Experimental and analytical evaluation of stress-strain behavior of basalt fibred concrete

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Abstract. The aim of this study is to determine the stress-strain behavior of basalt fibred concrete experimentally. Cylinders of standard size 150 x 300 mm are cast with and without basalt fibres and tested in uni-axial compression under strain control as per IS: 516-1999 to understand the stress-strain behavior of basalt fibred concrete. After developing empirical equations for stress-strain curves of basalt fibred concrete, theoretical values of stresses are calculated at different values of strains in concrete based on the developed empirical equations as given above and theoretical stress-strain curves are plotted. These theoretical stress-strain curves are compared with experimental stress-strain curves and found that, theoretical stress-strain curves have shown good correlation with experimental stress-strain curves for all concrete mixes.

1 Introduction

The purpose of this experiment is to examine the stress-strain behaviour of basalt fibred concrete. To study the stress-strain behaviour of basalt fibred concrete, cylinders of standard dimension 150 x 300 mm are cast with and without basalt fibres and tested in uni-axial compression under strain control as per IS: 516-1999. The average stress-strain curve for M30 grade basalt fibred concrete is drawn from the values of stresses and strains, using the average values of the three cylinders' findings.

2 Mathematical Modeling for Stress-Strain Behaviour

Following the experimental determination of the stress-strain behaviour of basalt fibred concrete, an attempt was made to derive the analytical stress-strain curves for the aforementioned mix. A variety of empirical equations have been presented to characterise uni-axial

stress-strain behaviour of ordinary concrete, however most of them can only be utilised for the climbing section of the curve. Carriera and Chu expanded Popovics' empirical equation, which covers both ascending and descending sections of the full stress-strain curve, presented in 1985. The stress-strain diagram is given in a non-dimensional manner along both axes to compare the behaviour of basalt fibred concrete. Divide the stress at any level by peak stress and the strain at any level by peak strain to get the above form. As a result, at peak stress, all stress-strain curves will have the same point (1,1). The behaviour may be expressed as a generic behaviour by non-dimensionalizing the stresses and strains as shown above. The stress-strain curves for basalt fibred concrete produced experimentally were normalised as described above, and normalised stress-strain values were computed.

3 Proposed Model for Stress-Strain Behaviour

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To get the entire stress-strain behaviour of recycled aggregate concrete, many equations in various forms were tested. Seanz's model was used to match the produced normalised stress-strain curves using analytical equations from a variety of potential trials.

The developed equation is in the form of

$$Y = Ax / (1 + BX^2)$$

Where X - Normalized strain, Y- normalized stress

A, B are constants for ascending portion and C, D are constants for descending portion for normalized stress-strain curves

A, B and C, D are a set of constants for basalt fibred concrete mix. Constants are determined based on the boundary conditions of normalized stress-strain curves. Boundary conditions for ascending and descending portions of stress-strain curves are,

i. At the origin the ratio of stresses and strains are zero

i.e. at origin $(\epsilon / \epsilon_0) = 0$, $(\sigma / \sigma_0) = 0$

ϵ_0 - strain at peak stress, σ_0 - peak stress

ii. The strain ratio and stress ratio at the peak of the non-dimensional stress-strain curve is unity.

i.e. at $(\epsilon / \epsilon_0) = 1$, $(\sigma / \sigma_0) = 1$

iii. The slope of non-dimensional stress-strain curve at the peak is

zero i.e. at $(\epsilon / \epsilon_0) = 1.0$ $\frac{d(\sigma/\sigma_0)}{d(\epsilon/\epsilon_0)} = 0$

iv. At 85% stress ratio the corresponding values of strain ratio is

1.3.

i.e. at $(\sigma/\sigma_0) = 0.85$ $(\epsilon/\epsilon_0) = 1.3$

Where σ_0 - corresponds to peak stress and

ϵ_0 - corresponds to strain at peak stress

The constants in the ascending section of the normalised stress-strain curve are determined by boundary conditions I and ii, whereas the constants in the descending portion of the curve are determined by boundary conditions ii, iii, and iv.

Constants for basalt fibred concrete are derived using the boundary conditions in non-dimensional stress-strain curves, and equations are built from there. Finally, analytical equations that describe the entire stress-strain behaviour are created. The suggested equation for basalt fibred concrete is $Y = Ax / (1 + Bx^2)$.

Further research will be conducted using these normalised stress-strain curves. The suggested empirical equations may be utilised to analyse the flexural behaviour of concrete structural components as a stress block.

4 Calculation of Theoretical Stresses Using Proposed Analytical Equations

Theoretical stresses have been calculated using proposed empirical equations for basalt fibred concrete which are derived from Seanz's model in the form of

$$Y = (AX) / (1 + BX^2)$$

Where $Y = (\sigma / \sigma_0)$ and $X = (\epsilon / \epsilon_0)$

Substituting

$$\frac{\sigma}{\sigma_0} = \frac{A(\epsilon/\epsilon_0)}{1 + B(\epsilon/\epsilon_0)^2}$$

$$\Rightarrow \sigma = \frac{\sigma_0 A (\epsilon/\epsilon_0)}{1 + B (\epsilon/\epsilon_0)^2} \quad \text{Let } (A\sigma_0) / \epsilon_0 = A^1 \text{ and } B/\epsilon_0^2 = B^1$$

$$\text{Then } \sigma = \frac{A^1 \epsilon}{1 + B^1 \epsilon^2}$$

Where ϵ_0 - is the strain corresponding to peak stress σ_0

σ - is the stress corresponding to any strain ϵ

A & B - are constants for normalized stress-strain curves.

σ_0 - Corresponds to cylinder strength (taken as) $= 0.8 f_{ck}$

$\epsilon_{0.85}$ - is strain corresponding to 85% peak stress on the descending portion of stress-strain curve

If A, B, σ_0 and ϵ_0 values are known, the constants A^1 and B^1 (constants for dimensional stress-strain curve) are determined using the relationships $A^1 = (A\sigma_0) / \epsilon_0$ and $B^1 = B/\epsilon_0^2$

Substituting the values of ϵ i.e. strain at extreme fibre of concrete, theoretical stress values at different values of ϵ are determined using the relationship

$$\sigma = \frac{A^1 \epsilon}{1 + B^1 \epsilon^2}$$

Theoretical values of stresses are calculated at different strains in concrete using the generated empirical equations and theoretical stress-strain curves are displayed after generating empirical equations for stress-strain curves of basalt fibred concrete. These theoretical stress-strain curves were compared to experimental stress-strain curves, and it was discovered that for all concrete mixes, theoretical stress-strain curves had a strong agreement with experimental stress-strain curves.

5 Theoretical Stress-Strain behaviour

Empirical equations for stress-strain behaviour of concrete mixes were established after experimentally getting the stress-strain behaviour of basalt fibred concrete. Stresses are computed using empirical formulae, and stress-strain curves are shown using theoretical stress values. The experimental stress-strain curves are compared to the theoretical stress-strain curves.

A generic behaviour of basalt fibred concrete may be described by non-dimensionalizing the experimental stresses and strains. As a result, at peak stress, all stress-strain curves will have the same point (1,1), which can

be found by dividing the stress at any level by peak stress and the strain at any level by peak strain. The experimentally acquired stress-strain curves for all concrete mixes were normalised, and normalised stress-strain values were computed.

To get the entire stress-strain behaviour of concrete mixtures including basalt fibres, several equations were tested.

Table 1. Experimental and Theoretical Stress –Strain values of M30 grade normal concrete

Experimental Values		Theoretical Values	
σ	E	σ	ϵ
0.00	0.0000	0.00	0.0000
2.29	0.0001	2.40	0.0001
4.58	0.0002	4.81	0.0002
6.87	0.0003	7.21	0.0003
9.16	0.0004	9.62	0.0004
11.45	0.0005	12.02	0.0005
13.73	0.0006	14.42	0.0006
16.02	0.0007	16.82	0.0007
18.31	0.0008	19.23	0.0008
20.60	0.0009	21.63	0.0009
22.89	0.0010	24.03	0.0010
25.18	0.0012	26.44	0.0012
27.47	0.0013	28.84	0.0013
29.76	0.0014	31.25	0.0014
32.05	0.0016	33.65	0.0016
34.32	0.0021	36.04	0.0021
33.39	0.0022	35.06	0.0022
29.76	0.0022	31.25	0.0022
24.50	0.0023	25.73	0.0023

Fig, 1. Experimental and Theoretical Stress –Strain curves of M30 grade normal concrete

Table 2. Experimental and Theoretical Stress –Strain values of M30 grade basalt fibred concrete

Experimental Values		Theoretical Values	
σ	E	σ	ε
0.00	0.0000	0.00	0.0000
2.98	0.0001	3.08	0.0001
5.94	0.0001	6.20	0.0001
8.92	0.0002	9.28	0.0002
11.90	0.0003	12.40	0.0003
14.86	0.0003	15.48	0.0003
17.86	0.0004	18.56	0.0004
20.84	0.0004	21.68	0.0004
23.80	0.0006	24.76	0.0006
26.78	0.0008	27.86	0.0008
29.76	0.0010	30.96	0.0010
32.72	0.0017	34.04	0.0017
35.70	0.0019	37.12	0.0019
38.68	0.0019	40.24	0.0019
41.66	0.0021	43.32	0.0021
44.62	0.0021	46.42	0.0021
43.40	0.0015	45.16	0.0015
38.68	0.0018	40.24	0.0018
31.86	0.0020	33.12	0.0020

Fig.2. Experimental and Theoretical Stress –Strain curves of M30 grade basalt fibred concrete

Table 3. Experimental Peak stress values and their corresponding strains of M30 grade Concrete mixes

Grade of the concrete	Type	Dosage	Peak Stress f_o	Corresponding strain at peak stress ϵ_o
M30	Normal Concrete	-	34.32	0.0021
	Basalt fibred Concrete	Dosage 0.4% by volume 50mm length	44.62	0.0021

Fig.3. Peak stress values for normal and basalt fibre concrete

6 Conclusions

From the observations made from stress-strain curves, the following conclusions are drawn:

1. When compared to regular concrete without fibres, optimally basalt fibred concrete has exhibited better stress values for the same strain levels.
2. Because the degree of internal micro cracking in basalt fibred concrete has decreased, the strain at peak stress is somewhat higher, and the slope of the falling section is steeper.
3. The model suggested for predicting stress-strain behaviour founds to be reasonable as the experimental values are correlating with the theoretical values validating the model developed.
4. For similar strains in basalt fibre concrete and normal concrete, peak stress in basalt fibre concrete is more indicating the ultimate load carrying capacity.
5. For similar stresses in basalt fibre concrete and normal concrete, the strains are improved in concrete due to inclusion of basalt fibres.

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