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STEEL I-BEAMS STRENGTHENED WITH CARBON FIBER REINFORCED POLYMER (CFRP) LAMINATES: A REVIEW

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Abstract: In recent years, the strengthening of the components of structures has become essential for any type of structure. So, FRP strengthening seems to be an effective alternative for such retrofitting. Various studies are available for strengthening of concrete structures with FRP but limitations are there in use of FRP in steel structures. Using Carbon Fiber Reinforced Polymer (CFRP) to strengthen steel structures, especially to steel beams has attracted a great opportunity to the researchers. Use of CFRP laminates than other forms of FRPs for rehabilitation of steel I-beams is rapidly increasing in recent years due to its properties such as, high tension strength, low weight and high strength to weight ratio. Also it is very flexible and forms all kinds of shapes and thus it is very easy to use on existing structures. This paper reviews the work of various researchers on use of CFRP laminates to strengthen the steel I-beams. The study shows that, this technique gives very good results on overall behavior of steel I-beams.

Keywords: *CFRP, Laminate, Strengthening, I-Beam, Adhesive*

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I INTRODUCTION

Steel structures play an important role in civil industry and therefore more attention is required for repairing and rehabilitation of such structures. A large number of steel structures, such as buildings, large mining equipment, bridges and offshore platforms get damaged due failure of beams and therefore special attention is to be given on structural stability of these beams. So if any beam found to be structurally damaged due to corrosion or other sources they need repairing. Conventional method of repairing or strengthening of these beams is to cut the damaged portion and replace it with another plate, or attach external steel plates to the damaged portion of the beam. These plates are usually bulky, heavy, difficult to fix and prone to corrosion in future. The methods of retrofitting which utilizes steel plates has some disadvantages like use of heavy lifting equipment to lift the plates and due to this additional dead load will be on the structure. So there is a need to look for alternatives.

In recent years, the strengthening of the steel components of structures has become essential for structural retrofits. FRP strengthening seems to be an effective alternative for such retrofitting. Fiber-reinforced polymer possesses great advantages as a structural material, including high strength, anti-corrosion properties, and high durability and is able to restore the lost capacity of damaged structures. Various forms of FRPs are available such as glass, carbon, aramid, basalt, etc.

Repairing or retrofitting of steel structures with CFRP (Carbon Fiber Reinforced Polymer) laminates costs far less than replacement and takes less time for construction. Different methods exist for strengthening various structures. Use of CFRP is more popular than other materials for strengthening structures because of their high tension strength, low weight, high strength to weight ratios and excellent resistance to corrosion and environmental degradation. It is very flexible and forms all kinds of shapes, and is easy to handle during construction. Applying CFRP for strengthening has been recognized as more appropriate than other types of FRPs because of its higher strength [1].

II.CFRP COMPOSITES

CFRP composite is normally used in steel strengthening because its strength and stiffness are comparable to the steel material. There are three types of CFRP materials: normal modulus (CFRP) with a stiffness less than steel, high modulus (HM-CFRP) with a stiffness similar to steel, and ultra high modulus (UHM-CFRP) with stiffness higher than steel [2]. Therefore, HM-CFRP and UHM-CFRP are preferred in strengthening steel structures hence they will carry the stresses before the steel is yielded. The CFRP composites are supplied in the forms of dry wrap sheets and plates, as shown in Fig. I and Fig. II respectively.

Fig. 1 CFRP sheet

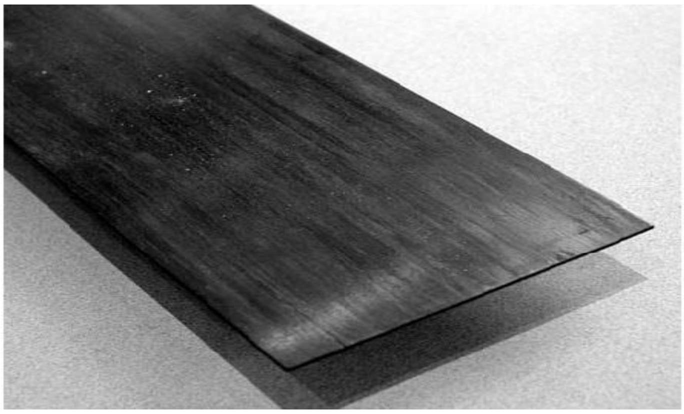

Fig. 2 CFRP plate

The properties of CFRP sheets and plates are different for different manufacturers. Some of the properties given by Hindoostan Mills Ltd. are given in Table I. Stress-strain relationship for one normal modulus and one ultra high modulus laminate specimens [3] is shown in Fig. III.

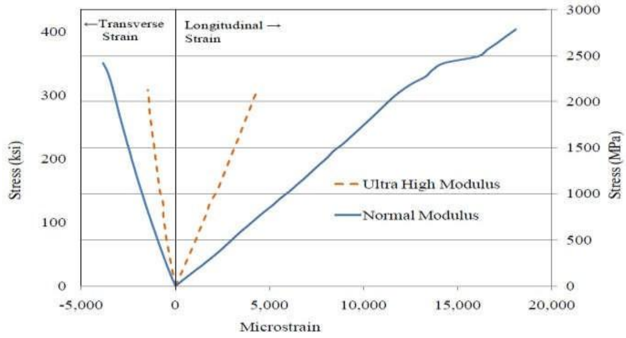

Fig. 3 Stress-strain graph of CFRP composites (adopted from 3) TABLE I

Properties	CFRP Sheet (200 GSM)	CFRP Sheet (400 GSM)	Plate
Areal Weight (g/m^2)	200	400	1400
Width (mm)	500	500	50
Dry Fabric Thick (mm)	0.22	0.43	1.4
Density (Kg/m^3)	1800	1800	1600
Tensile Strength (MPa)	4000	4000	4200
Tensile Modulus (MPa)	240000	240000	242000

III PROPERTIES OF CFRP MATERIALS

ADHESIVES

To maximize the effectiveness of FRP strengthening, the selection of an appropriate adhesive is very important. The adhesive layer is the weak link in FRP-strengthened steel structures, which cause adhesion failure. As a result, the material properties of the bonding adhesive play an important role in determining the load- carrying capacity of the strengthened structure. The selection process of proper adhesive needs to consider not only the short-term mechanical performance but also its long-term durability and ease for handling on the construction site. [4]

CFRP material in the form of sheet and plate are bonded to the steel surface using a two-part epoxy adhesive i.e. resin and hardener. An adhesive supplied by Hindoostan Mills Ltd. for CFRP sheets consists of two components Hinpoxy C Resin (Part-A) and Hinpoxy C Hardener (Part-B). Hinpoxy C Resin is a Bisphenol-a based liquid epoxy resin and Hinpoxy C Hardener is a colorless, low viscosity, modified amine hardener. The mixing ratio is 100 part of component A (resin) to 30 part of component B (hardener) by weight (Resin: Hardener = 100: 30). This adhesive is totally a water resistant and curing time after application is about 24 Hrs. The other properties of adhesive are as per the Table 3. [5,6,7]

An adhesive supplied by Hindoostan Mills Ltd. for CFRP plates consists of two components Hinpoxy CAD Resin (Part-A) and Hinpoxy CAD Hardener (Part-B). The mixing ratio is 100 part of component A (resin) to 35 part of component B (hardener) by weight (Resin: Hardener = 100: 35). This adhesive is also totally a water resistant and curing time after application is about 24 Hrs. The other properties of adhesive are as per the Table II.

IV CONTRIBUTION

Mertz and Gillespie [8] found the effectiveness of CFRP materials on naturally deteriorated steel bridge girders. Steel girders deterioration was due to loss of cross-section area through corrosion. These girders were removed from a highway bridge in Pennsylvania (USA) after being demolished. The members retrofitted with five different ways and results showed that the flexural stiffness and strength increased considerably.

Another study was conducted by Miller et al. [9] on full scale corroded girders to investigate the potential of reinforcement with CFRP plates. First the three-point bending tests were performed on the unreinforced girder to assess decrease in strength and stiffness due to reduction of cross-section area. The strengthening of four girders consists of bonding 5.25 mm-thick CFRP plates to the soffit of the tension flange. Test results showed that the stiffness had increased in the range 10-37% due to retrofit.

Strengthening of undamaged steel-concrete composite girders through attaching different number of layers 1, 3, and 5 of 1.27 mm- thick CFRP plates to the tension flanges of the steel section was investigated by Tavakkolizadeh and Saadatmanesh [10]. Their results showed that ultimate load carrying capacity of the girders was significantly increased. However, their elastic stiffness was slightly increased. Furthermore, it was noted that efficiency of reinforcement was reduced as the number of layers of CFRP increased.

Properties	Adhesive for Sheet		Adhesive for Plate	
	Resin	Hardener	Resin	Hardener
Density (g/cm^3)	1.15-1.2	0.94-0.95	1.15-1.35	0.9-1.1
Flash Point (°C)	>200	>123	>150	>150
Viscosity (mPa.s)	9000-12000	<50	Thixotropic Nature	Thixotropic Nature
Storage Life (Years)	3	1	1	1

In order to simulate severe service damage of the composite specimens, Sen et al. [11] overloaded steel-concrete composite beams until failure of the tension flange was induced and then the beams were reinforced with CFRP plates. Test results showed significant increases in the beams capacity. Habeeb et.al., [12], shows that maximum tensile strength and maximum bending strength of unidirectional CFRP strips is more compared to bidirectional CFRP strips.

The use of normal modulus CFRP and HM-CFRP sheets to restore artificially damaged steel concrete composite beams was indicated by Shaat and Fam [13]. It was noted that flexural strength and stiffness of the composite girders were reduced by 60 and 54%, respectively due to complete cut in the tension flange at mid-span. However, restoration with CFRP sheets was able to recover original strength and stiffness.

The effectiveness of CFRP sheets on improving fatigue strength of steel girders was examined by Tavakkolizadeh and Saadatmanesh [14]. They tested a number of small-scale steel beams strengthened with pultruded carbon fiber sheets. In order to create a fatigue sensitive detail, tension flanges of steel beams were cut to create a notch on each side. The CFRP patches with identical lengths were then bonded on to the cut sections. Different stress ranges of 69 to 379 MPa were considered in the study.

K. Soudki et al., [15] presents preliminary results on the effectiveness of using adhesively bonded prestressed carbon fiber reinforced polymer (CFRP) strips to increase the static flexural strength of a steel member. They also presented transfer length data of prestressed CFRP strips bonded with epoxy adhesive to a steel member. The CFRP prestressed system was very effective in enhancing the flexural behaviour of a steel beam. The increase in the yield strength ranged from 7 to 13% and the increase in ultimate strength ranged from 18 to 28% depending on the grade of steel.

V.SURFACE PREPARATION

Surface preparation is one of the most important steps in strengthening of steel structures where CFRP is used as a material for bonding purpose. It is the key to a strong and durable adhesive bond. The transfer of load between steel and CFRP composites mainly depends on the adhesive quality. This transfer is affected by surface preparation, bond length, type of material, etc. The surface preparation can be done effectively by grit-blasting techniques. Grit- blasting removes weak layers and modifies the chemical characteristics of the adhesive. It is discussed that application of the CFRP material can occur up to 150 h after completion of the surface preparation. If strengthening is made after this time, lower bond strength will be achieved as per Gholami et al., [16]. Surface grinders or sandblasters were used to remove all rust, paint and primer from the flange of I section. Also at the same time, the surface of be treated with very fine sandpaper to provide sufficient roughness and more bond strength [3].

D. Schnerch et al., [17] conclude that the reliability of joint is highly dependent upon the surface treatment processes for bonding the fiber-reinforced composite to the steel structural elements. For assessing the effect of the CFRP strengthening technique on the fatigue strength, Jiao et al., [18] used a grinder to remove the corrosion as well as to level the weld area on each steel beams of fit before applying the adhesive. Tavakkolizadeh and Saadatmanesh

[14] used a sand blaster carefully by number 50 glass bids and washed with saline solution just prior to the application of the composite sheet oxidation.

However Schnerch et al. [19] contended that preparing the surface with a hand grinder followed by sandpapering reduces the bonding ability of the surface. However, a chemically active steel surface that is free from contaminants is essential to enhance the chemical bond between the adhesive and the metallic surface. S. A. Hashim [20] claimed that, Brushing, ultrasonic, or vapour degreasing systems are the most efficient to remove oil and other potential surface contamination, especially when adequate solvents are used. Contamination may then be removed using the excess solvent, rather than simply re depositing it on the steel surface as the solvent evaporates.

The most efficient means of achieving a high-energy surface of the steel is by grit blasting said by Hollaway and Cadei [21]. Grit blasting with angular grit removes the inactive oxide and hydroxide deposits by cutting and deformation of the base material. The grit size also affects the surface profile of the steel. Harris and Beevers

[22] stated that finer particles created a smoother surface than coarser grit particles and smoother surfaces exhibited higher adhesive-steel surface bonding.

VI. ANALYTICAL STUDY

Analysis of strengthening effect on existing structures can be done by computer software. In most of the structural analysis software, the Finite Element Method (FEM) is used. Analytical method was evaluated by Colombi [23] to investigate the fracture mechanics of CFRP flexural strengthened steel beams by using ANSYS software. Deng et al. [24] validated an analytical solution to calculate the stress in the CFRP flexural strengthened steel beams by using ABAQUS software.

K. Narmashiri and M. Z. Jumaat [25] used 28 laboratory beam specimens for experimentation purpose which were strengthened by Carbon Fiber Reinforced Polymer and steel plates. They used ANSYS software to find the accuracies of Finite Element (FE) simulations, based on two and three dimensional (2D and 3D) modelling of strengthened steel I-beams in static linear and non- linear analyses. ANSYS software was used by P. R. Jagtap and S.M. Pore [5] for three-dimensional simulation to evaluate the experimental results. The steel I sections, CFRP strips and adhesive were simulated using the 3D solid triangle elements. Comparison of experimental and numerical study on the parameters such as deflection, load carrying capacity shows a good agreement between the results.

VII.CONCLUSION

This paper reviews the existing application of CFRP laminates to the steel I-Beams. This technique of strengthening the surfaces of steel sections with CFRP composites is a relatively promising field and must be used for steel I-beams. Various researchers show that CFRP wrapping system proves to be advantages over conventional strengthening processes. The CFRP system was very effective in enhancing the flexural strength and yield strength of a steel I-beam which results in increase in ultimate strength. Using CFRP to steel I- beams enables to restore lost capacity and take additional loads. Also it increases the fatigue life of steel structures and reduces the crack propagation.

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