International Journal of Scientific Research and Engineering Development-– Volume 7 Issue 4, July-Aug 2024
Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Mechanical Performance of Glass Fibre Reinforced Concrete: Compressive, Split Tensile and Flexural Strength

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***Abstract*—**
Glass fibre reinforced concrete (GFRC) improves the tensile and impact behaviour of concrete by dispersing short glass fibres in the cementitious matrix. This paper presents an experimental study of M25 concrete with a water–cement ratio of 0.45 and a superplasticiser, containing glass fibre at dosages of 2%, 3% and 4%. For each dosage, three 150 mm cubes, three 100 × 200 mm cylinders and three 100 × 100 × 500 mm beams were cast and tested at 28 days for compressive, split tensile and flexural strength. The mean compressive strengths were 35.79, 37.51 and 37.43 N/mm², the split tensile strengths 3.53, 3.76 and 3.64 N/mm², and the flexural strengths 4.32, 4.76 and 4.56 N/mm² for 2%, 3% and 4% fibre, respectively. The 3% dosage gave the highest value in all three tests, improving on 2% by 4.8%, 6.6% and 10.0%, while raising the dosage to 4% brought no further gain. All mixes exceeded the target mean strength of 31.6 N/mm².

***Index Terms*—glass fibre reinforced concrete, fibre dosage, compressive strength, split tensile strength, flexural strength.**

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I. Introduction

Glass fibre reinforced concrete (GFRC or GRC) is a composite of cement, sand, water and admixtures in which short, discrete glass fibres are dispersed [1], [2]. The fibres bridge micro-cracks and improve the tensile and impact strength of the otherwise brittle matrix. GFRC has been used for about thirty years, mainly in non-structural products such as façade and cladding panels (reported as about 80% of GRC production), sanitary pipes and decorative permanent formwork. It is also valued in architectural precast work because it can be moulded into complex shapes and is lighter than steel.

An early obstacle was durability: ordinary glass fibre becomes brittle with time because of the alkalinity of cement mortar. This problem has been largely solved by alkali-resistant (AR) glass fibres and by mortar additives that prevent embrittlement. Glass fibres are made by drawing molten glass through a heated platinum bushing; about 204 filaments are drawn together, coated with a protective sizing and wound into a strand. In practice AR glass is typically used at 2–5% in factory-made prefabricated products and at 1–2% in reinforced renders and for controlling plastic shrinkage cracking.

Fibres used in concrete include steel, polypropylene, nylon, polyester, asbestos, glass and carbon. Although many studies of glass fibre in concrete exist, reported dosages are often below 1%, and results differ between studies. This paper examines higher dosages of 2%, 3% and 4% in M25 concrete and reports their effect on compressive, split tensile and flexural strength.

II. Objectives of the Project

The objectives of the project are: (i) to study the mix design aspects of GFRC; (ii) to understand the various applications of GFRC; (iii) to compare GFRC with alternative materials such as stone, aluminium, wood, glass, steel, marble and granite; and (iv) to carry out laboratory tests on compressive, split tensile and flexural strength of concrete containing glass fibre.

III. Literature Review

Glass fibre has been studied in several media. Patel and Singh [3] found that the strength of glass-fibre-reinforced sandy soil increased with fibre content, owing to the tensile contribution of the fibres. Ge *et al.* [4] reported that pasting glass fibre reinforced plastic sheets on asphalt concrete beams extended their fatigue life by more than 8.8 times and raised their flexural stiffness.

For concrete, many studies report strength gains. Tajne and Bhandari [10] found that glass fibre raised 28-day compressive and flexural strength by 12–18% and 16–20%, and reduced bleeding. Ravikumar and Thandavamoorthy [15] reported that 0.5% glass fibre raised flexural, compressive and split tensile strength by 13%, 42% and 20%, while heating to 300 °C for 2 hours reduced compressive strength. Singh and Kumar [7] reported that 0.5% fibre improved compressive and flexural strength and that flexural strength could increase by up to 60% at 0.7%. Patel *et al.* [11] and Pitroda *et al.* [12] also reported gains in compressive, flexural and split tensile strength, with 0.1% fibre giving the best durability and mechanical results in [11]. Quadri *et al.* [17] reported strength gains of 20–30% in M20, M30 and M40 concretes.

Other studies are less consistent. Gupta *et al.* [5] found that alkali-resistant glass fibre did not improve the compressive and flexural strength of M25 concrete, although the 2% mix was comparable to the control at 28 days. Srinivasa Rao *et al.* [9] observed that glass fibre in self-compacting concrete (SCC) reduced bleeding and cracking but did not improve flexural strength. Shahanasheril *et al.* [8] reported compressive strength gains of up to 9.2% in M20 and 7.1% in M30 SCC at fibre contents of 0.05–0.2%. Subramani and Mumtaj [6] found that

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replacing 10% of sand with glass fibre gave higher strength than the conventional mix.

Fibre content also affects workability. Dawood and Hamad [14] noted that workability of lightweight concrete decreased as glass fibre increased, with flexural strength rising at 0.6%. Rathi *et al.* [13] reported an optimum near 0.75% for moderately deep beams, with balling and non-uniform distribution at higher contents. Manjunatha and Ashwini [16] found that the flow and passing ability of SCC fell with increasing aspect ratio and fibre volume, with compressive and flexural strength highest at 0.5% and split tensile strength at 0.75%. Most of these studies therefore used dosages of 1% or less, and the effect of 2–4% fibre in M25 concrete is the subject of the present work.

IV. Casting of Specimens

A. Materials

Ordinary Portland cement of 53 grade conforming to IS 12269 [18] was used, with fresh, colourless and odourless potable water. Fine and coarse aggregates (20 mm maximum size) and glass fibre had the properties given in Table I.

TABLE I
Properties of Materials

Material	Property	Value
Cement (OPC 53)	Specific gravity	3.1
Fine aggregate	Specific gravity	2.61
	Bulk density	1600 kg/m³
Coarse aggregate	Specific gravity	2.7
	Bulk density	1460 kg/m³
	Maximum size	20 mm
Glass fibre	Tensile strength	≈1700 MPa
	Elastic modulus	≈73 GPa
	Specific gravity	≈2.6
	Filament diameter	14 µm

B. Mix design

An M25 mix was designed using IS 10262 [19]. With a standard deviation of 4 N/mm², the target mean strength was 25 + 1.65 × 4 = 31.6 N/mm². A water–cement ratio of 0.45 was adopted, below the 0.50 limit of IS 456 [20]. The water content of 186 kg/m³ for 20 mm aggregate was increased by 6% for a slump of 100 mm and then reduced by 25% because a superplasticiser was used, giving about 148 kg/m³. The cement content was therefore 328.33 kg/m³, above the 320 kg/m³ minimum of IS 456. The volume fractions of coarse and fine aggregate were taken as 0.61 and 0.39. The resulting quantities are in Table II.

TABLE II
Mix Proportions per m³ of Concrete

Ingredient	Quantity
Cement	328.33 kg/m³
Water	147.75 kg/m³
Fine aggregate	772.90 kg/m³
Coarse aggregate	1204.42 kg/m³
Water–cement ratio	0.45
Glass fibre dosage	2%, 3%, 4%

C. Specimen preparation

Specimens were cast in cast-iron moulds with leak-proof base plates, and the joints were coated thinly with mould oil. The materials were mixed thoroughly, the glass fibre was then added and mixing continued for a further minute, after which the specimens were cast. Three specimens of each type were made for each of the three fibre dosages (Table III), 27 in all. The specimens were kept for 24 hours under damp matting, away from vibration, at 22–32 °C, then demoulded, marked and cured in clean potable water at 24–30 °C until testing at 28 days.

TABLE III
Test Specimens

Test	Specimen	Size (mm)	Number
Compressive	Cube	150×150×150	9
Split tensile	Cylinder	100 dia.×200	9
Flexural	Beam	100×100×500	9

V. Testing of Specimens

All specimens were tested at 28 days, immediately after being taken from the curing tank and dried. The compressive strength of the cubes was calculated as

$$f_c = P / A \tag{1}$$

where P is the failure load and A the loaded area of the cube [21]. The split tensile strength of the cylinders was calculated as

$$f_{sp} = 2P / (\pi D\, L) \tag{2}$$

where D and L are the diameter and length of the cylinder [22]. The beams were tested under two-point loading in a universal testing machine of 60 t capacity, the load being increased until failure and the failure load recorded. The flexural strength was calculated as

$$f_b = P\, l / (b\, d^2) \tag{3}$$

where l is the span between the supports and b and d are the width and depth of the beam [21].

VI. Results and Discussion

Table IV gives the mean 28-day strengths of the three specimens at each dosage, and Fig. 1 shows the individual results. All mixes exceeded the target mean strength of 31.6 N/mm².

TABLE IV
Mean 28-Day Strength (N/mm²)

Fibre	Compressive	Split tensile	Flexural
2%	35.79	3.53	4.32
3%	37.51	3.76	4.76
4%	37.43	3.64	4.56

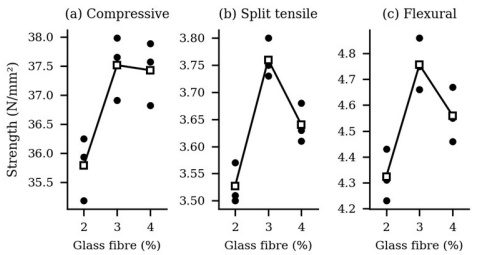


Fig. 1. Individual 28-day results (dots) and means (line) against glass fibre dosage.

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A. Compressive strength

Mean compressive strength rose from 35.79 N/mm² at 2% fibre to 37.51 N/mm² at 3%, an increase of 4.8%, and was practically unchanged at 4% (37.43 N/mm², 0.2% lower). The three 3% specimens (36.91–37.98 N/mm²) all exceeded the three 2% specimens (35.18–36.25 N/mm²), whereas the 3% and 4% ranges overlap, so the difference between these two dosages is within the scatter of the tests.

B. Split tensile strength

Split tensile strength was highest at 3% (3.76 N/mm²), 6.6% above the 2% mix (3.53 N/mm²) and 3.2% above the 4% mix (3.64 N/mm²). The 3% specimens (3.73–3.80 N/mm²) all exceeded those at 2% (3.50–3.57 N/mm²) and at 4% (3.61–3.68 N/mm²).

C. Flexural strength

Flexural strength showed the largest response to fibre dosage: 4.32 N/mm² at 2%, 4.76 N/mm² at 3% (10.0% higher) and 4.56 N/mm² at 4% (4.1% below the 3% value). The 3% beams (4.66–4.86 N/mm²) were again above the 2% beams (4.23–4.43 N/mm²), and the 4% beams (4.46–4.67 N/mm²) were nearly all below the 3% beams.

D. Optimum dosage

The 3% dosage gave the highest mean value in all three tests, so within the range tested it is the optimum. The lack of further gain at 4% is consistent with reports that higher fibre contents reduce workability and cause balling and uneven fibre distribution [13], [14], although fibre distribution and workability were not examined here.

E. Limitations

No control specimens without fibre were tested, so the gain over plain M25 concrete cannot be quantified from these results, and the comparisons above are between fibre dosages. Only three specimens were tested per dosage, and the properties of the concrete in the fresh state, impact resistance and durability were not measured.

VII. Conclusion

Concrete of M25 grade containing 2%, 3% and 4% glass fibre was tested for compressive, split tensile and flexural strength at 28 days. All mixes exceeded the target mean strength of 31.6 N/mm². The 3% dosage gave the highest mean compressive strength (37.51 N/mm²), split tensile strength (3.76 N/mm²) and flexural strength (4.76 N/mm²); compared with 2% fibre, these are increases of 4.8%, 6.6% and 10.0%. Increasing the dosage to 4% did not improve strength, and split tensile and flexural strength fell by 3.2% and 4.1%. Future work should include plain concrete controls, intermediate dosages, workability measurements, fibre length and aspect ratio, and impact and durability tests.

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