to an explicit stress-fatigue model and a calibrated residual-strength characterization. ACI guidance similarly permits performance-based design logic using characteristic flexural behaviour, but pavement thickness design remains a separate task from material qualification [4]. For basalt and macro-PP, transferring a steel-specific fatigue equation without verification could either overestimate or underestimate the structural benefit.

A rational design comparison would first produce the same traffic spectrum, foundation modulus, joint geometry, concrete grade and reliability target for all options. Second, it would characterize residual bending or fracture energy using consistent beam tests. Third, it would run compatible slab stress and fatigue calculations, incorporating any fibre benefit only where the adopted standard or independently validated method permits. Finally, it would perform sensitivity checks for saturation and weakened edge support. Thin-slab 'savings' that disappear under an unfavourable support modulus are not sufficiently robust for resource-constrained rural road agencies.

10. CRACK CONTROL, DURABILITY AND EXPOSURE

Crack control is a serviceability and durability mechanism rather than merely a visual outcome. Wider connected cracks admit water and aggressive ions, weaken aggregate interlock and can accelerate pumping when drainage is deficient. Surface cracks can develop from rapid moisture loss even before traffic begins; later shrinkage, curling and cyclic wheel loading can enlarge existing defects. PP microfibres have comparatively strong direct evidence for early-age shrinkage mitigation, including sensitivity to fibre geometry [15], [16]. Steel and structural macro-PP can contribute to holding an existing crack narrower, provided sufficient fibres intersect it and their anchorage survives cycling. Basalt also can reduce crack localization in laboratory tests, but its long-term effectiveness is

conditional on bond stability and homogeneous dispersion [11]–[14].

Durability findings should not be condensed into a single 'impermeable' label. A measured reduction in crack width may reduce water penetration through a cracked member, while intrinsic chloride transport through uncracked paste may show little change. Marcos-Meson et al. highlighted that carbon-steel fibre performance under chloride exposure differs markedly between uncracked and pre-cracked specimens [19]. Basalt-FRC reviews report heterogeneous results for porosity and ionic transport, cautioning against extrapolating a favourable freeze–thaw result to every exposure regime [13], [14]. PP is non-corroding but can still indirectly worsen durability if excessive dosage reduces compaction quality or leaves voids [18].

For Indian rural roads, priority actions typically include controlling water–binder ratio, ensuring adequate curing, protecting joint edges, maintaining shoulders and side drains, and preventing stagnant water. A fibre addition does not remove the need for contraction joints or drainage. Climatic stresses and moisture conditions should be documented, and field monitoring should distinguish distress attributable to material cracking from distress due to support loss, poor joints or construction deficiencies [1]–[3].

11. DIRECT COMPARISON AND EVIDENCE STRENGTH

Table 1 provides a qualitative synthesis of typical behaviours supported by the reviewed literature. These are tendencies, not guaranteed ranking positions. Steel usually has the most established design track record for pavement-scale structural residual strength, with the drawback of corrosion assessment and heavier handling. Basalt offers a high filament count and attractive mineral reinforcement characteristics, but performance changes markedly with processing and long-term concrete alkalinity, and pavement-scale fatigue evidence is less consolidated. PP microfibres perform a different task altogether and should be considered for early-age crack control; PP macrofibres are credible contenders for post-crack performance when specified and tested as structural fibres [10]–[21].

A critical limitation in the research base is the frequent absence of matched comparisons. Many steel studies select hooked fibres at a dose suitable for structural capacity, while PP microfibre studies use a lower volume to limit plastic shrinkage, and basalt studies use substantially different fibre lengths or matrix strengths. Ranking such results as 'steel > basalt > PP' would confound function, volume and test method. A defensible comparison must normalize by a defined design function such as residual strength at a nominated deflection, plastic crack area under one exposure, or discounted total cost for a specified pavement life rather

than by fibre material alone. The evidence ratings presented in Table 2 refer to availability of application-specific studies, not to inherent quality of a fibre.

Table 1. Qualitative material comparison for pavement-relevant performance (synthesis of [4], [10]–[21]; no universal ranking implied).

Criterion	Steel macrofibre	Chopped basalt	PP microfibre	PP macrofibre
Principal role	Post-crack toughness; fatigue resistance	Distributed tensile/crack bridging	Plastic shrinkage control	Post-crack residual toughness
Bond/load transfer	High modulus; hooked or deformed anchorage	Fine filament bonding; interface-sensitive	Numerous fine early-stage bridges	Engineered surface/shape; pull-out
Workability concern	Balling/orientation at high dose	Clumping and loss of slump	High surface area and finishing	Dispersion, low slump at high dose
Durability caution	Corrosion at exposed/weave cracks	Alkaline ageing and variable pore effects	Void risk if poorly compacted	Creep/relaxation; interface bond
Evidence basis	Substantial residual/fatigue design literature	Many material tests; less field pavement validation	Strong plastic-shrinkage literature	Growing residual flexural test literature

Table 2. Evidence confidence for specific claimed functions (qualitative interpretation of the reviewed literature).

Target function	Steel	Basalt	PP micro	PP macro
Plastic shrinkage	Moderate	Moderate /	Established	Moderate

Target function	Steel	Basalt	PP micro	PP macro
control		variable	ed	
Structural residual flexure	Established	Emerging / test-specific	Not normally applicable	Established if qualified
Pavement fatigue design	Relatively mature	Limited	Not applicable as structural FRC	Developing
Cracked-environment durability	Exposure-dependent	Uncertain / developing	Chemically non-rusting	Chemically non-rusting; creep study needed

12. ECONOMICS, RESOURCE USE AND LIFE-CYCLE PERSPECTIVE

Initial material price is not an adequate basis for recommending a fibre to a rural-road owner. Unit fibre costs, freight, mixer productivity, rework, required quality assurance, pavement thickness, maintenance frequency and premature cracking risk all contribute to the project total. Steel is relatively heavy and may carry a handling or corrosion-management cost, but an approved structural design could recover some expense through improved residual capacity or lower distress risk. Basalt may avoid metallic rusting, yet its procurement price and supply-chain variability can be significant. PP microfibres often require only small masses to address early-age cracking but should not be credited with steel-like slab capacity; macro-PP generally requires a larger mass than micro-PP and a verified performance grade [4], [15], [17].

Environmental comparisons are similarly conditional. 'Natural mineral' does not automatically mean lower embodied carbon: basalt melting uses energy, steel may incorporate recycled feedstock, and PP is derived principally from petrochemical processing. Transport distance, fibre yield, dosage and actual change in maintenance cycles determine project impacts. Without a common functional unit for example, one lane-kilometre of pavement meeting the same load, safety and service-life targets an emission ranking is speculative. A useful LVR study would combine inventory-based cradle-to-gate impacts with pavement thickness, construction processes, rehabilitation schedules and uncertainty in service life. Since robust field-life

databases for many basalt and PP configurations remain limited, economic and environmental comparisons should be treated as scenarios, not precise predictions.

13. PERFORMANCE-BASED SELECTION FOR LOW-VOLUME ROADS

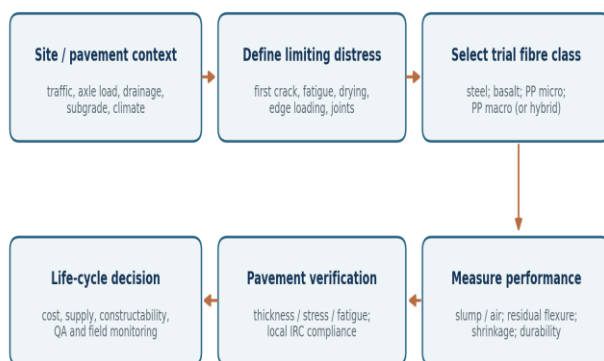


Fig. 3. Proposed performance-based fibre-selection and verification process for low-volume concrete road pavements (author-drawn conceptual framework).

Figure 3 proposes a practical decision sequence. Under repeated heavy wheel loading, a steel macrofibre or qualified PP macrofibre system can be shortlisted where measurable residual strength and fatigue resistance are required; chopped basalt may also be considered, but its use as a structural design input should await equivalent testing and a recognized design model. Where early-age drying and wide exposed paving surfaces dominate the cracking risk, a low-dose PP microfibre solution may be appropriate as an adjunct to curing, while it should never replace curing. Where wet-dry cycling and corrosive exposure are prominent, the corrosion-free nature of basalt or PP may influence selection, but only after confirming matrix permeability and fatigue performance [4], [15], [18], [19].

The procurement specification should state what is to be delivered rather than simply naming '1% fibre'. Suitable requirements include fibre identification and compliance documents, target matrix grade, acceptable workability and air content, mixing/dispersal procedure, required beam-test residual strength or shrinkage criterion, curing regime, trial-strip acceptance and routine production control. ACI SPEC-544.12-23 gives a useful performance-based precedent for structural macrofibre slabs and overlays, while explicitly excluding microfibres used for plastic-shrinkage control [22]. Its provisions cannot be inserted mechanically into an Indian road contract; the adopted IRC pavement design and project specifications must remain controlling.

For an M.Tech. student proposing subsequent experimental work, a meaningful comparative matrix would maintain one

base mix and aggregate system, select equivalent performance-driven dosage ranges for each fibre, quantify slump and dispersion, then test compressive strength, flexural response, residual capacity, restrained shrinkage and limited cyclic performance. Micro-PP and macro-PP should be reported as different treatment arms. Statistical replication, random specimen allocation and reporting of coefficient of variation would help identify whether apparent advantages are material or merely experimental scatter. The review itself does not present original measurements.

14. CONCLUSIONS

The reviewed evidence supports fibre reinforcement as a means of improving crack management in cement-concrete LVR pavements, but not as a cure for poor foundation support, drainage, joints, curing or paving practice. Among the materials considered, steel macrofibres possess the clearest established pathway to measured residual flexural response and structural fatigue design, with workability and cracked-state corrosion requiring attention. Basalt fibres can enhance distributed crack resistance and selected tensile or flexural properties, but inconsistent compressive and transport findings and limited pavement-scale long-term fatigue validation rule out blanket substitution claims. Polypropylene microfibres are particularly useful for early-age plastic shrinkage; structural macro-PP fibres can also furnish post-crack capacity when their geometry, dosage and test response warrant it.

For low-volume roads, there is consequently no defensible universal 'best' fibre. The appropriate choice depends on whether the governing objective is early-age shrinkage protection, fatigue resistance, post-crack toughness, aggressive-environment performance or minimized life-cycle cost. Fibre types should be compared at equivalent functional performance, through ASTM C1609 or another fit-for-purpose residual-strength method when structural behaviour is claimed, with pavement verification under IRC guidance. The principal recommendation is to select and accept fibre concrete on measured pavement-relevant performance, document construction variability, and validate promising alternatives through matched tests and field sections before claiming service-life or thickness advantages.

REFERENCES

- [1] Indian Roads Congress, Guidelines for Design and Construction of Cement Concrete Pavements for Low Volume Roads, IRC:SP:62-2014, 1st rev., New Delhi, India, 2014. Available: <https://gpims.wb.gov.in/Engineering/Codes/IRCSP062.pdf>
- [2] ACI Committee 325, Guide for Design of Jointed Concrete Pavements for Streets and Local Roads, ACI 325.12R-02

- (reapproved 2019), American Concrete Institute, Farmington Hills, MI, USA, 2002.
- [3] Indian Roads Congress, Guidelines for Design and Construction of Fibre Reinforced Concrete Pavements, IRC:SP:46-2013, 1st rev., New Delhi, India, 2013.
- [4] ACI Committee 544, Guide to Design with Fiber-Reinforced Concrete, ACI 544.4R-18, American Concrete Institute, Farmington Hills, MI, USA, 2018.
- [5] A. Bentur and S. Mindess, Fibre Reinforced Cementitious Composites, 2nd ed. London, U.K.: Taylor & Francis, 2007.
- [6] ASTM International, Standard Specification for Fiber-Reinforced Concrete, ASTM C1116/C1116M-23, West Conshohocken, PA, USA, 2023, doi: 10.1520/C1116_C1116M-23.
- [7] ASTM International, Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading), ASTM C1609/C1609M-24, West Conshohocken, PA, USA, 2024, doi: 10.1520/C1609_C1609M-24.
- [8] European Committee for Standardization, Test Method for Metallic Fibre Concrete—Measuring the Flexural Tensile Strength (Limit of Proportionality (LOP), Residual), EN 14651:2005+A1:2007, Brussels, Belgium, 2007.
- [9] C. D. Johnston, "Steel fibre-reinforced concrete—present and future in engineering construction," *Composites*, vol. 13, no. 2, pp. 113–121, 1982, doi: 10.1016/0010-4361(82)90047-7.
- [10] A. Koorikkattil, S. K. Nayar, and V. Venudharan, "Flexural fatigue design of steel fibre reinforced concrete pavements: A comparative study," *Road Materials and Pavement Design*, vol. 24, no. 9, pp. 2301–2321, 2023, doi: 10.1080/14680629.2022.2139285.
- [11] C. Jiang, K. Fan, F. Wu, and D. Chen, "Experimental study on the mechanical properties and microstructure of chopped basalt fibre reinforced concrete," *Materials & Design*, vol. 58, pp. 187–193, 2014, doi: 10.1016/j.matdes.2014.01.056.
- [12] Y. Zheng, Y. Zhang, J. Zhuo, Y. Zhang, and C. Wan, "A review of the mechanical properties and durability of basalt fiber-reinforced concrete," *Construction and Building Materials*, vol. 359, Art. no. 129360, 2022, doi: 10.1016/j.conbuildmat.2022.129360.
- [13] E. T. Al-Rousan, H. R. Khalid, and M. K. Rahman, "Fresh, mechanical, and durability properties of basalt fiber-reinforced concrete (BFRC): A review," *Developments in the Built Environment*, vol. 14, Art. no. 100155, 2023, doi: 10.1016/j.dibe.2023.100155.
- [14] Y. Li, J. Zhang, Y. He, G. Huang, J. Li, Z. Niu, and B. Gao, "A review on durability of basalt fiber reinforced concrete," *Composites Science and Technology*, vol. 225, Art. no. 109519, 2022, doi: 10.1016/j.compscitech.2022.109519.
- [15] N. Banthia and R. Gupta, "Influence of polypropylene fiber geometry on plastic shrinkage cracking in concrete," *Cement and Concrete Research*, vol. 36, no. 7, pp. 1263–1267, 2006, doi: 10.1016/j.cemconres.2006.01.010.
- [16] P. Soroushian, F. Mirza, and A. Alhozaimy, "Plastic shrinkage cracking of polypropylene fiber reinforced concrete," *ACI Materials Journal*, vol. 92, no. 5, pp. 553–560, 1995, doi: 10.14359/894.
- [17] J.-H. Lee, B. Cho, E. Choi, and Y.-H. Kim, "Experimental study of the reinforcement effect of macro-type high strength polypropylene on the flexural capacity of concrete," *Construction and Building Materials*, vol. 126, pp. 967–975, 2016, doi: 10.1016/j.conbuildmat.2016.09.017.
- [18] Y. Liu, L. Wang, K. Cao, and L. Sun, "Review on the durability of polypropylene fibre-reinforced concrete," *Advances in Civil Engineering*, vol. 2021, Art. no. 6652077, 2021, doi: 10.1155/2021/6652077.
- [19] V. Marcos-Meson, A. Michel, A. Solgaard, G. Fischer, C. Edvardsen, and T. L. Skovhus, "Corrosion resistance of steel fibre reinforced concrete—A literature review," *Cement and Concrete Research*, vol. 103, pp. 1–20, 2018, doi: 10.1016/j.cemconres.2017.05.016.
- [20] H. Rooholamini, A. Karimi, and J. Safari, "A statistical fatigue life prediction model applicable for fibre-reinforced roller-compacted concrete pavement," *Road Materials and Pavement Design*, vol. 24, no. 1, pp. 103–120, 2023, doi: 10.1080/14680629.2021.2011382.
- [21] A. A. Del Savio, D. La Torre Esquivel, F. de Andrade Silva, and J. A. Pastor, "Influence of synthetic fibers on the flexural properties of concrete: Prediction of toughness as a function of volume, slenderness ratio and elastic modulus of fibers," *Polymers*, vol. 15, no. 4, Art. no. 909, 2023, doi: 10.3390/polym15040909.
- [22] ACI Committee 544, Performance-Based Fiber-Reinforced Concrete for Slabs-on-Ground and Overlays Specification, ACI SPEC-544.12-23, American Concrete Institute, Farmington Hills, MI, USA, 2023.