

Influence of Fibre Aspect Ratio on the Mechanical Properties of Polypropylene and Polyolefin Fibre-Reinforced Cement Mortar

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Abstract

In this research the mechanical performance of cement mortar reinforced with Polyolefin (PO) and Polypropylene (PP) fibres with various aspect ratio is studied. All mixes included a constant 0.5% of PO and PP fibre Volume to the cement content were predetermined by initial studies. Four Different fibre lengths 55 mm, 27.5 mm, 13.75 mm and 6.8 mm were taken to develop different aspect ratio for both PP and PO variations. Specimens were subjected to flexural and compressive test after curing in water for 28 days. It is observed that the fibre aspect ratio will influence the strength improvement and also the mortar containing fibres with moderate aspect ratio of 15 to 17, when compared to unreinforced mortar gives good results by increasing flexural strength more than 21.53% and compressive strength upto 7.9%. This result leads to enhancement of load bridging at matrix cracks and superior fibre dispersion.

Keywords: Fibre-reinforced mortar; Aspect ratio; Polypropylene fibres; Polyolefin fibres; Compressive strength; Flexural strength

1.0 Introduction

Structural fibre reinforced with cementitious composite (SFRCCs) plays an important role than plain cement mixes against fracture resistance, post-crack toughness and longer life span for both structural and non-structural applications. Fibres in mortar or concrete plays an important role in durability and disperse energy by preventing unexpected cracks. Polypropylene (PP) and Polyolefin (PO) are valuable for their low cost, ease of mixing, light weight, and resistance against Corrosion. Earlier investigation shows the effect of fibre type, dosage and form in mortar and concrete mix with various fibres cause the negligible increase in compressive strength but moderate in flexural strength and performance against cracking. However, the exact selection criteria of influence of fibre aspect ratio particularly at very low dosage is very much limited. The fibres aspect ratio influences the transfer of stress from matrix to fibre for sharing loads and bridging cracks the longer fibres are better but the drawback is tangling, poor spread and workability issues. Shorter fibres mixes uniformly because they have less anchoring, but unable to stop the spread of cracks. The effect of geometry on stress and durability in cement composite is confirmed by studies by Li et al., Yoo et al and Alberti et al. But confusing matters such as dosage makes it tedious to isolate aspect ratio and constant volume mortar systems receive negligible attention. This study closes that gap by determining the impact of PP and PO fibre aspect ratio on the compressive and flexural strengths of mortar. Geometry is highlighted by keeping volume at 0.5% and adjusting length to find the ideal performance.

1.1 Literature Review

Effects on Workability, Dispersion and Fibre Factor: Many studies consider aspect ratio together with fibre volume through a fibre factor (FF) that scales with volume \times aspect ratio. For PP fibre-reinforced self-consolidating mortar, there is an optimal FF range; below a critical $FF \approx 90-100$ fibres have negligible effect, while above a dense fibre factor the mixture loses stability from clustering and segregation, reducing the mechanical properties (Mehdipour et al., 2013; Si et al., 2020; Li et al., 2018). For PVA mortars, $FF < 100$ has little effect on rheology and damages the matrix, 100-400 gives good dispersion and enhanced strength, while $FF > 400$ results in clustering and reduces workability and strength (Si et al., 2020). Similar FF-based models for PP mortars calculate workability as a function of water film thickness and FF, and indicate that increasing aspect ratio with fixed volume reduces flow significantly and increases blocking risk (Li et al., 2018). All of these results suggest that longer/thinner PP or polyolefin fibres can only be mechanically effective if their dispersion is maintained by keeping FF below a material-specific upper limit.

Compressive Strength and Modulus: For conventional PP fibres in mortars and concretes, aspect ratio has little to no effect on compressive strength. Addition of PP fibres with varying aspect ratios resulted in minor reductions or no significant alterations of the compressive strength and modulus of elasticity of mortars, since the introduction of voids and weak interfaces when over-dosing the fibres has negative effects on strength (Topçu et al., 2017; Broda & Brachaczek, 2015; Bagherzadeh et al., 2012). In PP-reinforced concrete, increasing aspect ratio (by using longer fibres at any given volume) mainly enhances toughness and crack control, but does not affect compressive strength (Bagherzadeh et al., 2012). In review work on geopolymer concretes, it was found that at optimal PP volume, increasing PP fibre aspect ratio generally reduces compressive strength, unlike for steel fibres which improve compressive strength as a function of aspect ratio (Wang et al., 2023). Macro-polyolefin fibres in geopolymer concrete at a relatively low aspect ratio achieved very high fracture energy but only marginally reduced compressive strength, suggesting that moderate aspect ratios can already trigger useful crack-bridging in compression-dominated loading (Noushini et al., 2018).

Flexural/Tensile Strength, Toughness and Ductility:

Aspect ratio plays a more decisive role in tensile-related properties:

- In PP-reinforced mortars, fibres do not affect compressive strength but increase bending strength drastically, and the range of improvement depends on fibre geometry and fibrillation; fibrillated PP with effective crack-bridging yields the greatest flexural improvements (Broda & Brachaczek, 2015).
- For standard polypropylene fibres, greater availability in the matrix (higher effective aspect ratio) increases splitting tensile and flexural strengths by providing more capacity for micro-crack bridging (Bagherzadeh et al., 2012).
- In mortars reinforced with corrugated plastic fibres of aspect ratios of 37 and 46, flexural strength at low fibre contents (0.5 wt%) showed clear flexural improvements as a function of fibre aspect ratio: higher AR raised flexural strength as high as ~68%, while lower AR produced much smaller effects (Gulli et al., 2022).
- For PP and PE blended fibres in mortars, lower effective aspect ratio combined with a large cross-section and high surface roughness resulted in superior mechanical properties: at a high volume fraction compressive strength increased by ~38% and flexural strength by ~40% Silva et al. attribute this to "strong mechanical anchorage and self-fibrillation," indicating that geometry can compensate for non-ideal aspect ratios when bond is strong. In geopolymer mortars and concretes, review work confirms that for PP fibres at optimal volume, smaller aspect ratios yield higher splitting tensile and flexural strengths than slender fibres which tend to ball and perform poorly (Noushini et al., 2018; Wang et al. 2023). In contrast with this divergence, moderate to high aspect ratios improve tensile strength for steel fibres. This finding indicates that the effectiveness of aspect ratio as a variable changes depending on the type of fibre used, surface characteristics and stiffness.

Effect of Aspect Ratio in Hybrid & Macro-Polyolefin Fibre Systems

Hybrid systems and macro-polyolefin fibres further establish the effect of aspect ratio on toughness:

- Macro-polyolefin fibres with relatively low aspect ratios in geopolymer concrete yielded the highest fracture energy among synthetic fibres due to sufficient length without excess (Noushini et al., 2018).
- Hybrid polypropylene systems combining different lengths (therefore different effective aspect ratios) showed significant improvement in fracture toughness and specific fracture energy in high-strength concrete, since longer fibres bridged macro-cracks and shorter ones restrained micro-cracks; however excessive total fibre content reduced strength through clustering Hrabová et al. (2025).

Conclusions & Design Implications Drawn from Synthesised Results

Synthesising findings for PP/polyolefin reinforced mortars/concretes et al., several consistent findings emerge:

- Workability limits maximum usable aspect ratio at a given fibre volume (top boostoe); too high FF causes clustering and reduced strength (Mehdipour et al., 2013; Si et al. 2020; Li et al., 2018)
- Compressive strength shows limited response to changes in aspect ratio; it may be reduced at high AR
- (Topçu et al., 2017; Broda & Brachaczek, 2015; Bagherzadeh et al. 2012; Wang et al. 2023)
- Flexural/tensile strength shows clear improvements as a function of increasing aspect ratio (Silva et al., 2013; Broda & Brachaczek, 2015; Bagherzadeh et al. 2012; Wang et al. 2023; Gulli et al., 2022)
- For relatively flexible polymeric fibres (PP/polyolefine), moderate aspect ratios combined with increased surface roughness rather than greater slenderness outperform greater aspect ratios (Silva et al., 2013; Noushini et al., 2018; Gulli et al., 2022).

Due to the potential of 3D printing to revolutionize the construction industry in terms of automation and sustainability, additive manufacturing in construction has garnered significant attention [9]. Alumina silicates have been proven to play a key role in enhancing the fresh and hardened properties of self-consolidating concrete [10]. The use of agro-industrial waste, such as bagasse ash, in the production of adobe bricks has led to improvements in strength and sustainability in the construction of bricks [11]. Alumina silicates in construction concrete have been proven to exhibit superior performance in high temperatures [12]. The incorporation of demolished construction waste with pozzolanic materials in the production of bricks has been proven to significantly increase the strength of the resulting bricks [13].

These results indicate that for polypropylene and polyolefine-reinforced mortars/concretes the best mechanical properties will be obtained using materials where FF stays below the threshold for clustering/breakdown (indicating the importance of dispensing effect), as well as selecting AR values that enhance bond while giving good dispersion yet does not exceed sizes that lead to negative effects on workability.

2 Materials and Methods

2.1 Materials

Ordinary Portland Cement (OPC) conforming to 43-grade specifications (Zuari make) and locally sourced river sand served as the primary constituents. The mortar matrix was formulated with a 1:3 cement-to-sand mass proportion and a water-cement ratio of 0.50, taken to maintain uniform flow characteristics and accommodate the targeted 0.5% of volumetric fibre addition to cement. Polypropylene fibres (Mapefibre IT 39 NV grade) with a measured diameter of 0.91 mm and polyolefin fibres (Mapefibre BG 55 grade) with a measured diameter of 0.8 mm were selected as reinforcing components.

2.2 Fibre Configuration and Aspect Ratio

Four distinct fibre length were generated in the lab from full length fibres by cutting commercially available 55 mm fibres to produce:

- AR₁ (Full length fibre): 55 mm length → Aspect ratios of 60.4 (PP) and 68.7 (PO)
- AR₂ (Half length fibre): 27.5 mm length → Aspect ratios of 30.2 (PP) and 34.4 (PO)
- AR₃ (Quarter length fibre): 13.75 mm length → Aspect ratios of 15.1 (PP) and 17.2 (PO)
- AR₄ (Half a quarter length fibre): 6.88 mm length → Aspect ratios of 7.5 (PP) and 8.6 (PO)

All aspect ratios were calculated using the formula: Aspect Ratio = Fibre Length (mm) / Fibre Diameter (mm)

2.3 Mix Preparation and Specimen Casting

The cement, fine aggregate, and fibres were initially dry-mixed using a mechanical mixer to achieve uniform dispersion of the fibres within the matrix. Water was then mixed gradually and continued mixing till the desired workability was achieved. Specimens were prepared following IS 4031 (Part 6): 1988 procedures. Compressive strength cubes (70.6 mm side) and flexural prisms (160 × 40 × 40 mm) were cast in triplicate for each mix and curing age, compacted using a table vibrator for 30 seconds, demolded after 24 hours, and subjected to water immersion curing at 27 ± 2°C.

3 Results and Discussion

3.1 Compressive Strength Results

The Compressive strength outcomes at 28 days are documented in Table 1. Both fibre types indicates the strength improvement over the control specimens. The PP reinforced mortar exhibited a maximum compressive strength of 48.44 N/mm² (10.4% increase) with AR₃ configuration (13.75 mm length). The PO mortar exhibited a maximum of 47.58 N/mm² at the same aspect ratio, corresponding to an 8.5% improvement. Intermediate aspect ratios (AR₂ and AR₃) consistently outperformed both extreme configurations (AR₁ with excessive aspect ratio and AR₄ with minimal aspect ratio).

Table 1: Compressive Strength Development Across Fibre Aspect Ratios

Fibre Configuration	Fibre Length (mm)	PP Aspect Ratio	PO Aspect Ratio	PP Compressive Strength (N/mm ²)	PO Compressive Strength (N/mm ²)	PP % Strength Gain	PO % Strength Gain
Control Specimen	—	—	—	44.89	44.89	Baseline	Baseline
AR ₁	55	60.4	68.7	47.17	46.69	5.08	4.01
AR ₂	27.5	30.2	34.4	47.31	46.90	5.39	4.48
AR ₃	13.75	15.1	17.2	48.44	47.58	7.91	5.99
AR ₄	6.88	7.5	8.6	47.15	46.81	5.03	4.28

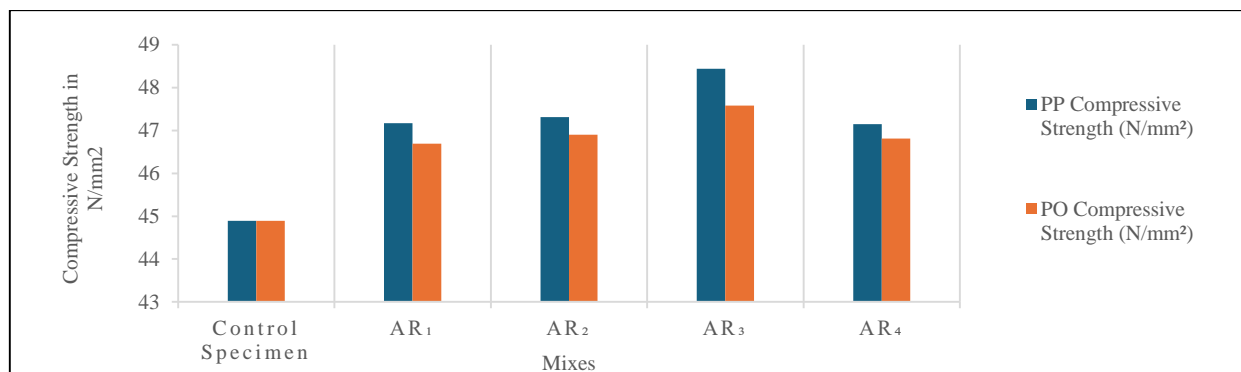


Figure 1: Compressive Strength Test Results (N/mm²)

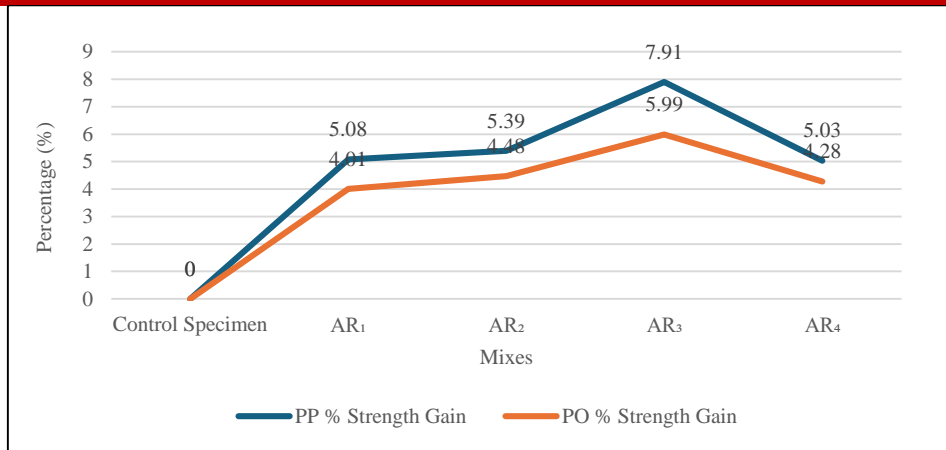


Figure 2: Percentage of strength gain

3.2 Flexural Strength Results

Flexural strength outcomes at 28 days are documented in Table 2. Fibre incorporation produced substantial flexural improvements compared to plain mortar (3.12 N/mm²). The PP system reached peak flexural strength of 5.51 N/mm² at AR₃ (13.75 mm), yielding a 76% improvement. The PO configuration produced 4.93 N/mm² at identical aspect ratio, representing a 58% increase. As with compressive results, mid-range aspect ratios proved markedly superior to both high and low ratio extremes.

Table 2: Flexural Strength Development Across Fibre Aspect Ratios

Fibre Configuration	Fibre Length (mm)	PP Aspect Ratio	PO Aspect Ratio	PP Flexural Strength (N/mm ²)	PO Flexural Strength (N/mm ²)	PP % Strength Gain	PO % Strength Gain
Control Specimen	—	—	—	4.32	4.32	Baseline	Baseline
AR ₁	55	60.4	68.7	4.96	4.68	14.81	8.33
AR ₂	27.5	30.2	34.4	5.11	4.76	18.29	10.19
AR ₃	13.75	15.1	17.2	5.25	4.93	21.53	14.12
AR ₄	6.88	7.5	8.6	5.05	4.77	16.90	10.42

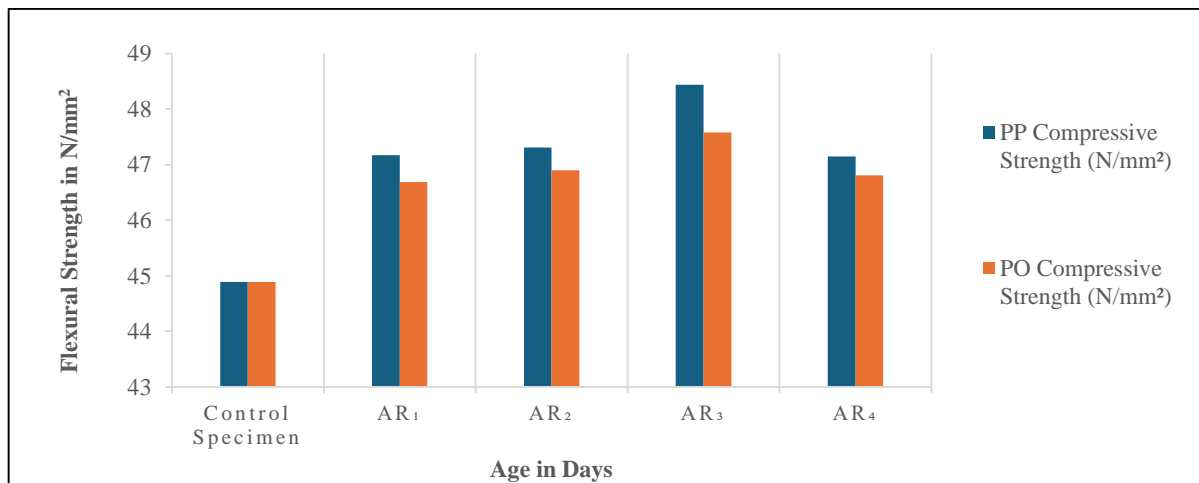


Figure 3: Flexural Strength Test Results (N/mm²)

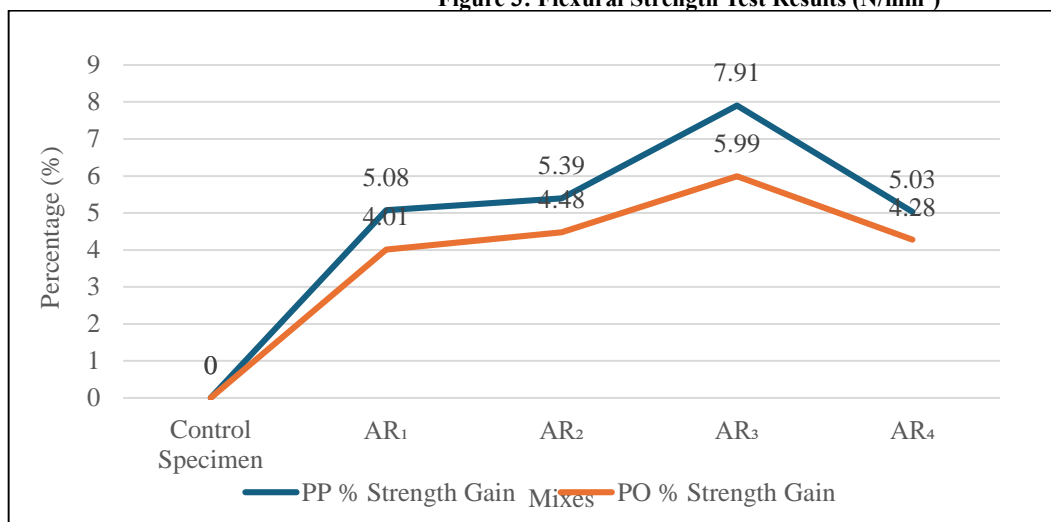


Figure 4: Percentage of strength gain

3.3 Interpretation and Discussion

The experimental outcomes illustrate a clear relationship between aspect ratio and mechanical performance in both fibre types. The superiority of intermediate aspect ratios (15–17 range) over extreme configurations—whether excessively high or low—reflects competing mechanisms governing fibre reinforcement effectiveness.

High Aspect Ratio Performance (AR₁): At aspect ratios exceeding 60, the extended fibre length enhances individual crack-bridging but creates clustering tendencies during mixing and placement. Fibre-to-fibre contact increases, reducing effective fibre spacing within the mortar matrix and compromising overall stress distribution efficiency.

Moderate Aspect Ratio Performance (AR₃): The optimal performance range (aspect ratios 15–17) achieves a beneficial balance. Fibre lengths remain sufficiently extended to bridge evolving crack widths, while diameters permit adequate spatial separation and uniform three-dimensional dispersion. This configuration maximizes stress-transfer pathways while minimizing entanglement penalties.

Low Aspect Ratio Performance (AR₄): Shorter fibres below aspect ratio 10 distribute more evenly but provide limited individual crack-bridging capacity. Load transfer between fibre and matrix becomes less efficient due to reduced contact area and stress concentration zones.

The observed trends are consistent with earlier studies reported by Alberti et al. (2020) and Azandariani et al. (2023), which highlighted improvements in post-cracking response and overall strength due to the inclusion of structural fibres. This research focuses on how the aspect ratio the mechanical properties of cement mortar, while keeping the amount of fibre constant by finding through earlier investigation work. This investigation shows that by choosing the right fibre aspect ratio, it is possible to get mechanical properties improvement of cement mortar as good as or even better than those achieved by simply adding more fibres in earlier investigations.

The increase in flexural strength of 21.53% achieved in polypropylene fibre-reinforced mortar at the optimum aspect ratio is higher than the improvement usually obtained by changing the fibre type or by using moderate increases in fibre dosage. This shows that the aspect ratio of the fibres plays a very important role in improving strength. From a practical point of view, the results suggest that better performance of fibre-reinforced mortar can be achieved by selecting the right fibre geometry, instead of only increasing the fibre content. This approach helps maintain good workability, reduces material usage, and reduce overall cost.

4 Conclusion

This systematic investigation examined the influence of fibre aspect ratio on compressive and flexural strengths of cement mortar reinforced with polypropylene and polyolefin fibres under constant 0.5% volumetric dosage. The research yields the following principal findings:

1. Fibre reinforcement effectiveness depends critically on aspect ratio optimization rather than solely on fibre content or type selection. Compared to unreinforced control specimens, all fibre configurations produced strength improvements; however, performance varied substantially with geometric parameters.
2. Intermediate aspect ratios (15–17) deliver maximum mechanical benefit, generating compressive strength increases up to 7.91% (PP) and 5.99% (PO), alongside flexural strength enhancements reaching 21.53% (PP) and 14.12% (PO).
3. Extreme aspect ratios underperform through distinct mechanisms: excessively high ratios (>60) promote fibre agglomeration and workability degradation, while very low ratios (<10) restrict crack-bridging effectiveness and stress transmission capacity.
4. Aspect ratio emerges as a primary design parameter for structural fibre-reinforced composite engineering, offering practitioners a refined optimization pathway for achieving superior mechanical performance while maintaining constant material volumes and controlling production costs.

These conclusions provide evidence-based guidance for fibre selection and geometric specification in cement-mortar design, enabling engineered composites with predictable, optimized mechanical responses.

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