

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

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Abstract - Low-volume cement-concrete roads require mixtures that balance flexural resistance, cracking behaviour and site workability under constrained construction conditions. This paper critically compares steel, chopped basalt and polypropylene (PP) fibre systems using the conceptual and methodological framework of an M30 concrete dissertation and a limited reanalysis of explicitly identified published data. The proposed primary programme comprises a fibre-free control and nine single-fibre mixes: steel at 0.5–1.5%, basalt at 0.1–0.3% and PP at 0.1–0.3% by concrete volume. However, the dissertation supplies no original batching records or mechanical test measurements; accordingly, no local experimental results are claimed. Secondary values extracted in the dissertation from Jiang et al. (2014) indicate that increasing basalt or PP content improved reported 28-day flexural strengths relative to the source control but substantially decreased slump. For the selected data, flexural change ranged from +5.25% to +10.37%, while slump change ranged from –15.14% to –68.11%. These results pertain to the published source matrix, not to the proposed M30 mixes, and contain no steel-fibre observations. The paper establishes a reproducible comparison framework emphasizing fibre identity, equivalent volume accounting, replication, workability, peak and residual flexural performance and cautious pavement interpretation. The main conclusion is that fibre selection for low-volume pavements must be performance- and constructability-based; no universal ranking or pavement-life benefit is defensible without primary testing.

Keywords: low-volume roads; fibre-reinforced concrete; steel fibre; basalt fibre; polypropylene; flexural strength; slump; M30 concrete

1. INTRODUCTION

Village roads, agricultural connections and market-access routes carry relatively modest traffic yet remain essential to social and economic mobility. Their low average traffic does not exclude heavy occasional axle loads or adverse combinations of drainage, inadequate support and infrequent maintenance. Cement-concrete pavements can provide a useful surfacing option, but slab behaviour is controlled by bending, tensile cracking, joint action, subgrade support and construction quality rather than cube compressive strength alone. Indian Roads Congress guidance

for low-volume cement-concrete pavements addresses the combined effects of traffic, temperature, foundation and construction (IRC, 2014). Improvements in laboratory concrete strength therefore cannot automatically be translated into reduced slab thickness, fewer joints or longer service life.

Plain concrete has limited tensile strain capacity. Discrete fibres may intersect developing cracks and transfer force through bond, friction, pull-out resistance or mechanical anchorage. Fibre reinforcement may thus modify crack development and post-cracking response, even where compressive strength changes are modest. Crucially, resistance to the first crack and sustained load after cracking are distinct responses. A conventional peak-load beam test cannot quantify residual flexural strength or energy absorption; these require controlled load–deflection measurements and suitable testing procedures (ASTM International, 2024; Gopalaratnam and Gettu, 1995).

Steel, basalt and PP fibres provide contrasting material characteristics. Steel macrofibres are relatively stiff and may exploit deformed or hooked anchorage; chopped basalt comprises mineral filaments whose dispersion and matrix compatibility are important; PP is a low-density polymer supplied either as microfibres often used for early cracking control or as engineered macrofibres capable of structural post-crack contribution. Material labels alone are therefore poor predictors of performance. This paper converts the supplied dissertation into a focused research manuscript while explicitly separating its proposed experimental design from externally published observations.

2. RESEARCH OBJECTIVE AND EVIDENCE BOUNDARIES

The objective is to establish what can presently be concluded about the applicability of three separately incorporated fibre types to low-volume pavement concrete, and to define a controlled M30 test programme able to resolve the remaining questions. Specifically, the comparison concerns fresh consistency, compressive strength, splitting tensile strength, flexural performance, fibre dispersion, specimen variability and practical dosage. It does not attempt a hybrid-fibre optimization, life-cycle assessment or numerical pavement structural design.

An evidence audit of the dissertation is essential. Chapters 1–3 define intended procedures, mix groups and test ages, whereas Chapter 4 explicitly reports that final material certificates, reference-mixture quantities, specimen registers, curing histories and testing-machine readings were not provided. Its quantitative figures are either secondary observations taken from Jiang et al. (2014) or transparent arithmetic based on assumed densities and planned quantities. The distinction is maintained throughout this article. The absence of primary measurements is not treated as a zero result or used to infer which fibre achieved the highest strength.

3. COMPARATIVE BACKGROUND

3.1 Steel-fibre concrete

Steel fibres can bridge relatively wide cracks because their stiffness and mechanical anchorage support post-crack force transfer. Steel-fibre fatigue investigations by Singh and Kaushik (2001, 2003) examined flexural loading and highlighted the effects of dosage, cyclic stress parameters and substantial scatter in life estimates. Meda et al. (2004) investigated steel-fibre slabs on grade, underscoring the relevance of support conditions beyond isolated beam strength. Such evidence establishes mechanical plausibility, not a verified advantage for the untested steel mixes in the present dissertation. Greater steel volume or longer fibre geometry may also hinder mixing, compaction and finishing; exposed fibres can create local corrosion or surface issues depending on product and exposure.

3.2 Basalt-fibre concrete

Basalt fibres originate from basaltic feedstock and are available as chopped strands of different lengths and surface treatments. Their comparatively fine filament form can intersect small cracks, but dispersion, interfacial interaction and alkaline exposure require consideration. Jiang et al. (2014) examined chopped basalt fibres, mechanical properties and microstructure; their dataset forms the limited numerical benchmark analysed below. Other work on basalt reinforcement identifies fibre length, dosage and the surrounding matrix as substantial performance modifiers (Jalasutram et al., 2017; Kizilkanat et al., 2015). Short-term static strengths cannot establish long-term alkali stability, field wear or resistance to moisture ingress.

3.3 Polypropylene-fibre concrete

Polypropylene has a much lower density than steel, so apparently small mass dosages may produce a large count of fine filaments. Micro-PP fibres are frequently considered for controlling early-age shrinkage cracking, while macro-PP reinforcement is intended to contribute at larger crack openings. Results obtained with one form cannot be transferred to the other. Song et al. (2005) examined

selected strength outcomes of PP-fibre concrete, whereas Roesler et al. (2006) evaluated structural behaviour of slabs with synthetic fibres. A static flexural-strength value must not be represented as a direct measurement of restrained shrinkage, impact resistance or post-crack structural capacity.

3.4 Fair basis of comparison

The comparison must specify both fibre volume fraction and mass per cubic metre. Equal mass does not mean equal reinforcing volume, and equal volume does not standardize fibre length, aspect ratio, surface area, orientation, stiffness or anchorage. Ideally, identical binder, aggregates, water-to-binder ratio, curing and specimen dimensions should be used, while each product is tested within a pilot-verified workable dosage range. A common control can reveal the effect of adding each selected fibre to that concrete system; it cannot establish that every steel fibre outperforms every basalt or PP product. This restriction is particularly relevant because the proposed steel percentages are much higher than those for basalt and PP.

4. MATERIALS AND METHODS: PROPOSED M30 INVESTIGATION

4.1 Mixture matrix and material characterization

The dissertation specifies an M30 nominal design objective with proportions to be developed under IS 10262:2019 and the relevant provisions of IS 456:2000. No finalized mixture quantities, admixture schedule or material test certificates accompany the uploaded document. Consequently, M30 is reported as a design target, not as a demonstrated characteristic strength. Each fibre product should be identified by commercial grade, physical form, density, fibre length, diameter or equivalent dimension, tensile characteristics, surface condition and supplier lot. Cement, aggregate grading, moisture and admixture properties also require documentation.

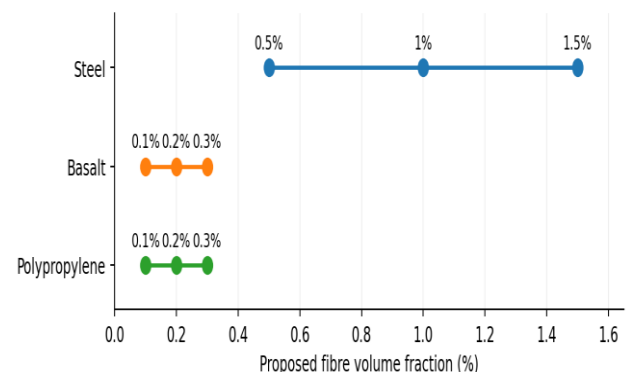


Figure 1. Proposed fibre-dosage levels in the dissertation (not tested mixtures). The fibre-free M30 control is 0%.

4.2 Dosage accounting and fresh-concrete testing

For a final concrete volume of 1 m^3 , theoretical fibre mass follows $m_f = (V_f/100)\rho_f$, where V_f is fibre percentage by volume and ρ_f is fibre density in kg/m^3 . As the specific commercial product densities are unverified, illustrative values in the dissertation are 7850 kg/m^3 for steel (assumed), 2650 kg/m^3 for basalt and 910 kg/m^3 for PP (reported for products in Jiang et al., 2014). These values produce nominal masses of 39.25, 78.50 and 117.75 kg/m^3 for the three steel levels; 2.65, 5.30 and 7.95 kg/m^3 for basalt; and 0.91, 1.82 and 2.73 kg/m^3 for PP. They are planning calculations, not actual batched weights. Yield and matrix displacement must be considered in final proportioning.

Pilot trials are needed to examine fibre balling, dispersion, segregation, cohesion, consolidation and finishing. The mixing order, time, batch size and any permitted admixture correction should be fixed and logged. Slump measurements should be accompanied by qualitative observations rather than interpreted as a complete measure of site constructability. If a dose cannot be mixed or cast properly, its impracticality should be reported openly rather than corrected by undisclosed addition of water.

4.3 Proposed specimen testing and analysis

The intended destructive programme uses ten mixes, three mechanical response categories, two curing ages (7 and 28 days) and three specimens per category and age, giving 180 total planned specimens. Nominal sizes stated in the dissertation are 150 mm cubes for compression, 150×300 mm cylinders for splitting tension and $150 \times 150 \times 700$ mm beams for flexure; test span and the exact applicable procedures must be verified before casting. IS 516 (Part 1/Sec 1):2021 is identified for strength testing. The equation $f_c = P/A$ gives compressive strength from ultimate load and loaded area; flexural stress should be computed using the geometry and fracture-location rules of the adopted third-point loading standard.

For each outcome, individual results, mean, sample standard deviation and coefficient of variation should be reported; percentage change relative to C0 is $100(X_f/X_0 - 1)$. Tests using calibrated midspan deflection and the procedures of ASTM C1609/C1609M are additionally needed before making numerical claims about residual strength and flexural toughness. Photographs of fracture faces can document crack patterns but cannot substitute for an instrumented post-peak response. Comparison across mixes must consider whether observed mean differences are larger than measurement scatter and whether workability changed meaningfully.

5. SECONDARY-DATA RESULTS AND INTERPRETATION

5.1 Source and quantitative dataset

The dissertation extracts a selected subset from the published experiment of Jiang et al. (2014), Materials & Design, 58, 187–193, DOI: 10.1016/j.matdes.2014.01.056. This subset shares a published reference control and includes two PP levels plus 12 mm and 22 mm basalt fibres at two levels each. It does not include steel. The reported published control had a 28-day compressive strength of 45.12 MPa and a flexural strength of 7.62 MPa; it is not the untested M30 reference specified for the dissertation. Because the original source used its own ingredients and procedures, the observations are external benchmarks only.

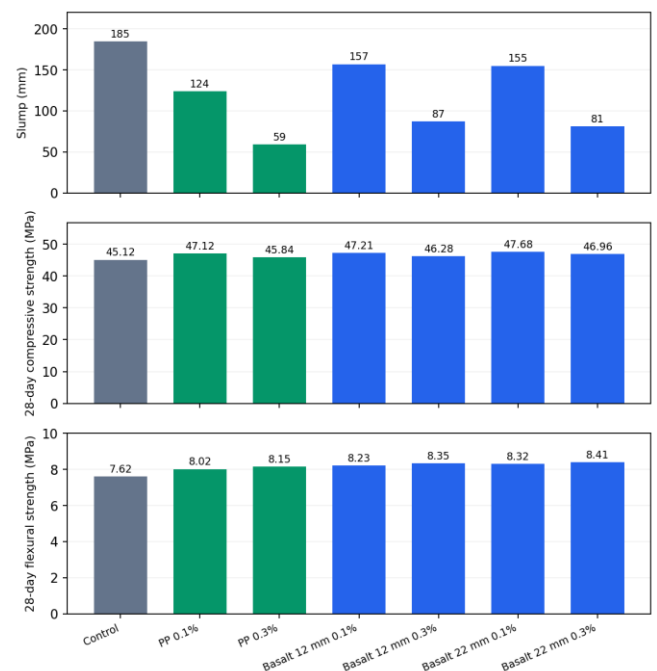


Figure 2. Published comparison dataset reproduced from the dissertation's discussion of Jiang et al. (2014).

5.2 Workability trade-off

In the published series, slump falls from 185 mm for the control to 124 and 59 mm for 0.1 and 0.3% PP, corresponding to -32.97% and -68.11% . The 12 mm basalt series decreases to 157 and 87 mm (-15.14% and -52.97%); the 22 mm basalt series decreases to 155 and 81 mm (-16.22% and -56.22%). These are simple recalculations of tabulated slump, not estimates from local tests or statistically adjusted treatment effects. All selected fibre mixtures exhibit less slump than the published control, with pronounced loss at 0.3%.

This trade-off is highly relevant to rural pavement work, which may use modest mixing and placing equipment. Lower slump can complicate placing and compaction; however, slump alone does not prove a specimen was poorly consolidated. Changes in fibre geometry, surface area, mixing procedure and admixtures may contribute to observed differences, and the selected dataset cannot isolate these mechanisms causally. Constructability should therefore be assessed alongside strength, not treated as an afterthought or solved through arbitrary water addition.

5.3 Compression and flexural strength

Relative to the published control, the 28-day compressive change was +4.43% and +1.60% for PP at 0.1 and 0.3%; +4.63% and +2.57% for 12 mm basalt; and +5.67% and +4.08% for 22 mm basalt. Within the reported subset, the higher fibre fraction did not produce a larger compressive-strength gain. This reinforces the view that fibre addition is not simply a route to higher cube strength and that changes in concrete packing, entrained air and fibre-matrix interaction deserve investigation. These percentages cannot be compared with an unmeasured M30 baseline.

Flexural strength in the same published mixes increased to 8.02 and 8.15 MPa for PP (+5.25% and +6.96%), 8.23 and 8.35 MPa for 12 mm basalt (+8.01% and +9.58%), and 8.32 and 8.41 MPa for 22 mm basalt (+9.19% and +10.37%). The highest selected absolute flexural figure is thus 8.41 MPa for 22 mm basalt at 0.3% in that source. It is not evidence that basalt is the strongest universal fibre, nor can it be ranked against steel using this data. The magnitude of flexural benefit must also be evaluated against the reduction in fresh consistency and the unknown uncertainty of the selected individual means.

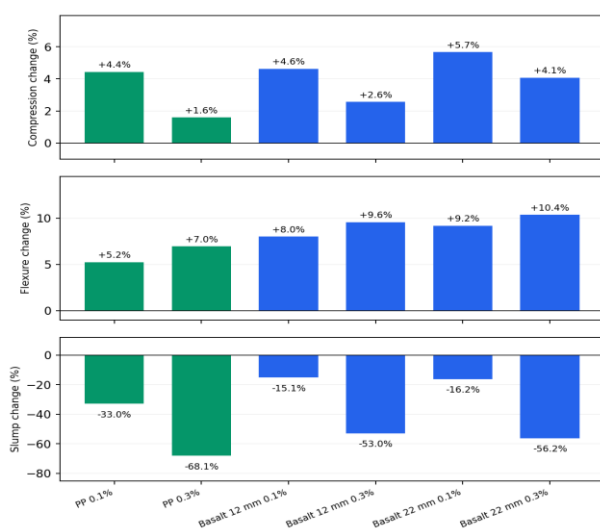


Figure 3. Percentage changes calculated from the published control shown in Figure 2; values are external secondary data.

5.4 Implications for steel, cracking and pavement service

No steel-fibre strength, slump or post-crack observation is present in the numerical benchmark. Although established studies discuss steel-fibre fatigue resistance and anchored crack bridging, substituting such literature for local steel-mix results would make the comparison invalid. The steel percentages in the proposed design also exceed basalt and PP percentages substantially, emphasizing the need to distinguish useful practical dosing from nominal volume equality. A balanced conclusion is that steel is a credible candidate for testing where post-crack load carrying is important, not that it has already achieved a superior outcome in this M30 programme.

A second limitation concerns the interpretation of flexural strength. A larger modulus of rupture can indicate increased peak bending resistance, but it does not directly describe residual load, crack width control, fracture energy or fatigue under repeated axle loads. ASTM C1609/C1609M specifies flexural response parameters obtained using instrumented beam testing. To link laboratory findings to pavement life, further tests would need to address restrained shrinkage, repeated-load bending, durability and slab-scale behaviour with realistic support, joints and environmental conditions. Any proposal to reduce pavement thickness would also require a code-compliant structural design rather than extrapolation from a few static beams.

6. DISCUSSION: SELECTING A PAVEMENT-RELEVANT FIBRE SYSTEM

For low-volume concrete roads, fibre selection should be framed as a multi-criterion decision. The principal mechanical question is whether a chosen material and dosage can improve flexural or crack-transfer performance in the specified matrix. The companion construction question is whether the improvement remains achievable with reliable mixing, placement and curing. The external dataset illustrates the tension: reported flexural increases of roughly 5–10% coexist with substantial reductions in slump. A dose producing the numerically highest peak strength may not be preferable where site compaction is unreliable.

The three systems are not interchangeable. Hooked steel fibres may be designed primarily for post-crack structural response; selected chopped basalt configurations may improve tensile-related response, subject to length and matrix compatibility; micro-PP can address different crack mechanisms from macro-PP. Even within the same family, product specifications and fibre-matrix bond may change performance. The required basis for an engineering recommendation is therefore not the generic fibre name but the tested commercial form, dosage, fresh-state condition and measured response at an appropriate age.

At the study-design level, one unfibred reference and nine single-fibre mixes provide a clear structure for screening. However, the planned dosage series cannot reveal a globally optimum fibre, because each family has a different numerical range and because only one product from each would be tested. Robust inference requires batch replication or carefully randomized production sequences, documented curing and individual specimen readings. If only three specimens per response are produced, descriptive statistics and uncertainty should be reported rather than making strong claims based on small mean differences. Where the laboratory lacks controlled post-peak instrumentation, the manuscript should restrict itself to ordinary peak flexure and explicitly state that toughness is unmeasured.

Economic claims would also require care. A transparent first-stage estimate is additional fibre cost per cubic metre, calculated from verified actual fibre mass and dated unit-price quotations. This is not a whole-life pavement cost: labour, transport, construction rate, maintenance, repair timing, drainage and foundation preparation are excluded. The dissertation supplies neither current purchase quotations nor comparative service-life evidence. Consequently, no cost-saving percentage or payback can responsibly be assigned to any fibre system.

7. LIMITATIONS AND FUTURE RESEARCH

This paper is limited primarily by absence of original project-level data. Its quantitative comparison is restricted to selected observations extracted from one identified external source and to percentage changes recomputed from that source. No source-matched steel benchmark is available, no local M30 batches are confirmed, and no specimen-level variability or significance testing is possible. The published reference concrete itself achieved 45.12 MPa at 28 days, highlighting its difference from the intended M30 research system. Differences in fibre form, binder composition, procedures and curing further constrain numerical transfer.

A logical next phase is to procure and fully characterize all three commercial products, establish and pilot a common M30 mixture and finalize workable doses. All ten selected mixtures should then be batched under controlled conditions, with water content, admixture, temperature, fibre mixing sequence and replicate identification recorded. At 7 and 28 days, compression, splitting tension and flexure should be tested using compliant apparatus and standard-calibrated calculations. Instrumented post-peak bending, shrinkage restraint and repeated flexural loading would extend the evidence from peak capacity towards crack-management performance. Small slab trials on documented foundations should precede design recommendations for field roads.

8. CONCLUSIONS

The supplied dissertation supports an engineering rationale and a detailed plan for comparing steel, basalt and polypropylene fibres in M30 concrete, but it does not contain original test results. Its proposed work comprises ten mixes and 180 planned destructive specimens across compression, splitting tension and flexure at 7 and 28 days. This distinction is critical for credible reporting.

The selected published basalt and PP benchmark showed a general increase in 28-day flexural strength alongside a considerable reduction in slump. Against the published control, the six selected fibre conditions gave flexural changes between +5.25% and +10.37% and slump changes between -15.14% and -68.11%. These effects apply only to the cited experimental matrix; no comparable steel observation or locally measured M30 benefit can be claimed.

A defensible fibre selection for low-volume road concrete must consider actual fibre type and geometry, volumetric dosage, verified workability, replicate strength outcomes and in applications relying on post-crack resistance—proper residual flexural testing. The currently available evidence is insufficient to rank all three fibres universally, predict fatigue life or justify thinner slabs. Completion of the documented laboratory programme is required before an application-specific recommendation can be made.

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