Steel Fibre Reinforced Concrete Beams with Externally Bonded FRP Laminates

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ABSTRACT— ***This paper presents regression equations for predicting the performance characteristics of steel fibre reinforced concrete beams strengthened with glass fibre reinforced polymers (GFRP) laminates. A total of four beams of dimension 150mm x 250mm x 3000mm were cast and tested to study the effectiveness of GFRP on steel fibre reinforced concrete beams. A fibre volume fraction of 1% was used in this study. Beams were strengthened with UDCGFRP laminates of 3mm and 5mm thickness. All the beams were subjected to two-point loading and tested upto failure. Deflections were measured through appropriate instrumentation at all stages of loading. The GFRP strengthened SFRC beams exhibit increased strength and composite action until failure.***

Keywords— GFRP, Regression analysis, SFRC, Strengthening.

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1. INTRODUCTION

Strengthening reinforced concrete members using fibre reinforced polymer (FRP) has emerged as a potential method to address strength deficiency problem. This approach has shown significant advantages compared to traditional method mainly due to outstanding mechanical properties of the composites. Alberto et al (2012) studied the effectiveness of fibre reinforced concrete in improving the structural response of RC members under different loading conditions. The authors concluded that the overall ductility is influenced by fibres which depend on ratio between FRC toughness and the reinforcement ratio. Song et al (2004) studied the mechanical properties of high strength steel fibre reinforced concrete. The toughness index of fibre reinforced concrete include with increase in fibre volume fraction was observed. Li et al (2005) studied the effect of thickness and length of CFRP on performance of repaired reinforced concrete beams. The authors reported that CFRP can effectively increase the ultimate load, stiffness and ductility of concrete beams. Yang et al (2011) examined the basic behavior of ultra high strength concrete beams reinforced with steel fibers. The principal parameters considered in their study were steel rebar ratio and the method of placing ultra high performance concrete. The authors reported that bending behavior of UHPC members was characterized by multi-microcracking and a localized macrocrack. In addition, numerical predictions for the ultimate bending moment capacity for test beams showed good agreement with experimental results. Fatih Altun et al (2006) investigated the effects of steel fiber addition on mechanical properties of concrete and reinforced concrete beams. The authors concluded that both the ultimate loads and the flexural toughnesses of reinforced-concrete beams produced with steel fibre at a dosage of 30 kg/m3 increase appreciably as compared to those RC beams without steel fibers. Yin et al (2003) studied the structural performance of short steel fibre reinforced concrete beams strengthened with externally bonded fibre reinforced polymer sheets. The authors concluded that the strengthened beams exhibit higher load carrying capacity. Lijuan Li et al (2006) conducted a test analysis for fibre reinforced concrete beams strengthened with externally bonded FRP sheets. The authors reported that strengthened beams exhibit improvement in ductility and strength.

2. EXPERIMENTAL INVESTIGATION

2.1 Materials

Table 1 shows the details of mix design of utilized concrete. Four beams having geometry and reinforcement as shown in **Figure 1** were cast and tested under two-point loading. The longitudinal reinforcement consisted of high yield strength deformed bars of characteristic strength 547.38 Mpa. The lateral ties consisted of mild steel bars of yield strength 330 Mpa. The beams were provided with 8mm diameter 2-legged stirrups at 150mm spacing. Steel fibre volume fraction of

1% and UDC type of GFRP laminates of 3mm and 5mm thickness were used in the study. The properties of UDC GFRP are shown in **Table 2**. The details of beams are presented in **Table 3**.

Table 1: Concrete Mix Proportion

Ingredient	Quantity
53 grade OPC	450 kg/m^3
Fine aggregate	780 kg/m^3
Course aggregate 20mm	680 kg/m^3
Course aggregate 10mm	450 kg/m^3
Water	160 lit/m^3
Silica flume	25 kg/m^3
Hyper plasticizer	0.80 %

Table 2: Properties of FRP

Type of FRP	Thickness of FRP (mm)	Elastic Modulus (Mpa)	Ultimate Elongation (%)	Tensile Strength (Mpa)
UDC	3mm	13965.63	3.02	446.9
UDC	5mm	17365.38	2.60	451.5

Table 3: Specimen Details

Sl.No	Beam Designation	Fibre volume Fraction	% of steel reinforcement	GFRP Laminate	
				Type	Thickness
1	CB	-	0.6698	-	-
2	SF	1%	0.6698	-	-
3	SFU3	1%	0.6698	UDC	3mm
4	SFU5	1%	0.6698	UDC	5mm

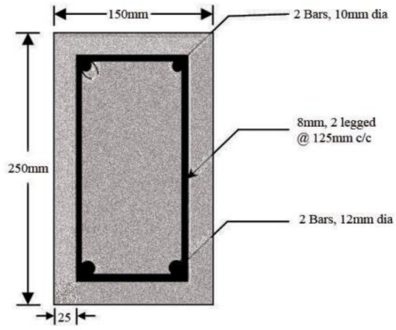

Figure 1: Beam Details

Figure 2: Experimental Setup

2.2 Test set-up

The SFRC beams were strengthened with GFRP laminates following standard procedures. The beam soffits were first prepared to receive the GFRP laminates. A two-component room temperature curing epoxy adhesive was used for bonding the GFRP laminates. The beams were tested under four-point bending till failure. The deflections were measured at the mid-span as well as at the loading points using deflectometers with a least count of 0.01mm. The crack widths were measured using the crack detection microscope with a least count of 0.02mm. The loading arrangement and instrumentation adopted for the test are shown in **Figure 2**.

3. REGRESSION MODELING

The regression helps us to evaluate the unknown coefficient in an equation. The form of equation is assumed a priori in such a way that it might best suit the anticipated relation between the input and the output. The regression coefficient is an unknown parameter introduced in the equation, to modify the input variables. On solving the regression problem using the principle of least squared errors, all the regression coefficients are evaluated. The multivariate linear regression helps to construct first order equation involving more than one independent variable. The basic formulation of multi variable linear regression is

$$\sum_{i=1}^{K}\left(P_i-(a_0+a_1x_{1i}+a_2x_{2i}+a_3x_{3i}+\cdots+a_nx_{ni})\right)\begin{Bmatrix}\frac{\partial}{\partial a_0}\\ \frac{\partial}{\partial a_1}\\ \frac{\partial}{\partial a_2}\\ \frac{\partial}{\partial a_3}\\ \vdots\\ \frac{\partial}{\partial a_n}\end{Bmatrix}=\begin{Bmatrix}0\\0\\0\\0\\ \vdots\\0\end{Bmatrix} \qquad \text{(a)}$$

where, $a_0 \cdots a_n$ are the coefficients to be determined, $x_1 \cdots x_n$ are the independent variables, P is the dependent variable or the actual result value for the set of ith input data and K is the number data sets available for regression. On executing the partial derivative operators, equation (a) reduces to,

$$\sum_{i=1}^{K}\begin{bmatrix}1 & x_{1i} & x_{2i} & x_{3i} & & x_{ni}\\ x_{1i} & x_{1i}^2 & x_{1i}x_{2i} & x_{1i}x_{3i} & & x_{1i}x_{ni}\\ x_{2i} & x_{2i}x_{1i} & x_{2i}^2 & x_{2i}x_{3i} & & x_{2i}x_{ni}\\ x_{3i} & x_{3i}x_{1i} & x_{3i}x_{2i} & x_{3i}^2 & & x_{3i}x_{ni}\\ \\ x_{ni} & x_{ni}x_{1i} & x_{ni}x_{2i} & x_{ni}x_{3i} & & x_{ni}x_{ni}\end{bmatrix}\begin{Bmatrix}a_0\\a_1\\a_2\\a_3\\ \\a_n\end{Bmatrix}=\sum_{i=1}^{K}\begin{Bmatrix}P_i\\P_1P_i\\P_2P_i\\P_3P_i\\ \\P_nP_i\end{Bmatrix} \qquad \text{(b)}$$

By summing up the values of independent and dependent variables, the above equation (b) can be solved.

Table 5: Regression Equations for the Performance Parameters

Sl. No	Performance Parameter	Regression Equation	Fitness
1	First Crack Load	59.78+1.07E-10Vf+1.967Tf+2.25E-05Esf	0.98404
2	Deflection at First Crack	3.4-1.71E-11Vf+0.18947 Tf-3.60E-06Esf	0.99843
3	Yield Load	64.76+6.06E-10Vf+8.65453Tf+1.27E-04Esf	0.90284
4	Deflection at Yield	6.17-5.51E-12Vf+0.56868Tf-1.16E-06Esf	0.98492
5	Ultimate Load	104.62+1.31E-09Vf+25.69816Tf+2.75E-04Esf	0.99383
6	Deflection at Ultimate	12+7.92E-11Vf+0.18132Tf+1.66E-05Esf	0.9692
7	Deflection Ductility	1.945+1.39E-11Vf+0.18132Tf+2.92E-06Esf	0.94859
8	Crack Width	0.1+3.34168E-12Vf+0.06474Tf+7.01754E-07Esf	0.98813

Table 6: Predicted Results

REG	First Crack Load	First Crack Deflection	Yield Load	Yield Deflection	Ultimate Load	Ultimate Deflection	Deflection Ductility	Crack Width
CB	59.78	3.40	64.76	6.17	104.62	12.00	1.95	0.10
SF	64.50	2.64	91.50	5.93	162.30	15.49	2.56	0.25
SFU3	70.40	3.21	117.47	7.63	239.40	24.76	3.10	0.44
SFU5	74.33	3.59	134.78	8.77	290.79	30.94	3.46	0.57

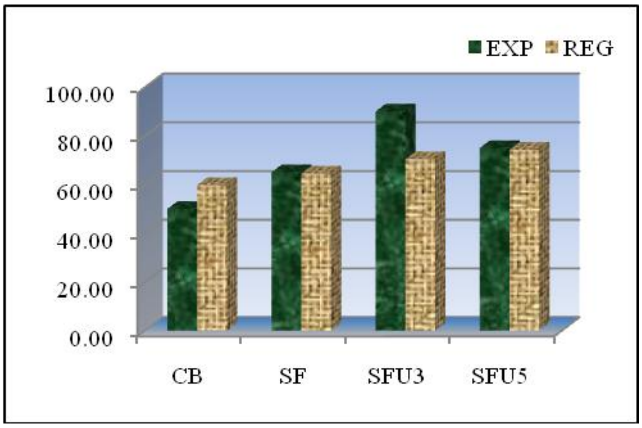

Figure 3: First Crack Load

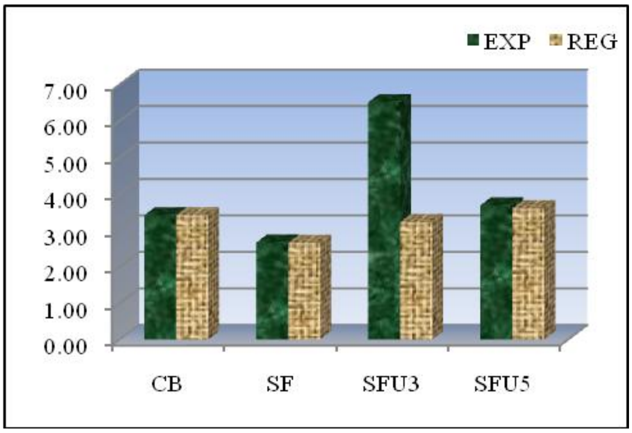

Figure 4: Deflection at First Crack

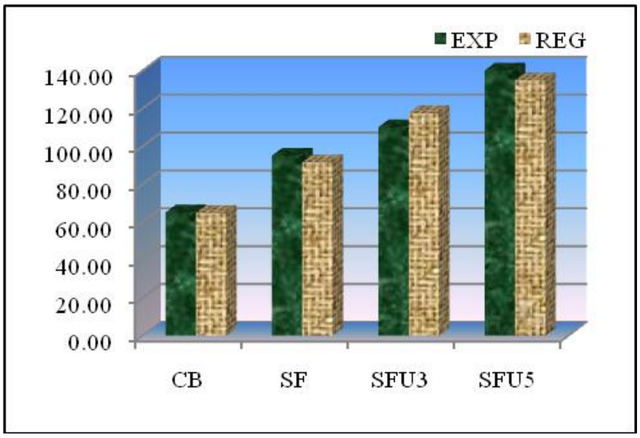

Figure 5: Yield Load

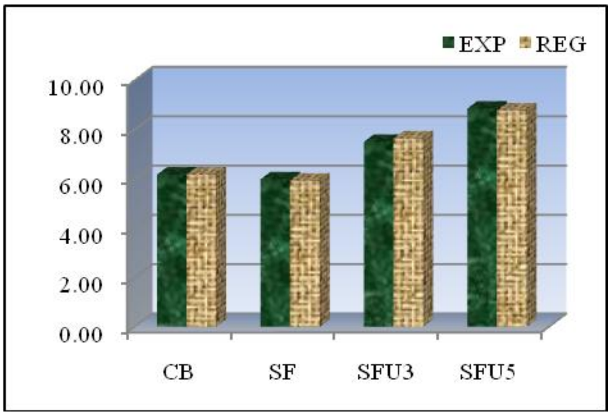

Figure 6: Deflection at Yield Load

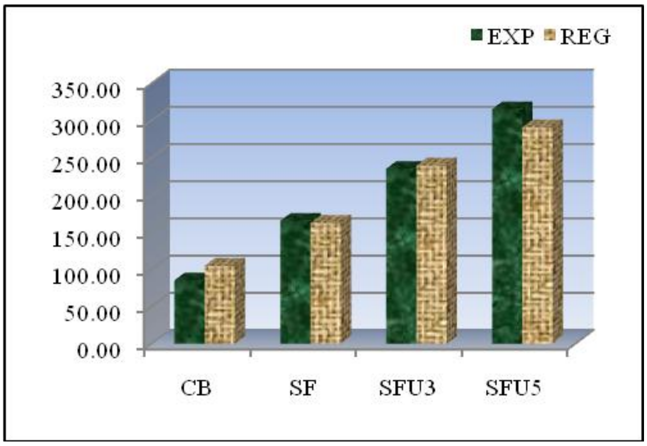

Figure 7: Ultimate Load

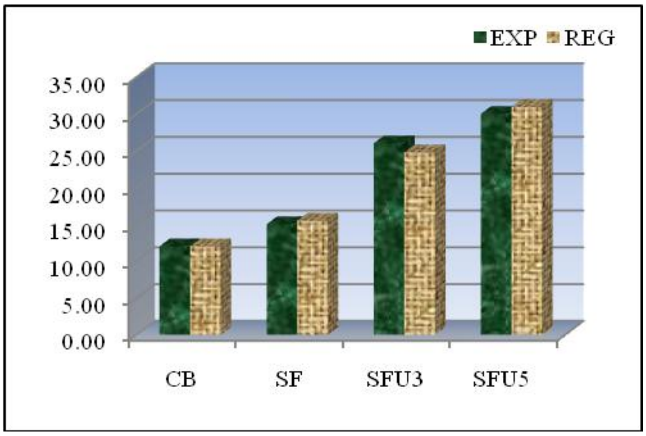

Figure 8: Deflection at Ultimate Load

4. RESULTS AND DISCUSSION

The experimental and predicted results for four beams are presented in **Tables 4 and 6**. It can be observed from the **Table 4** that at all load levels, GFRP strengthened SFRC beams exhibit a significant increase in strength. The ultimate load increased by 29.78 % and 47.61 % for 3mm and 5mm thick UDCGFRP laminated SFRC beams.

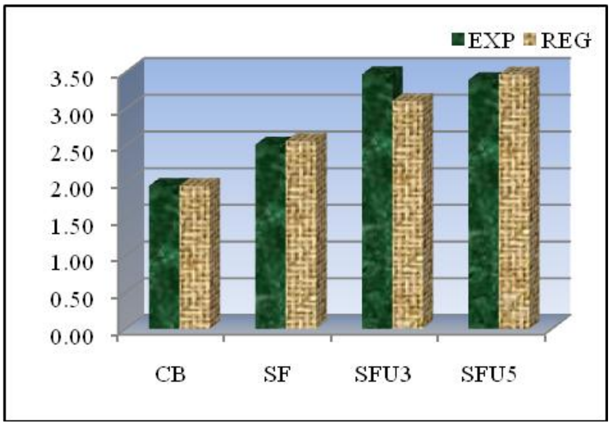

Figure 9: Deflection Ductility

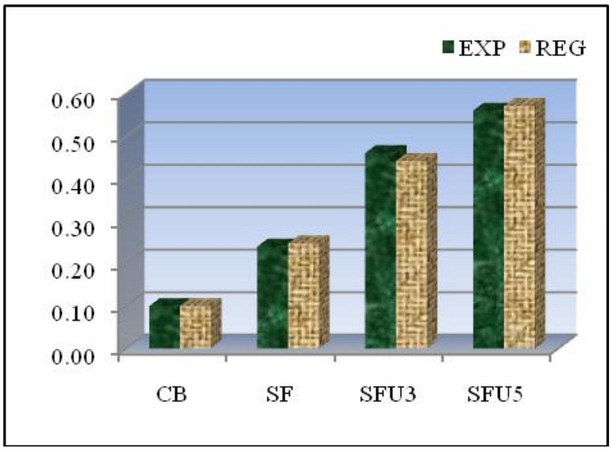

Figure 10: Crack Width

The GFRP strengthened SFRC beams showed enhanced ductility. The increase in ductility varied from 25.95% to 27.66%. The GFRP strengthened SFRC beams exhibited decreased deflection. The decrease in deflection varied from 42.30% to 50.00%. All the GFRP strengthened beams failed in flexural mode only.

Regression equations have been proposed for predicting the performance parameters of GFRP strengthened SFRC beams. The data used for conducting regression analysis is presented in **Table 4** and the regression equations are presented in **Table 5**. Comparisons were made between the predicted and experimental values and presented in **Figure 3 to 10**. The predicted results obtained through regression equation showed a close agreement with the experimental results.

5. CONCLUSIONS

The following conclusions are drawn based on the test results.

1. Addition of steel fibre has significant improvement in flexural strength.
2. The maximum increase in load carrying capacity of GFRP strengthened SFRC beam was about 47.61 %.
3. The GFRP strengthened SFRC beams exhibited an enhanced ductility upto 27.66%.
4. The maximum decrease in deflection for GFRP strengthened SFRC beams was 50.00%.
5. The proposed regression equation provided satisfactory prediction of the performance parameters.

6. REFERENCES

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