

Performance Evaluation of Polypropylene Fiber Reinforced Concrete for Highway Pavements using GGBS as Cement Replacement

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ABSTRACT

Polypropylene fibre reinforced concrete offers crack-control and post-cracking benefits, while ground granulated blast-furnace slag (GGBS) can reduce Portland-cement demand and improve concrete durability. This experimental investigation evaluates M40 concrete for highway-pavement applications using five paired polypropylene-fibre/GGBS combinations: 0%/0%, 1%/10%, 2%/20%, 3%/30%, and 4%/40%, expressed by weight of cement. The reference mix was designed using IS 10262:2009 with a water-cement ratio of 0.35. Cubes, cylinders, and prisms were cast and water-cured for 7 and 28 days. Fresh-concrete workability was evaluated by slump, and hardened performance was assessed through compressive, splitting tensile, and flexural strength tests. Slump decreased from 95 mm for the control mix to 77 mm at the highest combined dosage. All three strength measures increased up to Mix M-3 containing 2% polypropylene fibre and 20% GGBS, then decreased at higher dosages. At 28 days, M-3 achieved 47.19 N/mm² compressive strength, 3.64 N/mm² splitting tensile strength, and 6.17 N/mm² flexural strength, compared with 42.07, 3.35, and 5.05 N/mm² for the control. The findings identify M-3 as the optimum combination within the investigated series.

Keywords: Polypropylene fibre; GGBS; M40 concrete; Highway pavement; Compressive strength; Splitting tensile strength; Flexural strength

I. INTRODUCTION

Concrete is widely used in pavement and structural construction because of its compressive strength, durability, and material availability. Its principal limitations are low tensile capacity, brittleness, and susceptibility to cracking under shrinkage, repeated loading, and impact. Discrete fibres can bridge developing cracks and improve toughness, tensile behaviour, flexural response, and resistance to crack propagation.

Polypropylene fibres are hydrophobic, chemically inert, lightweight, and available in monofilament and fibrillated forms. Their inclusion in concrete is primarily intended to control cracking and improve post-cracking behaviour. The present work used 12 mm fibrillated polypropylene fibres with a reported density of 900 kg/m³ and negligible water absorption.

Ground granulated blast-furnace slag is a steel-industry by-product containing calcium silicates and aluminates. When finely ground and combined with Portland cement, GGBS can contribute to strength development, lower permeability, improve resistance to chloride and sulphate exposure, and reduce the environmental burden associated with cement production.

For concrete pavements, workability, compressive strength, tensile crack resistance, and flexural performance are directly relevant to construction and service behaviour. This study therefore examines paired increases in polypropylene fibre and GGBS content in M40 concrete and identifies the combination that provides the best strength response within the tested range.

II. OBJECTIVES

- To design M40 grade concrete containing polypropylene fibres and partial replacement of cement by GGBS.
- To study the effect of paired polypropylene-fibre and GGBS contents on concrete workability.
- To determine compressive strength at 7 and 28 days.
- To determine splitting tensile strength at 7 and 28 days.
- To determine flexural strength at 7 and 28 days and identify the optimum investigated mix for pavement-oriented use.

III. LITERATURE SURVEY

Early investigations established the use of discrete fibres in cementitious materials and documented their effects on cracking, toughness, and impact behaviour [1]-[4]. Dave and Ellis examined polypropylene-fibre-reinforced

cement, while ACI Committee 544 summarized measurement procedures and the state of fibre-reinforced concrete technology [5], [6].

Research on polypropylene fibres indicates that low fibre contents often have limited influence on peak compressive strength but can improve flexural behaviour, impact resistance, and crack control. Studies also show that workability generally decreases as fibre content increases because the fibres restrict movement within the fresh mixture and increase internal surface area [7]-[10].

GGBS has been studied as a supplementary cementitious material because of its latent hydraulic properties. Ganesh Babu and Sree Rama Kumar examined GGBS efficiency in concrete, while other investigations have addressed permeability and long-term material performance [11]-[13]. The combined use of GGBS and polypropylene fibres offers a potential balance between cement replacement, mechanical performance, and crack resistance.

IV. MATERIALS AND METHODOLOGY

Materials

The concrete contained 53-grade ordinary Portland cement, Zone II river sand, 12.5 mm crushed granite coarse aggregate, potable water, AUROMIX 400 superplasticizer, 12 mm fibrillated polypropylene fibres, and GGBS obtained from JSW, Vidyanagar, Bellary. Selected properties are summarized in Table 1.

Table 1. Selected material properties

Material / property	Reported value
Cement specific gravity	2.95
Cement initial / final setting time	62 min / 210 min
Fine aggregate specific gravity	2.65
Fine aggregate water absorption	2.1%
Coarse aggregate specific gravity	2.60
Coarse aggregate water absorption	0.24%
Polypropylene fibre geometry / length	Fibrillated / 12 mm
Polypropylene fibre density	900 kg/m ³
GGBS major oxides	SiO ₂ 40%; CaO 39.2%; Al ₂ O ₃ 13.5%

Mix design and experimental matrix

M40 concrete was designed using IS 10262:2009. The mix-design calculation reported 425.142 kg/m³ cement, 148.8 kg/m³ water, 778.624 kg/m³ fine aggregate, and 1076.87 kg/m³ coarse aggregate, corresponding to a nominal proportion of 1:1.83:2.53 and a water-cement ratio of 0.35. The later Chapter 4 mix-summary table separately lists 189.6 kg/m³ water while retaining the same water-cement ratio; the strength analysis is therefore organized by mix designation and the detailed tested results.

Table 2. Experimental mix matrix

Mix	Cement (kg/m ³)	PP fibre (%)	GGBS replacement (%)	Fine aggregate (kg/m ³)	Coarse aggregate (kg/m ³)
M-1	425.14	0	0	778.62	1076.87
M-2	382.62	1	10	778.62	1076.87
M-3	340.11	2	20	778.62	1076.87
M-4	297.59	3	30	778.62	1076.87
M-5	255.08	4	40	778.62	1076.87

Specimen preparation and testing

Dry constituents, including fibres, were mixed for approximately three minutes before water and superplasticizer were introduced. Concrete was placed in standard moulds, compacted, demoulded, and water-cured. Three specimen types were used: 150 × 150 × 150 mm cubes for compression, 150 mm diameter × 300 mm cylinders for splitting tension, and 100 × 100 × 500 mm prisms for flexure. Testing was performed at 7 and 28 days.

Table 3. Experimental test programme

Property	Specimen	Testing ages
Slump	Fresh concrete	Immediately after mixing
Compressive strength	150 × 150 × 150 mm cube	7 and 28 days

Splitting tensile strength	150 × 300 mm cylinder	7 and 28 days
Flexural strength	100 × 100 × 500 mm prism	7 and 28 days

V. RESULTS AND DISCUSSION

Workability

Table 4. Slump results

Mix	PP fibre (%)	GGBS (%)	Slump (mm)
M-1	0	0	95
M-2	1	10	91
M-3	2	20	87
M-4	3	30	83
M-5	4	40	77

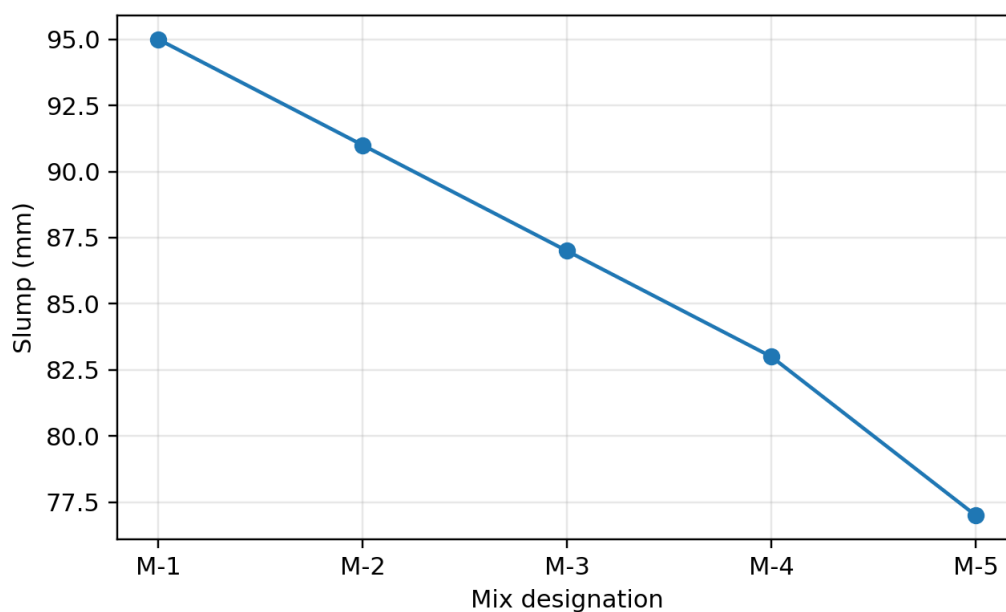


Fig. 1. Slump variation across the five concrete mixes.

Slump decreased progressively from 95 mm for M-1 to 77 mm for M-5. The reduction is consistent with the increasing fibre content, which raises internal friction and restricts movement of the fresh concrete. Despite the loss of workability, all mixes remained measurable by the slump test.

Compressive strength

Table 5. Average compressive strength

Mix	PP fibre (%)	GGBS (%)	7 days (N/mm ²)	28 days (N/mm ²)
M-1	0	0	28.60	42.07
M-2	1	10	29.32	44.00
M-3	2	20	31.93	47.19
M-4	3	30	26.40	40.50
M-5	4	40	22.80	37.61

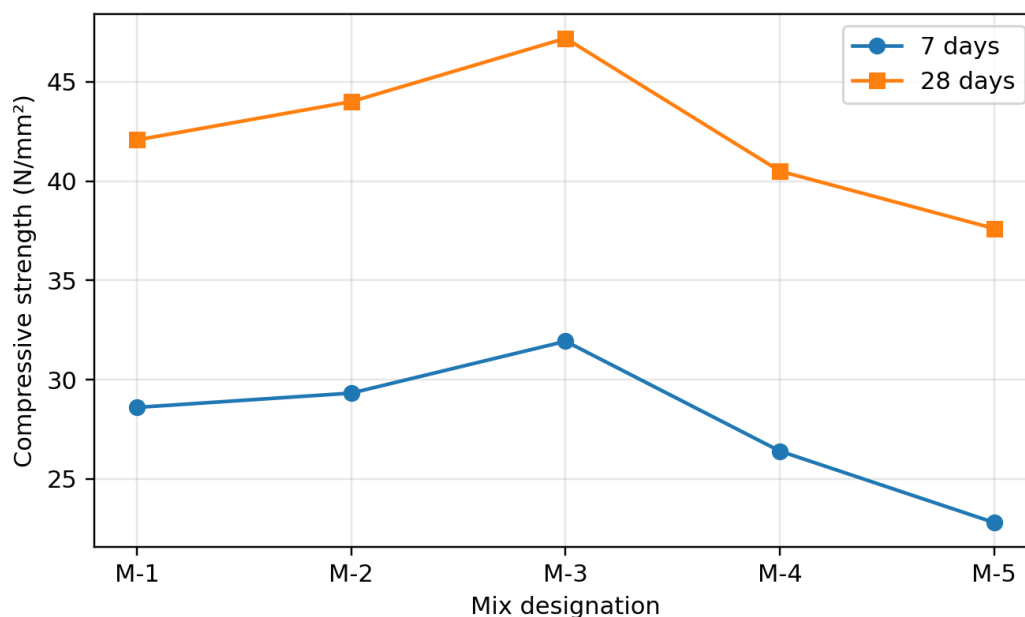


Fig. 2. Compressive-strength development at 7 and 28 days.

Compressive strength increased from the control to M-3 and then declined. At 28 days, M-3 reached 47.19 N/mm² compared with 42.07 N/mm² for M-1, an increase of approximately 12.2% based on the tabulated averages. M-4 and M-5 fell to 40.50 and 37.61 N/mm², showing that the benefit did not continue beyond the 2% fibre and 20% GGBS combination.

Splitting tensile strength

Table 6. Average splitting tensile strength

Mix	PP fibre (%)	GGBS (%)	7 days (N/mm ²)	28 days (N/mm ²)
M-1	0	0	2.33	3.35
M-2	1	10	2.43	3.52
M-3	2	20	2.56	3.64
M-4	3	30	2.15	2.90
M-5	4	40	1.87	2.55

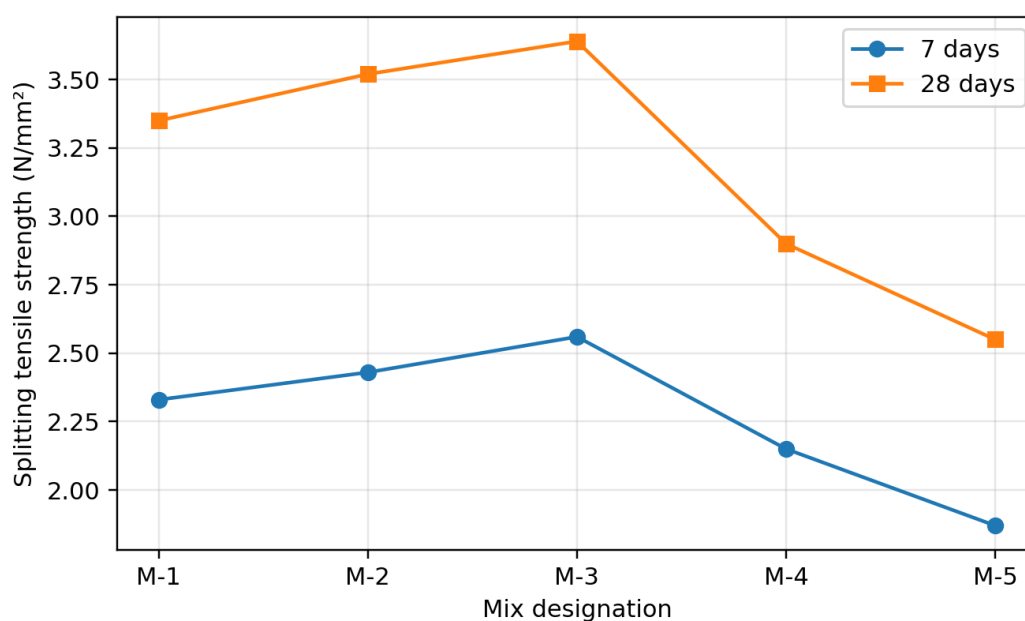


Fig. 3. Splitting tensile strength at 7 and 28 days.

The splitting tensile strength followed the same optimum trend. M-3 achieved 3.64 N/mm² at 28 days, compared with 3.35 N/mm² for the control, representing an increase of approximately 8.7% from the tabulated averages. The value decreased to 2.90 N/mm² at 3% fibre/30% GGBS and to 2.55 N/mm² at 4%/40%.

Flexural strength

Table 7. Average flexural strength

Mix	PP fibre (%)	GGBS (%)	7 days (N/mm ²)	28 days (N/mm ²)
M-1	0	0	3.60	5.05
M-2	1	10	3.90	5.52
M-3	2	20	4.01	6.17
M-4	3	30	3.27	4.88
M-5	4	40	2.90	4.25

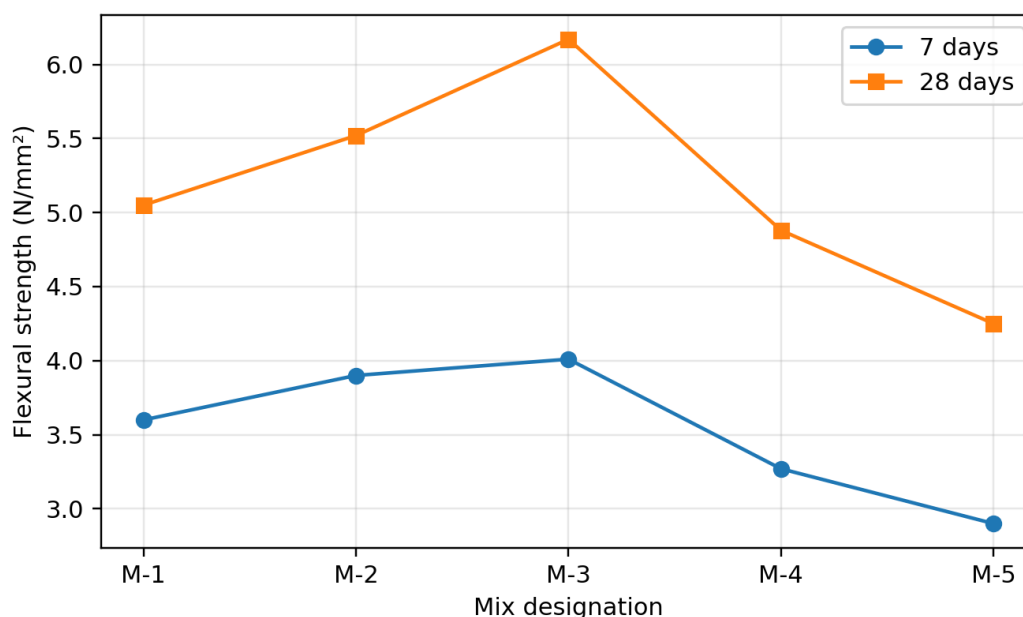


Fig. 4. Flexural-strength development at 7 and 28 days.

Flexural strength increased from 5.05 N/mm² for M-1 to 6.17 N/mm² for M-3 at 28 days, corresponding to an increase of approximately 22.2% from the tabulated averages. The reduction after M-3 indicates that excessive combined fibre content and cement replacement adversely affected the matrix and outweighed the crack-bridging benefit.

Pavement-oriented interpretation

Within the investigated series, M-3 provided the highest compressive, splitting tensile, and flexural strengths. The enhanced flexural and tensile response is relevant to pavement slabs because these properties influence crack initiation and bending resistance. However, the experimental programme reported workability and static mechanical strengths only; direct pavement fatigue, abrasion, impact, shrinkage, and durability tests were not included.

VI. CONCLUSION

- Slump decreased continuously as the paired polypropylene-fibre and GGBS dosage increased, falling from 95 mm for M-1 to 77 mm for M-5.
- All three strength measures increased up to M-3, containing 2% polypropylene fibre and 20% GGBS, and decreased at higher paired dosages.
- M-3 achieved 28-day compressive strength of 47.19 N/mm², splitting tensile strength of 3.64 N/mm², and flexural strength of 6.17 N/mm².
- Based on the detailed result tables, M-3 improved the 28-day compressive, splitting tensile, and flexural strengths by approximately 12.2%, 8.7%, and 22.2%, respectively, relative to the control.
- The 3%/30% and 4%/40% combinations produced lower strengths, indicating that excessive fibre content and cement replacement were not beneficial within this mix system.

- The 2% polypropylene fibre and 20% GGBS combination was the optimum mix among the five investigated formulations.

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