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Effect of CFRP Strengthening on Web of Steel I-Beam

P.R. Jagtap, S.M. Pore

Abstract: This study is aimed to strengthen the structural steel I beam with carbon fiber reinforced polymers (CFRP) composites to its web to increase its shear strength capacity. Lightweight Beam LB-100 @ 5.1 Kg/m and LB-115@ 8.1 Kg/m is used for this purpose. CFRP have light weight and high-strength as compare to other types of FRPs, so it can be used for strengthening purpose instead of using conventional methods of repair such as replacement and other. The web portion of the I-beam is made rust free to achieve proper bonding between the web and fiber sheet. A web of the beam is strengthened by carbon fiber reinforced polymer (CFRP) strips in layers with the help of adhesive. The beam with CFRP is cured in air for 48 h before testing. Experimentation is done at the UTM of 100 Ton capacity. A three point bending tests were performed on various beams and results show that the load carrying capacity of a strengthened beam is increased by 20 to 35% as compared with control beam (non-strengthened) and the local failure of beam is also avoided. It is observed that the deflection of strengthened beam is also reduced as compared to a non-strengthened beam. So, this technique of strengthening can be used to improve the performances of various old structures in civil engineering which undergoes loss of strength due to corrosion.

Keywords: CFRP, I-Beam, Strengthening, Deflection.

I. INTRODUCTION

Fiber-reinforced polymer (FRP) is used as a strengthening technique in various fields such as civil engineering structures, aeronautical fields, naval industries, etc. [1], [2]. FRP materials have found to be successful for flexural strengthening as well as for shear strengthening in case of concrete structures [3], [4]. Steel structures also need to improve their properties such as load carrying capacity, fatigue performance, etc. This can be possible by strengthening the steel sections with the help of FRPs. In comparison to all types of FRPs, carbon fiber-reinforced polymer (CFRP) has high strength to weight ratio, resistance to corrosion, lightweight, and easy for installation and therefore used for steel structures [5]-[8]. Steel plate girders are widely used in buildings and bridges and have good flexure capacity and serviceability performance due their deep webs. These members are susceptible to corrosion due to environmental effects and may loss their strength. Rehabilitation of such sections could be very tricky.

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* Correspondence Author
P.R. Jagtap*, Civil Engineering Department, Dr. Babasaheb Ambedkar Technological University Lonere (Raigad), Maharashtra. Email: prjagtap26@gmail.com
S.M. Pore, Civil Engineering Department, Dr. Babasaheb Ambedkar Technological University Lonere (Raigad), Maharashtra.
Email: smpore@dbatu.ac.in

The traditional rehabilitation techniques are based on welding steel plates and stiffeners to the damaged web. However, increase in temperature due to the welding process may cause more damage to the steel section. So FRP laminates may offer an attractive alternative in such cases [1], [9].One of the most important criteria for the CFRP strengthened steel structures is the bonding between CFRP, adhesive, and steel surfaces [10].

It is seen that adhesively bonded composite joints can be significantly affected by the service environment: however, this is highly dependent on the joint type and materials involved [11].

II. OBJECTIVES

The objective of present study is to strengthen the web of steel I-beams with two and three layers of CFRP strips and to compare its behavior with non strengthened beam. The research also examined the properties of adhesive used for attaching the CFRP to the web of I-section.

III. MATERIAL PROPERTIES

A. I-Beam

Two types of structural I beams are used for strengthening purpose. They are light weight beam (LB) 100 @ 5.1 Kg/m and LB 115 @ 8.1 Kg/m [12]. The other properties of steel sections are as per Table-I. The cross section of I-beam is shown in Fig. 1

Fig. 1. Cross section of Beam *(adopted from [12])*

Table- I: Properties of steel I beam *(adopted from [12])*

Properties	LB-100	LB-115
Weight (Kg/m)	5.1	8.1
Length (mm)	1000	1000
Height (mm)	100	115
Width (mm)	50	65
Flange Thickness (mm)	4	5
Web Thickness (mm)	3	4
E-Modulus (N/mm^2)	200000	200000
Yield Strength (N/mm^2)	250	250

B. CFRP

The CFRP strips used in all the experiments were unidirectional woven carbon fabric strips (HinFab™ HCU403) with a thickness of 0.43 mm. The other properties of the CFRP are as per provided by the manufacturer and are mentioned in Table II while the Poisson ratio is taken as 0.3 [12]. The elastic tensile modulus of the CFRP strips is verified and an average value of 240000 MPa is obtained. Fig.2 shows the Photograph of CFRP strips [12].

Table- II: Properties of CFRP strips *(adopted from [12])*

Weight (g/m^2)	Width (mm)	Thickness (mm)	Density (Kg/m^3)	Filament Diameter (micron)	Tensile Strength (N/mm^2)	Tensile Modulus (N/mm^2)	Elongation (%)
400	500	0.43	1800	7	4000	240000	1.7

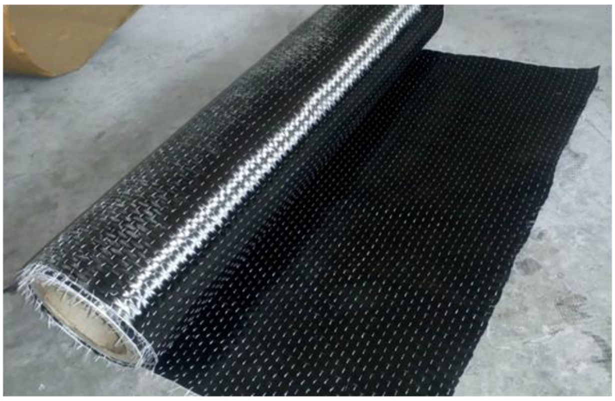

Fig. 2. Unidirectional CFRP strips *(adopted from [12])*

C. Adhesive

An adhesive consists of two components Hinpoxy C Resin and Hinpoxy C Hardener. Hinpoxy C Resin is a Bisphenol-a based liquid epoxy resin and Hinpoxy C Hardener is a colorless, low viscocity, modified amine hardener. The mixing ratio of the epoxy was 100 part of component A (resin) to 30
part of component B (hardener) by weight (Resin: Hardener = 100: 30) [12]. The other properties of adhesive are as per the Table III .

Table III: Properties of adhesives *(adopted from [12])*

Characteristic	Resin	Hardener
Density (Kg/m^3)	1150-1200	940-950
Viscosity at 25 °C (mPas)	9000-12000	< 50
Flash Point (°C)	> 200	> 123
Storage Life (Yrs)	3	1

IV.EXPERIMENTATION

The transfer of load between steel and CFRP is depends on the adhesive quality and surface of the steel. Surface of the steel must be clean and smooth before application of CFRP, therefore surface preparation is one of the most important steps for strengthening of steel structures. It is the key to a strong and durable adhesive bond [1]. In this study surface grinders are used to remove all rust from the web of I section. To examine the effects of CFRP strips on web of steel I-beams total twelve beams were considered: six for LB-100 and six for LB-115. Three point loading (TPL) test were performed on all these beams. General specification of beam sections is indicated in table 3. First six specimens were used for LB-100, from which first and second specimen (CB1 & CB2) was not strengthened. The web of third and forth beam (SB3 & SB4) was strengthened by using two layers of CFRP strips and the web of fifth and sixth beam (SB5 & SB6) was strengthened by using three layers of CFRP strips. Remaining six specimens (B7 to B12) were used for LB-115 and strengthened in similar manner as LB-100.

V.LOADING PROCEDURE

The web portion of I-beam was well prepared for installation of CFRP strips by sandblasting. The maximum duration after sandblasting and before attaching CFRP strips at 30°C must be less than 48 h (SIKA® product information, 2008). Then, CFRP strips were cut to a width equal to web height of I-beam (LB-100 and LB-115) and length equal to 1000 mm. Later, an adhesive (i.e. combination of resin and hardener) was prepared with a proportion 100:30 (resin: hardener) by weight, and a layer of approximately 1 mm was formed on web of I section. Then, CFRP strips were pasted one by one on web by using adhesive with the average thickness of 1 mm for each layer as shown in fig. 3. After 48 h of curing the adhesive had appropriately been hardened, and the tests were carried out. The same procedure was followed for both the beams.

For test setup, first, beams were placed on the roller supports. Then, a load cell with a maximum capacity of 200 kN was placed at the mid span of the beam. After that, one linear variable deformation transducer (LVDT) was installed at the mid span for measuring vertical deflections. Then, load cell and LVDT were connected to the Data Logger to measure the load and deflection of the beams. The load was applied through UTM (100T capacity). The experimental setup based on the three-point loading, is shown in fig. 4

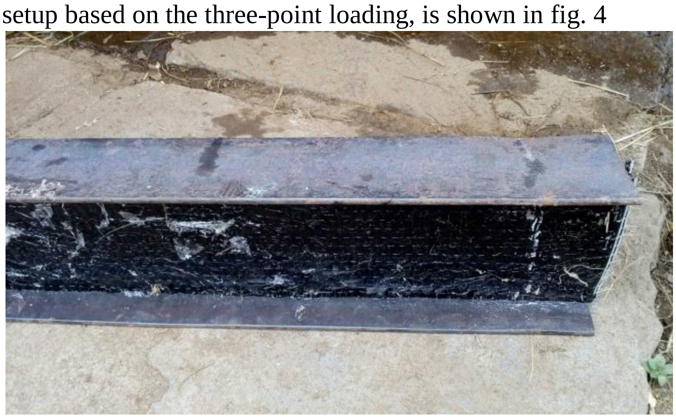

Fig. 3. Web of beam strengthen with CFRP strips

Fig. 4. Experimental setup showing Three Point Loading

VI. TEST RESULTS AND DISCUSSION

D. Load carrying capacity

The local failure of compression flange of the beam is due to application of point load at the middle and this is common in various sections due to insufficient thickness of flange and also due to web buckling or web crippling. The beam will not fail due to plastic hinge formation but fails so earlier than its actual load carrying capacity. So to avoid such earlier failure of beam the web of section is strengthened with two and three layers of CFRP strips from both sides of sections. Then the load is applied on top flange through UTM. The beam continues to take load until it fails by plastic hinge formation. The load carrying capacity of the beam increases as compared to non-strengthened beam (control beam) and local failure of the compression flange is also not observed. The deflection in strengthened beam is also very less compare to control beam.

Table 4 shows the results obtained from experimentation for two types of sections used. The increase in LCC of SB1, SB2, SB3 and SB4 is due to the strengthening of web with two and three layers of CFRP strips.

E. *Deflection*

To measure the vertical deflection at the mid span of beam, LVDT was installed at the bottom side of the tension flange exactly below the point load [12]. The deflection in control beam at failure load is remarkable and has values as per Table 4, but in case of strengthened beam LCC increases at minimum deflection. Also deflection in beam with three layers of CFRP is less as compare to two layers of CFRP.

Table- IV: Results of experimental study

Name of Beam	Control Beam				Strengthen Beam (2 Layers)				Strengthen Beam (3 Layers)			
	CB1		CB2		SB1		SB2		SB3		SB4	
	LCC	Defle	LCC	Defle	LCC	Defle	LCC	Defle	LCC	Defle	LCC	Defle
LB-100	38.60	30.50	38.3	32.0	46.7	20.6	45.7	19.5	51.6	17.1	49.4	19.5
LB-125	60	28	62	30	74.6	17.2	73.5	18	79.5	12.5	80.2	14.2

* Load Carrying Capacity (LCC) is in kN and Deflection (Defle) is in mm

VI. CONCLUSIONS

Strengthening of steel structures using CFRP is a new technique used for many civil engineering structures. This technique is very successful for increasing load carrying capacity of beams and various structural elements. Web strengthening of I-beams increases its shear capacity. Also due to this technique web crippling and local failure of web is totally avoided.

In the present study following points are concluded from the results and discussions:

1. Application of CFRP strips on the web of steel I-beams is a successful method for increasing the load capacity and its shear behavior.
2. When two layers of CFRP strips are attached on both sides of web the load carrying capacity of strengthened I-beam is increased up to 20% compared to control beam for both the sections.
3. When three layers of CFRP strips are attached on both sides of web the load carrying capacity of strengthened I-beam is increased up to 35% as compared to control beam for both the sections.
4. Application of thicker CFRP strips causes significant increment in the load carrying capacity.
5. As the thickness of CFRP strips increases there is less deflection in strengthened beam as compare to control beam.
6. So CFRP strengthening technique is the best method compare to other conventional methods to improve the performance of old steel structures.

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AUTHORS PROFILE

Prashant R. Jagtap, Research Scholar, Civil Engineering Department, Dr. Babasaheb Ambedkar Technological University (DBATU) Lonere (Raigad), Maharashtra.

Dr. Sachin M. Pore, Associate Professor and Head of Civil Engineering Department, Dr. Babasaheb Ambedkar Technological University (DBATU) Lonere (Raigad), Maharashtra.