An Experimental Investigation on Basalt Fibre Reinforced Concrete with Acrylic Polymer

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Abstract: *This paper presents an experimental investigation on polymer modified basalt fibre reinforced concrete. The compressive strength, flexure strength, shear strength and split tensile strength are considered for investigation. The basalt fibre content varies from 1 % to 5% at the interval of 1 % by weight of cement. The amount of acrylic polymer introduced in each mix is 10 % by weight of cement. Standard specimens for cubes, beams, push-off and cylinder were cast, respectively, for compression, flexure, direct shear and split tensile strengths. This study explores the behaviour of polymer modified fibre reinforced concrete (PMFRC) to assess its potential as a superior construction material. The results show improved strength performance with the addition of basalt fibbers and the acrylic polymer.*

Keywords: Acrylic Polymer, Basalt fibre, workability, Compressive strength, Flexural strength, Shear strength, Splitting Tensile strength

1. Introduction

The rapid increase in the use of fibres in concrete is attributed to its positive effect on the mechanical properties of the cementations composites. It is proven that the addition of fibres to concrete has a significant impact on improving the mechanical properties of fresh and hardened concrete, such as compressive strength, tensile strength, flexural strength, and workability [1]. Fibre reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. Fibres include steel fibres, glass fibres, synthetic fibres and natural fibres, each of which lends varying properties to the concrete. The effect of compression, flexure and split tensile can be improved from brittle to ductile behaviour [2].

Basalt is a volcanic igneous rock which performs well in terms of strength, temperature range, and durability. Basalt fibres (BF) are obtained from basalt rocks through melting process. The physical and mechanical properties of concrete can be affected by basalt fiber. The abrasion resistant is achieved by low fiber content. [3]. Basalt fibre is a relatively new construction material. It has many advantages over other fibres commonly used to improve the performance of plain concrete. The production of basalt fibre does not create any environmental waste. Fibres of different length and amount can greatly affect the optimum strength of concrete, but also caused trouble with large amount of fibre content [4]. It is known that the BFs have better tensile strength than the E-glass fibres, greater failure strain than the carbon fibres as well as good resistance to chemical attack, impact load and fire with less poisonous fumes. This paper reviewed on the mechanical, thermal and chemical properties of concrete with addition of basalt fibre in it [5].

Ahmad et al. The effective elastic properties of fibre reinforced concrete were carried out by analytical approach. The fibres are oriented randomly, and analysis was carried out same as that of composites systems. The effective properties of fibrous concrete were obtained and compared with the experimental results [6].

In modern concrete construction and repair works the role of polymers is increasing day by day. Polymers are either incorporated in a cement-aggregate mix or used as a single binder. The composites made by using polymer along with cement and aggregates are called polymer-modified mortars (PMM) or polymer-modified concrete (PMC), while composites made with polymer and aggregates are called polymer mortar (PM) or polymer concrete (PC). By using polymers the concrete can give superior strength and better resistant compared to conventional concrete [7]. Polymer as admixture can improve the properties like higher strength and lower water permeability than the conventional concrete. Different polymers impart different behaviour with PMC, and on fresh and hardened properties of concrete [8].

Also, PC has unique characteristics such as rapid hardening and easy-to-adjust setting time. In contrast to conventional cement concrete, which commonly requires about 6–7 hours reaching its final setting at room temperature. The use of PC has been widely encouraged for repair of existing concrete structures such as concrete pavements, bridge decks, floors and airport runways in which closure time is quite limited as well as for fabrication of precast components such as sewage pipes, piles for port, tunnel liner segments and footpath panels. The deformation characteristics, setting shrinkage and coefficient of thermal expansion were being investigated showing that it deceases with increase in polymers content [9].

To improve the performance of concrete, polymers are mixed with concrete. Polymer modified concrete considered to be more durable than conventional concrete. Here SBR latex has been used for investigating the compression and flexure strength. On experimental study, the SBR shown negative

effect at early age of 28 days,then the SBR imparted strength to both compression and flexure. For the mixes rich in cement, the dosage of SBR latex needs to be adjusted to maintain required workability of concrete and optimum polymer content which can be required was also been evaluated in this paper [10].

Effects of the acrylic admixture include decreasing the required water/ cement ratio, enhancing the resistance to deterioration in water, and improving the mechanical properties, the dispersant properties, and the corrosion resistance. Acrylic has also been used as a coating on concrete to improve concrete durability. Also, acrylic dispersion used can enhance the tensile properties of fiber reinforced mortar. [11].

2. Experimental

Ordinary Portland cement of 53 grade was used and fine and coarse aggregates confirming to IS383 (1970) [11] were used. The fineness modulus of fine and coarse aggregates was 2.9 and 6.75, respectively. The performance of fibres depends on the dosage and the fibre parameters i.e. tensile strength, length, diameter, anchorage, etc. The properties of fibre are shown in Table 1 were used.

Table 1: Properties of basalt fibre

Sr. No	Description	Values
1	Length of Fibre	18 mm
2	Thickness of Fibre	0.016 mm
3	Aspect ratio	1125
4	Tensile strength	4.84 GPa
5	Modulus of elasticity	89 GPa

2.1 Concrete mix proportioning

The mix proportioning was done according to Indian Standard code 10262:2009[12]. The standard mean strength was 40MPa. The concrete mix proportion was taken as 1:1.70:2.25:0.38 (Cement: Coarse Aggregate: Fine Aggregate: water). A fixed dosage of Acrylic polymer 10% by weight of cement was used. The specimens were cast and then demoulded after 24 hours. The specimens were first wet cured for 7 days and then air cured for about 21 days

3. Test Setup

3.1 Test on fresh concrete

The workability of polymer modified BFRC is determined with the help of slump cone test. Results of these properties are shown in Table 2.

Table 2: Workability of normal concrete, polymer concrete and PMBFRC concrete

Fibre Content (V_f)%	Slump (mm)	% Decrease in slump
0	17	-
0	15	11.76
1	13	23.53
2	9	47.05
3	5	70.59

4	4	76.47
5	4	76.47

3.2 Test on Hardened Concrete

A UTM of 2000 kN capacity was used as a test setup for carrying out all the tests on hardened concrete. The tests were carried out conforming I.S. 516 (1959) [13].

3.2.1 Compressive Strength:
The compressive strength of concrete is the most common performance measure used by civil engineers in designing buildings. Compressive strength is defined as the capacity of materials to withstand load that reduces its size. In general, concrete is strong in compression and can exhibit high strength. However adding different basalt fibre lengths and content has an effect on the compressive strength of concrete. The compressive strength was calculated by the formula:

$$f_{cu} = \frac{P_c}{A} \qquad (1)$$

The test results are shown in Table 3. A graph shows comparisons of compressive strength with respect to fibre content.
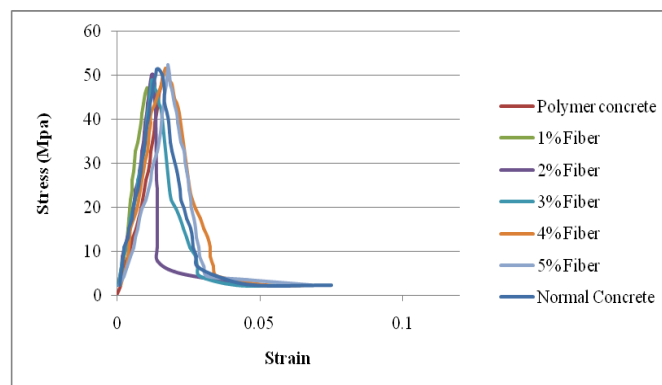

Figure 1: Comparisons of normal concrete, polymer concrete and PMBFRC

3.2.2 Flexural Strength
For determining this strength, each specimen of size 100x100x700mm was supported over a span of 600mm and a two-point load was applied at the middle third of the span. The central deflections were recorded up to the first crack. All the beams were loaded up to failure. The flexural strength using strength of materials theory was calculated by the formula:

$$f_{cr} = \frac{P_f L}{b d^2} \qquad (2)$$

The results are shown in table 3.

Table 3: Compressive strength and Flexural strength of PMBRFC

Fibre content (%)	Polymer content (%)	Compressive strength f_{cu} (MPa)	% increase in Compressive strength	Flexural strength f_{cr} (MPa)	% increase in Flexure strength
0	0	50.14	-	3.73	-
0	10	47.08	-6.10	4.80	18.69
1	10	47.96	-4.34	4.44	19.03
2	10	50.57	0.86	4.62	23.86

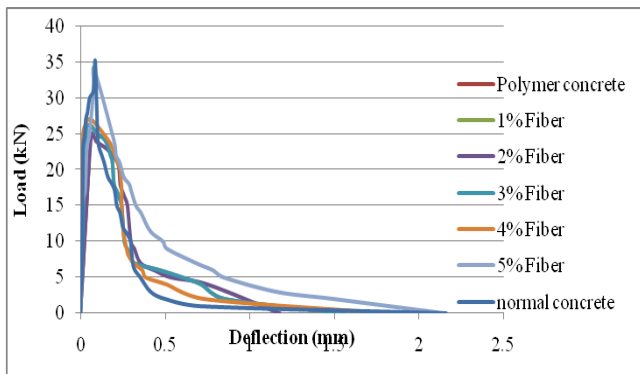| 3 | 10 | 51.66 | 3.03 | 4.80 | 28.67 |
| 4 | 10 | 52.32 | 4.35 | 6.04 | 61.93 |
| 5 | 10 | 51.48 | 2.67 | 5.68 | 52.27 |

Figure 2: Comparison of normal concrete, polymer concrete and PMBFRC under Flexure

3.2.3 Split tensile strength

The split tensile strength test is done to evaluate tensile strength of concrete which it can withstand. The specimens of size 150mm dia and 300mm length were cast and air dried cured for 28 days. Split Tensile Strength is determined by:

$$f_t = \frac{2P}{\pi LD}$$

(3)

Where, P= Load at which sample fails, L= length of the specimen cylinder, D= diameter of the specimen cylinder.

Table 4: Shear strength and Split Tensile strength of PMBRFC

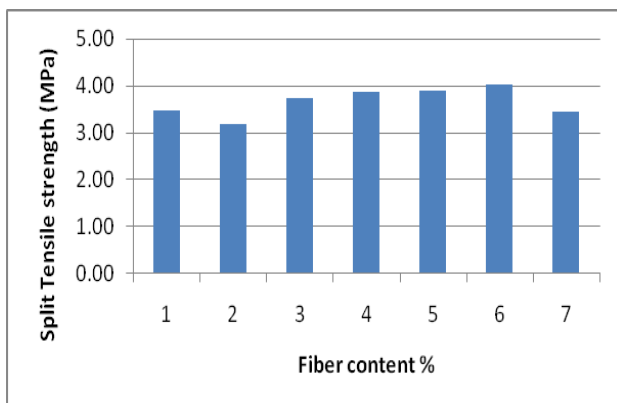| Fibre content (%)	Shear strength (MPa)	% Increase in strength shear strength	Split Tensile Strength (MPa)	% Increased in strength split tensile
0	1.77	-	3.47	-
0	1.92	8.47	3.19	-8
1	1.95	10.17	3.74	7.78
2	1.97	11.30	3.86	11.24
3	1.97	11.30	3.89	12.10
4	2.07	16.95	4.03	16.14
5	2.00	13.00	3.44	-0.86

Figure 3: Variation of splitting tensile strength with respect to fiber content (%)

3.2.4 Shear Strength

To find out the shear strength of concrete, two types of shear test(push-off) specimens were prepared in the laboratory. In the first type, specimens of size 150mmx150mmx450mm with two notches on opposite side (Push-off) were cast. The shear strength of concrete is determined by the formula

$$\tau_s = \frac{P_s}{A_s}$$

(4)

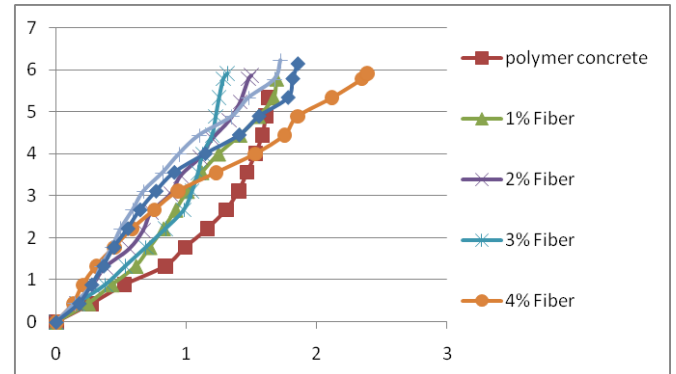The results of split tensile strength obtained using these expressions are presented in Table 4.

Figure 4: Comparison of normal concrete, polymer concrete and PMBFRC under Shear

3.3 Relation between Split tensile strength and Compressive strength

Table 5: The relation between compressive strength and split tensile strength is tabulated as

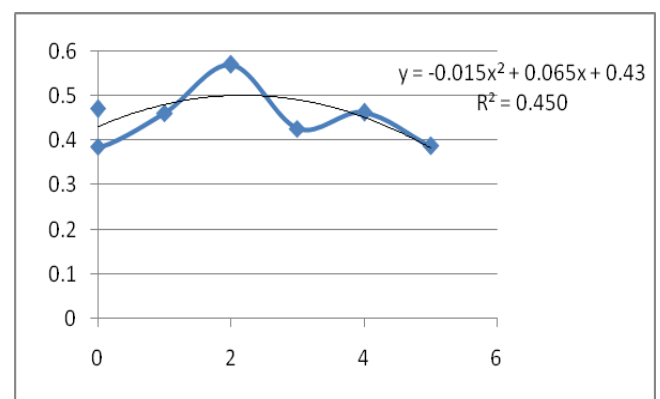| Fibre content (V_f)%	Split Tensile strength f_t (MPa)	Compressive strength f_{cu} (MPa)	$f_t/\sqrt{f_{cu}}$ Ratio
0	3.47	50.14	0.49
0	3.19	47.08	0.46
1	3.75	47.96	0.54
2	3.86	48.83	0.55
3	3.82	51.66	0.53
4	4.03	52.32	0.55
5	3.44	51.48	0.48

Figure 5: Variation of $f_t/\sqrt{f_{cu}}$ ratio with respect to fibre content (%)

3.4 Elastic Constants

In the analysis of structures, elastic constants viz, E, μ, and G are always required. The modulus of elasticity (E_{fc}) of PMBFRC can be determined using the formula given by

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IS456 [10] depending upon the compressive strength of concrete (f_{cu}). It is given by

$$E_{fc} = 5\sqrt{f_{cu}} \tag{5}$$

A formula is proposed for calculating the modulus of elasticity of PMBFRC in terms of volume fraction of glass fibres (V_f)and cube compressive strength (f_{cu}) as:

$$E_{tc} = 5(1\text{-}2.65V_f)\sqrt{f_{cu}} \tag{6}$$

3.5 Computations of Elastic Constants using Halpin–Tsai Equations

Halpin Tsai equations based on micromechanics analyses can also be used to predict the elastic constant of short fibre composites. The longitudinal E_L and transverse E_T moduli can be evaluated using equation (7) & (8)

$$E_L = E_M \left[\frac{1+2\lambda\eta_L V_f}{1-\eta_L V_f} \right] \tag{7}$$

$$E_T = E_M \left[\frac{1+2\lambda\eta_T V_f}{1-\eta_T V_f} \right] \tag{8}$$

Where,

$$\eta_L = \left[\frac{(E_F/E_M)-1}{(E_F/E_M)+2\lambda} \right] \tag{9}$$

$$\eta_T = \left[\frac{(E_F/E_M)-1}{(E_F/E_M)+2} \right] \tag{10}$$

Static modulus of elasticity E_R and G_R shear modulus of randomly oriented FRC can be predicted using following equations:

$$E_R = \left[\frac{3}{8} E_L \right] + \left[\frac{5}{8} E_T \right] \tag{11}$$

$$G_R = \left[\frac{1}{8} E_L \right] + \left[\frac{1}{4} E_T \right] \tag{12}$$

Where, E_L and E_T are respectively the longitudinal and transverse moduli of short fibre composite having the same fibre aspect ratio and fibre volume fraction. The results obtained using Equations (11) and (12) are presented in Table 6.

3.6 Computation of Poisson's Ratio

The Poisson's ratio (μ) can be determined using the strength of material theory based on first crack flexural and first crack compressive strengths and is given by the relation:

$$\mu = \frac{First\ crack\ flexural\ strength}{First\ crack\ compressive\ strength} \tag{13}$$

Since a random fibre composite is considered isotropic in its plane, its in-plane Poisson's ratio can be calculated using the following isotropic relationship between E_R, G_R, and Poisson's ratio (μ_R):

$$\mu_R = \frac{E_r}{2G_r} - 1 \tag{14}$$

The results of the Poisson's ratio μ_R obtained using Equation (14) are presented in Table 6. However, Equation (14) overestimates the values compared to those obtained by Equation (13). Hence to get the correct results, the new expression for Poisson's ratio (μ_{fc}) of PMBFRC based on Equation (14) is developed in terms of aspect ratio and volume fraction of fibres which is given as:

$$\mu_{fc} = \frac{\mu_R}{3} (1 + V_f \sqrt[3]{\lambda}) \tag{15}$$

The results of elastic constants obtained are shown in Table 6.

Table 6: Elastic constants: modulus of elasticity, shear modulus and Poissons' ratio of PMBRFC

Fibre content (V_f)%	Modulus of elasticity (GPa)			Shear modulus using Halpin-Tsai Eq.	Poisson's ratio		
	Using IS456	Using proposed formula	Using Halpin-Tsai Eq.		Using Eq. (13)	Using Eq. (14)	Using Eq.. (15)
0	34.62	36.16	36.16	13.56	0.524	0.333	0.111
0	34.3	34.3	36.16	13.56	0.502	0.333	0.113
1	34.63	34.44	36.12	13.54	0.438	0.333	0.116
2	34.95	34.57	36.52	13.69	0.505	0.333	0.118
3	35.94	35.36	37.36	14.01	0.417	0.333	0.120
4	36.17	35.4	36.73	13.77	0.499	0.333	0.123
5	35.88	34.92	35.95	13.48	0.486	0.333	0.111

4. Discussion of Results

In this article, all the tests on fresh and hardened concrete are carried out according to the relevant standards wherever applicable. The results obtained from experiments are shown in table 2.

4.1 Workability

Workability is measured in terms of slump. The results from Table 5 indicate that the workability of PMBFRC reduces with the increase in the fibre content as compared to that of normal concrete. The maximum decrease in slump i.e., 76.47%is observed at 5% fibre content.

4.2 Compressive Strength

The results of the compressive strength are presented in Table 3. The compressive strength increased upto 4% and the decrease with the increase in the fibre content. The maximum increase in compressive strength is obtained at 4% of fibre content. The reduction in strength might be due to insufficient hydration process.

4.3 Flexural Shear Strength
The results of the flexural shear strength are computed using Equation (2) of strength of material theory and presented in Table 3.

4.4 Split Tensile Strength

The results from Table 4 show that cylinder split tensile strength of concrete increases considerably with an increase in fibre content. A continuous increase in strength is observed. The 4% of fibre content has given 16.14% maximum increase in split tensile strength as compared to that of normal concrete.

4.5 Shear strength

The shear strength of normal concrete, polymer concrete and polymer modified basalt fibre reinforced concrete is obtained from equation (4). The shear strength is observed at 4% fibre content upto 16.15% increase in strength.

4.6 Elastic Constants

The results of elastic constants viz, modulus of elasticity, shear modulus, and Poisson's ratio are presented in Table 6.

5. Conclusions

Following conclusions are drawn from the results and discussion of this investigation.

1) The workability of polymer modified basalt fibre reinforced concrete (PMBFRC) decreases with increase in the fibre content.
2) Due to inclusion of polymer alone in concrete, the compressive strength of polymer concrete does not show any increase with respect to normal concrete.
3) The maximum compressive strength, flexure strength, shear strength and split tensile strength achieved are 52.32 MPa, 6.04MPa, 2.07MPaand 3.82MPa respectively, at 4%, 4%, 4% and 3% of fibre content with constant polymer dosage of 10% at the age of 28 days.
4) Elastic constants of PMBFRC are obtained by various methods. An empirical expression for modulus of elasticity has been developed in terms of fibre volume fraction and cube compressive strength of PMBFRC and an expression for Poisson's ratio is established in terms of fibre volume fraction and the aspect ratio of fibre.

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