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Mechanical strength of fibrous concrete with waste rural materials

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This study presents reusing of locally available waste fibrous materials as concrete composites. Mechanical strength properties (compressive strength, split tensile strength, modulus of elasticity, modulus of rupture and shear strength) of synthetic fibres (nylon, plastic and tyre) with volume fractions (0.5%, 1% and 1.5%) and aspect ratios (30, 60 and 90) were evaluated. Empirical relation was proposed for mechanical strength in relation with fibre reinforcing index (FRI) and compared with experimental results. Concrete mixed with rural waste fibres improved mechanical strength.

Keywords: Fibre reinforced concrete, Fibre reinforcing index (FRI), Mechanical strength, Waste rural materials

Introduction

A huge amount of waste as plastic, nylon, rubber is produced as automobile parts, household goods, industrial wastes etc. A feasibility study was conducted for recycling commingled plastics fibre in concrete[1]. Lathe and wire winding wastes are reported[2] to improve significantly compressive, split tensile and flexural strength values of concrete. Thomas & Ramasamy[3] studied mechanical properties of steel fibre reinforced concrete. Effects of aspect ratio and volume fractions of steel fibre on mechanical properties of steel fibre reinforced concrete have been studied by multilinear regression analysis[4]. Mechanical properties and post cracking toughness of glass and palm tree fibres on high strength concrete are reported[5]. Ramakrishna *et al*[6] compared theoretical and experimental results on compressive strength (CS) and elastic modulus of coir and sisal fibre reinforced concretes for various volume fractions. Sugarcane bagasse fibre reinforced cement composites have also been studied[7]. Study[8] is available on development of vegetable fibre-mortar composites of improved durability.

In this study, fibre reinforced concrete mixes with locally available waste materials (nylon, plastic, tyre, coir, sugarcane bagasse) have been cast and tested.

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Materials and Methods

Materials, Mix and Casting

Materials used include ordinary Portland cement (43 grade, conforming to IS 8112-1989), coarse aggregate of crushed rock (Max. size, 20 mm), fine aggregate of clean river sand (Zone II of IS: 383-1970) and portable water. Locally available rural materials were taken from waste stream and converted into fibres of required length and diameter. Diameter of fibres was measured through microscope. Specific gravity was determined as per IS: 2386 (Part III). Uniform length of fibres was obtained by using a cutting machine. Plastic fibres were collected from recycled waste materials, nylon waste fibres from nylon industries, and bicycle rubber tyres from local automobile workshops. Coconut coir fibre, sugarcane baggasse and rice husk were collected from respective mills. GI steel wires were used for binding reinforcement mesh. Fibre sample (5g each) was accurately weighed in an electronic balance and water absorbed after 24 h of continuous immersion was determined (Table 1). Ultimate tensile strength of fibers were determined by tension test using 4 kN tensile testing machine. A gauge (length, 100 mm) was chosen to measure maximum elongation.

A mix was designed as per IS 10262-1982 to achieve a concrete grade of M_{20}. Designed and adopted mix proportion was 1:1.38:3.09. A water cement ratio of 0.5 was used. A laboratory type concrete mixer machine

Table 1— Typical properties of fibres

Properties of fibres	Fibre type						
	Steel	Nylon	Plastic	Tyre	Coir	Sugarcane bagasse	Rice husk
Diameter/Equivalent diameter, mm	0.60	0.44	1.51	1.50	0.48	1.50	1.60
Aspect ratio	83.3	113.6	33.1	33.1	104.2	33.1	12.5
Specific gravity	5.86	0.7	1.25	1.08	0.87	0.52	0.4
Water absorption, %	13.33	42.24	44.76	72.21	104.2	126.6	123.7
Density, kg/m^3	6879	657	763	530	2057	260	564

was used to mix ingredients of concrete. In order to avoid balling of fibers, aggregates and cement weremixed for 1 min and water was being added for 2 min. Then fibres were manually added and dispersed throughout the mass in slow increment. Then, materials were allowed to mix thoroughly for 3 min. Fibrous concrete was manually placed in respective moulds. All specimens were well compacted using a table vibrator. Specimens were demoulded after 24 h.

Experimental Set up

Compression test on cubes and cylinders and flexural strength test on beams (10 cm × 10 cm × 50 cm) were conducted as per IS: 516-1959. Split tensile strength test was carried out on compression testing machine. Casting and testing of specimens were done as per IS 5816-1999. For modulus of elasticity, California test 522[9] was followed. Cylindrical specimens (diam, 100 mm; length, 300 mm) were cast and cured. Load was applied continuously without shock and following readings were taken: i) applied load when longitudinal strain is 50×10^{-6} m/m; and ii) longitudinal strain when applied load is equal to 40% of the ultimate. Chord modulus of elasticity was obtained as

$$E = \frac{(S_2 - S_1)}{(C - 0.00005)} \quad \ldots(1)$$

where, E, chord modulus of elasticity, Mpa; S_2, stress corresponding to 40% of ultimate load; S_1, stress corresponding to a longitudinal strain of 50×10^{-6} m/m; C, longitudinal strain produced by stress S_2.

Based on studies[10,11], L-shaped shear test specimens were prepared from 150 mm cubes by inserting a wooden block (90 mm × 60 mm × 150 mm) into cube moulds before casting of concrete. Specimens were placed on compression testing machine. A MS plate (150 mm × 85 mm × 10 mm) was placed on left side portion of 90 mm face. Mild steel (MS) bar (diam, 12 mm) was placed over the centre of plate. Another MS bar (diam, 22 mm) was placed at the edge of plate. Over these bars, another MS plate (150 mm × 110 mm × 10 mm) was placed. Load was applied on top plate, which forms shear plane below the centre of bar (22 mm). Loading was continued until failure.

Results and Discussion

Linear regression analysis was carried out to form empirical relations between different parameters in terms of fibre reinforcing indices (FRIs). Equations to give relation between particular parameter and CS of cylinder are also proposed. Six fibres of three aspect ratio (AR: 30, 60 and 90), except for rice husk, with three volume fractions (V_f: 0.5%, 1% and 1.5%) were cast. Three specimens each were cast for each mix. Hence, 174 specimens with 58 mixes were cast for each strength parameter and tested. Model for strength of fibre reinforced concrete [steel fibre concrete (SFC), nylon fibre concrete (NFC), plastic fibre concrete (PFC), tyre fibrous concrete (TFC), coir fibre concrete (CFC), and sugarcane bagasse fibre concrete (BFC)] was predicted in terms of FRI as

$$f_f = A(FRI) + f \quad \ldots(2)$$

where, f_f, strength of fibrous concrete; A, coefficient; f = strength of plain concrete (FRI = 0).

First term of model shows contribution of fibre dosage and fibre geometry, whereas second term represents contribution of controlled concrete strength. Numerical coefficients of FRI indicate contribution of

Table 2— Predicted models of different strength parameters

Mix	Predicted model					
	f_{cuf}	f_{cyf}	f_{cyf}	f_{mrf}	E_f	f_{ssf}
SFC	4.43(FRI)+f_{cu}	4.19(FRI)+f_{cy}	1.68(FRI)+f_{sp}	2.62(FRI)+f_{mr}	7.18(FRI)+E	1.73(FRI)+f_{ss}
NFC	2.83(FRI)+f_{cu}	4.17(FRI)+f_{cy}	1.03(FRI)+f_{sp}	2.15(FRI)+f_{mr}	5.55(FRI)+E	1.85(FRI)+f_{ss}
PFC	2.43 (FRI)+f_{cu}	4.14(FRI)+f_{cy}	1.04(FRI)+f_{sp}	2.01(FRI)+f_{mr}	4.43(FRI)+E	2.06(FRI)+f_{ss}
TFC	1.80 (FRI)+f_{cu}	3.62(FRI)+f_{cy}	0.72(FRI)+f_{sp}	1.27(FRI)+f_{mr}	5.82(FRI)+E	1.49(FRI)+f_{ss}
CFC	1.92 (FRI)+f_{cu}	4.42(FRI)+f_{cy}	0.83(FRI)+f_{sp}	1.96(FRI)+f_{mr}	3.63(FRI)+E	1.08(FRI)+f_{ss}
BFC	1.97 (FRI)+f_{cu}	4.33(FRI)+f_{cy}	0.71(FRI)+f_{sp}	1.56(FRI)+f_{mr}	3.10(FRI)+E	0.86(FRI)+f_{ss}

Table 3—Relation between different strength parameters and cylinder compressive strength

Mix	Predicted relation with			
	f_{sp}	f_{mr}	E_f	f_{ss}
Control	$0.62\sqrt{f_{cy}}$	$0.73\sqrt{f_{cy}}$	$4.69\sqrt{f_{cy}}$	$1.30\sqrt{f_{cy}}$
SFC	$0.78\sqrt{f_{cy}}$	$0.94\sqrt{f_{cy}}$	$6.10\sqrt{f_{cy}}$	$0.94\sqrt{f_{cy}}$
NFC	$0.71\sqrt{f_{cy}}$	$0.93\sqrt{f_{cy}}$	$5.43\sqrt{f_{cy}}$	$0.93\sqrt{f_{cy}}$
PFC	$0.71\sqrt{f_{cy}}$	$0.90\sqrt{f_{cy}}$	$5.24\sqrt{f_{cy}}$	$0.90\sqrt{f_{cy}}$
TFC	$0.70\sqrt{f_{cy}}$	$0.93\sqrt{f_{cy}}$	$4.97\sqrt{f_{cy}}$	$0.93\sqrt{f_{cy}}$
CFC	$0.69\sqrt{f_{cy}}$	$0.93\sqrt{f_{cy}}$	$5.31\sqrt{f_{cy}}$	$0.93\sqrt{f_{cy}}$
BFC	$0.67\sqrt{f_{cy}}$	$0.91\sqrt{f_{cy}}$	$5.20\sqrt{f_{cy}}$	$0.91\sqrt{f_{cy}}$

different fibres towards improvement in strength (Table 2).

Cube Compressive Strength

A sample comparison graph for SFC was plotted to study effect of FRI on conventional concrete strength (Fig. 1a). SFC possessed maximum CS. NFC and PFC contributed significantly in strength enhancement, whereas strength increase was least by TFC. For concrete with inorganic fibres, NFC and PFC contributed significantly in strength enhancement, whereas strength increase was least by TFC. Among organic fibrous concrete, CFC and SCFC exhibited more strength than rice husk. CS of SFC with FRI 0.45 (V_f, 0.5%; AR, 90) showed highest value; nearly 20% increment over conventional concrete. Increase in VF reduced increment of CS for higher AR. While increase in AR of fibres, increased strength for all mixes. But in case of V_f (1.5%), strength of concrete with higher AR fibre showed lesser strength than lower. Thus proposed CS model predicts test data accurately. In all fibres, except rice husk, CS enhancement was effective up to 1% V_f.

Cylinder Compressive Strength

A sample comparison graph for NFC was plotted to study effect of FRI on conventional concrete strength (Fig. 1b). SFC possessed maximum strength. For concrete with inorganic fibres, NFC and PFC contributed significantly in strength enhancement, whereas strength increase was least by TFC. Among organic fibrous concrete, CFC and BFC exhibited more strength than rice husk. Ratio (0.96-1.1) between model and experimental values showed reliability of experimental results. Similar behaviour was observed in all cases.

Split Tensile Strength

A sample comparison graph for PFC was plotted to study effect of FRI on conventional split tensile strength (Fig. 1c). SFC found to possess maximum strength. For concrete with inorganic fibres, NFC and PFC contributed significantly in strength enhancement, whereas strength increase was least by TFC. Among organic fibrous concrete, CFC and BFC exhibited more strength than rice husk. Another relationship was proposed between split tensile strength and cylinder CS (Table 3).

Modulus of Rupture

A sample comparison graph for TFC was plotted to study effect of FRI on conventional modulus of rupture (Fig. 1d). It was observed (Table 2) that at a particular FRI value, SFC, NFC and PFC contributed more in flexural strength, followed by CFC, BFC, TFC and rice husk. Comparison indicated that proposed models for modulus of rupture predicted test data accurately.

Modulus of Elasticity

A sample comparison graph for CFC was plotted to study effect of FRI on conventional modulus of elasticity (Fig. 1e). SFC possessed maximum value. For concrete

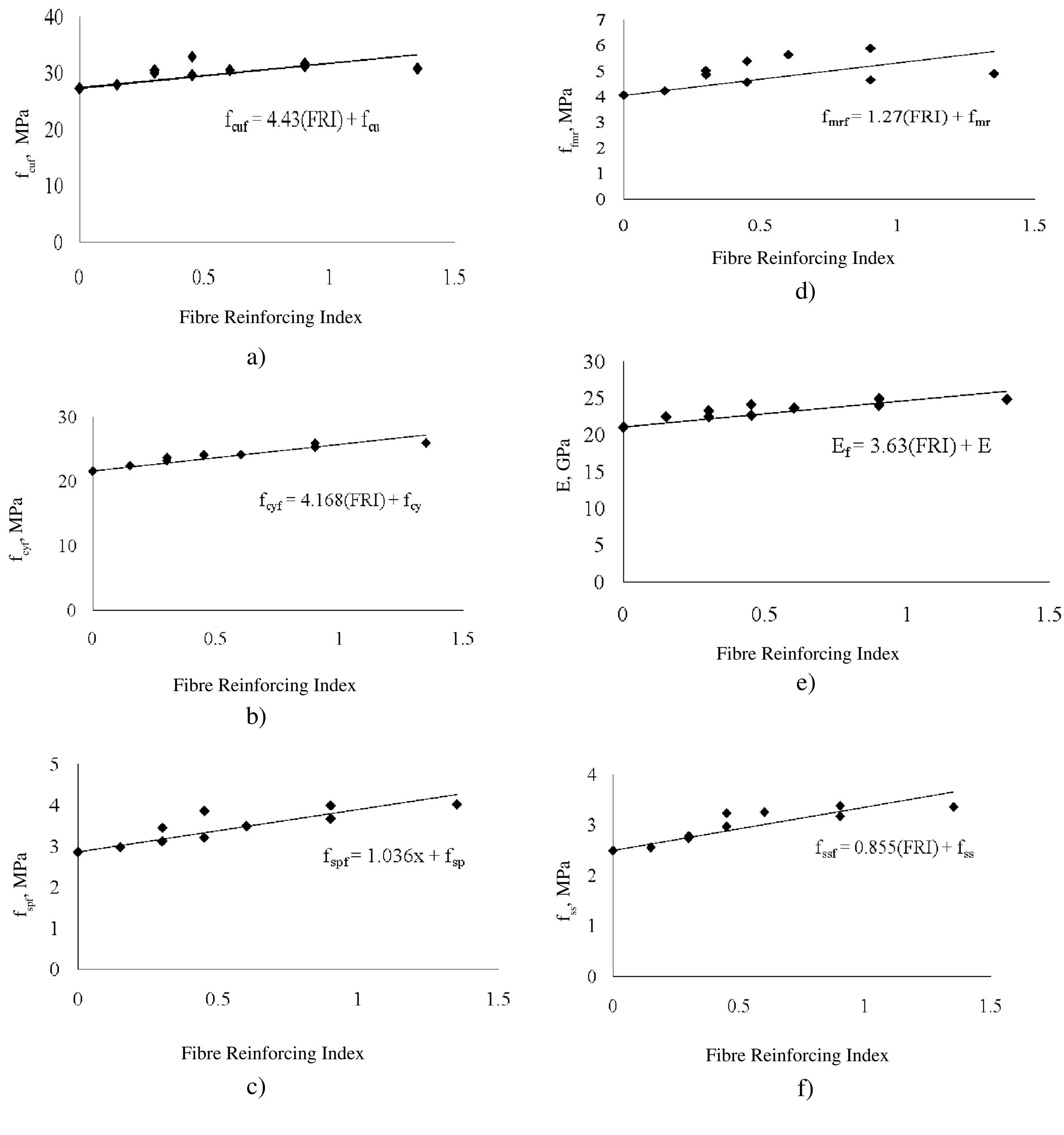

Fig.1—Plot of FRI versus: a) Cube compressive strength of steel fibre concrete (SFC); b) Cylinder compressive strength of nylon fibre concrete (NFC); c) Split tensile strength of plastic fibre concrete (PFC); d) Modulus of rupture of tyre fibre concrete (TFC); e) Modulus of elasticity of coir fibre concrete (CFC); and f) Shear strength of sugarcane bagasse fibre concrete (BFC)

with inorganic fibres, NFC and TFC contributed significantly in strength enhancement, whereas strength increase was least by PFC. Among organic fibrous concrete, CFC and rice husk exhibited more strength than BFC. Proposed models for modulus of elasticity predicted test data accurately. Another relationship has been proposed between modulus of elasticity and cylinder CS (Table 3).

Shear Strength

A sample comparison graph for SCFC was plotted to study effect of FRI on conventional concrete strength (Fig. 1f). SFC possessed maximum strength. For concrete with inorganic fibres, PFC and NFC contributed significantly in strength enhancement, whereas strength increase was least by TFC. Among organic fibrous concrete, CFC and BFC exhibited more strength than rice husk. Another relationship was proposed between shear strength and cylinder CS (Table 3).

Conclusions

Contribution of steel, nylon, plastic and coir fibers in mechanical strength enhancement was found more than that of other fibers. Optimum volume fraction of fibres was 0.5-1.0%. FRI was most influential parameter and increase in strength of fibrous concrete is proportional to FRI. All proposed models exhibited correct correlation with experimental results. Apart from regular relations between FRI and strength, relations between different strength parameter corresponding to cylinder compressive strength were also proposed.

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