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Review Paper on Experimental Study On Flexural Behavior Of Steel Section Bonded With Fiber Reinforced Polymer Sheets

[1]Naeem Md Haneef Injarwale,[2]Dr. Sunilkumar.S. Patil
[1]P.G.Student, [2]Professor and Head
Of Civil Engineering department,
Walchand Institute of Technology, Solapur, Maharashtra, India

Abstract: **This paper provides a review of some of the progress in the area of fiber reinforced polymers (FRP)-strengthening of steel sections. The addition of FRP materials to upgrade deficiencies or to strengthen structural components can save lives by preventing collapse, reduce the damage to infrastructure, and the need for their costly replacement. The retrofit with FRP materials with desirable properties provides an excellent replacement for traditional materials, such as steel jacket, to strengthen the reinforced concrete structural members. Existing studies have shown that the use of FRP materials restore or improve the flexural strength of steel section and in some cases allow the structure to carry more load than it was designed for.**

Index Terms **– Fiber reinforced polymer, steel section, different position of wrapping, and testing.**

I.INTRODUCTION:

FRP has been widely used in strengthening concrete structures, and extensive research has already been conducted. High resistance against corrosion and chemical attacks. Another significant advantage of FRP, which applies only to FRP laminates formed via the wet layup process, is the ability of such FRP laminates to follow curved and irregular surfaces of a structure. This is difficult to achieve using steel plates. These uses of FRP sheets to upgrade the resistance of steel structures have recently been studied. The importance to rehabilitate ageing and deteriorated existing steel structures has motivated researchers to develop simple and efficient rehabilitation techniques. FRP sheets are formed by embedding continuous fibers in a polymeric resin matrix which binds the fibers together. Common fibers used in FRP sheet include carbon, glass, aramid and basalt fibers while common resins are epoxy, polyester, and vinyl ester resins. In this study, BFRP, CFRP, GFRP strips are used

The use of structural steel in buildings' retrofitting can be often considered economical and efficient because:

• Steel buildings are particularly effective under performance-based design.

• Steel members exhibit ductile behavior beyond elastic limit, hence dissipate considerable amount of energy before damages occur.

• Steel members have higher strength-to-weight and stiffness-to-weight ratios; hence, the buildings attract less base shear under an earthquake.

• A better quality control is practiced in the production of the material as well as the fabrication and erection of them, while ensuring results close to the theoretical predictions.

• Steel can be generally used to retrofit all types of structures without increasing the dead weight dramatically, making the works less intrusive and time consuming.

Depending on the desired properties, usage and level of damage in structural members, these can be repaired and strengthened by several widely used methods.

In this review paper, review of an experimental study will be carried out different authors for finding the increase in strength of Steel sections with FRP wrapping.

II. LITERATURE REVIEW

The intrinsic advantages of strengthening the steel-based structures by the use of fiber reinforced plastic (FRP) material have not yet been fully exploited. In this study, a succinct overview of recent studies made to enhance the strength of steel beams using FRP laminates is presented. The results presented and discussed in this study were obtained by closely studying the behavior of steel beams strengthened with carbon FRP material

. This provided a better understanding of the behavior of the rehabilitated Beam. Based on this following conclusion can be made.

1. An analytical model capable of predicting the linear and nonlinear behavior of steel beams rehabilitated using FRP sheets is developed
2. The model predictions for the midspan strains and deflections and for the failure load were compared against the experimental results.
3. It can also predict the deformations of the rehabilitated beam up to failure.
4. The tested specimen failed when the FRP sheet reached its maximum tensile strength.

Mohammad Al-Emrani and Robert Kliger. (2006) studied about the use of advanced composite materials to strengthen and repair existing structures is increasing rapidly. One specific area in which the technique has recently been introduced is the strengthening of metallic structures with bonded carbon-fiber laminates. In this paper, the behavior of composite steel-CFRP members is studied experimentally and using FE analysis. A new type of test specimen has been developed to examine the effect of various material parameters on the behavior and strength of bonded steel-CFRP elements. Finite element analysis of the tested elements was also employed to examine the type and magnitude of interfacial stresses in the bond line of these elements. Moreover, different types of fracture mode could be examined by testing composite elements with different combinations of CFRP-laminates and adhesives. The tested composite elements displayed different behavior and a large difference in strength and ductility could be observed.

1. The degree of ductility which was observed for the tested specimens also varied, ranging from brittle to very ductile failure.
2. The stiffness of the composite laminates and the adhesive used for bonding both play a dominant role in the type of fracture mode and thereby the ultimate load-carrying capacity that can be achieved for steel elements strengthened with adhesively bonded laminates.
3. The degree of ductility which was observed for the tested specimens also varied, ranging from brittle to very ductile failure. The tests succeeded in reproducing the failure modes that can be obtained in steel elements strengthened with bonded composite laminates. The tensile rupture of the laminate, as well as debonding and delamination failures in the middle and at the ends of the laminates, could be observed.

Kambiz Narmashiri1, Mohd Zamin Jumaat and N. H. Ramli Sulong. (2011) studied about structural performances of the CFRP flexural strengthened steel I-beams were entirely depending on the CFRP bond length. Four CFRP failures occurred i.e. the below load splitting, below load debonding, end delimitation, and end debonding. The CFRP bond length played a great role in occurrence and sequence of failures. Applying shorter CFRP bond length caused early end debonding, and using longer CFRP bond length resulted in retarding the end debonding. The higher load bearing capacity was achieved by using longer bond length. High strain intensity occurred on plate at the CFRP tip resulted in delimitation (interlinear failure). Application of longer CFRP plate to retard delimitation is ineffective. Strain intensity occurred on adhesive at both below point load and the CFRP tip resulted in debonding (adhesion failure). This strain intensity was much significant after yielding especially for shorter CFRP plate. Using longer plate could decrease strain on adhesive at both regions significantly. Application of CFRP decreased deformations in both lateral and vertical directions. The reduction was more significant for lateral deformation in both before and after yielding, but for vertical deflection, it occurred especially after yielding. Based on this following conclusion can be made.

1. Applying thicker CFRP plate, the load carrying capacity increased significantly.
2. The specimens were strengthened by using CFRP with same thickness, but they have different material properties. Higher modulus of elasticity caused higher load capacity.
3. The application of different thickness and CFRP Plates used in strengtning steel I-beam caused change in the CFRP Failure Modes.
4. One of the most efficient approaches to increase the strength beam against the below load splitting by increasing the CFRP thickness.

Yail J.Kim, Kent A, Harries (2011) studied about the flexural behavior of damaged steel beams repaired with carbon fiber reinforced polymer (CFRP) strips. The damage is intentionally created by notching the tension flange of the beams. Six beams are tested to evaluate the static and fatigue performance of the repaired beams with emphasis on local plasticity and the CFRP–steel interface. A three-dimensional finite element analysis (FEA) is conducted to predict the experimental behavior. A modeling approach is proposed to simulate the fatigue response of the repaired beams, based on the strain-life method and cumulative damage theory. CFRP Prepair results in a recovery of static load-carrying capacity of the damaged beam to that of an undamaged beam. The stress range at the damage influences the fatigue life, damage propagation, and plastic strain development of the repaired beams. Fatigue-crack propagation across the web of the beams is not significant up to 50% of their fatigue life, whereas brittle web fracture follows beyond the threshold. A bilinear fatigue response is observed at the CFRP-steel interface, whose magnitudes are dependent upon the number of fatigue cycles and the applied stress range. An empirical model is proposed to predict the fatigue behavior of the interface Based on this following conclusion can be made.

1. The fatigue response of the CFRP–steel interface was bilinear and was dependent upon the stress range and the number of fatigue cycles. The local bond failure of the CFRP strip due to fatigue damage caused a sudden increase in the bond stress and corresponding slip of the strip. The proposed empirical model may be useful for estimating the fatigue behavior of CFRP–steel interfaces.
2. The behavior of damaged steel beams repaired with CFRP strips subjected to monotonic and fatigue eventually resulting in brittle web fracture. The stress range affected the crack propagation rate of the repaired beams. The fatigue cycles resulted in a gradual increase in CFRP strains near the damage and debonding strains were noticed when the cycles further increased.
3. The elastic strains at the root of notch were essentially constant up to 10% of the fatigue life of the repaired beams, irrespective of the stress range. The development of the plastic strains was influenced by the stress range; however, their magnitude was not significantly affected when the stress range was below 40% of the yielding strength of the steel (FY = 393 MPa).

K. Galal, MASCE; H. M. Seif ElDin, and L. Tirca (2012) studied about there are many existing deteriorated steel bridges that need to be retrofitted. The author investigates the effectiveness of using carbon fiber-reinforced (CFRP) composite systems in retrofitting deteriorated steel beams. A total of 13 medium-scale steel I-beams with a span of 1.6 m were tested in a four-point bending setup. The tested beams were divided into four groups according to their studied parameter. Group 1 consists of four retrofitted beams with different percentages of artificial deterioration to simulate corrosion in the bottom flange with the aim to investigate their behavior and to determine the residual flexural capacity. The other three groups have deteriorated steel beams that were retrofitted with different CFRP systems with the aim to evaluate the effectiveness of the proposed retrofit schemes. Four deteriorated beams were retrofitted with CFRP sheets bonded to the tension flange and were tested in Group 2. Group 3 consists of two deteriorated steel beams that were retrofitted with CFRP plates externally bonded to the bottom flange of the tested beams. Group 4 consists of three beams retrofitted using an unbounded CFRP sheet attached to two ductile anchorage systems at the beams' ends. Their study shows that steel beams retrofitted with external bonded CFRP systems experienced limited ductility upon the failure of the CFRP either by debonding or rupture at higher load capacities than that of the retrofitted beams. The proposed anchorage system could increase the strength of the deteriorated beam, behave in a ductile manner, and eliminate the early peel off of the CFRP sheet. Based on this following conclusion can be made.

1. Retrofitting deteriorated steel beams with externally bonded CFRP composites would increase its post yield carrying capacity yet will result in reduced displacement ductility.
2. Local deterioration in the bottom flange of retrofitted steel beams has negligible effect on the load-deformation behavior of the beam. This is mainly attributable to the insignificant reduction in the stiffness of the beam. However, there is a local increase in the strains of the deteriorated section.
3. The end detail of the unbounded CFRP sheets in a ductile anchorage system has a significant influence on the efficiency of retrofitting scheme.
4. Transverse wrapping of the CFRP longitudinal retrofit plates (that are externally bonded to the bottom of the tension flange of steel beams) using CFRP sheets wrapped around the bottom flange at both ends did not have significant influence on delaying/eliminating the debonding of the CFRP plates of the retrofitted steel beam.

Mohamed Kamruzzaman, Mohd Zamin Jumaat, N. H. Ramli Sulong, and A. B.M. Saiful Islam (2014)
Studied about The application of fiber-reinforced polymer (FRP) composites for strengthening structural elements has become an efficient option to meet the increased cyclic loads or repair due to corrosion or fatigue cracking. Hence, the objective of this study is to explore the existing FRP reinforcing techniques to care for fatigue damaged structural steel elements. This study covers the surface treatment techniques, adhesive curing, and support conditions under cyclic loading including fatigue performance, crack propagation, and failure modes with finite element (FE) simulation of the steel bridge girders and structural elements. FRP strengthening composites delay initial cracking, reduce the crack growth rate, extend the fatigue life, and decrease the stiffness decay with residual deflection. Prestressed carbon fiber-reinforced polymer (CFRP) is the best strengthening option. End anchorage prevents debonding of the CRRP strips at the beam ends by reducing the local interfacial shear and peel stresses. Hybrid-joint, nonadhesive, and carbon-flex can also be attractive for strengthening systems. . Based on this following conclusion can be made.

1. The modulus of elasticity, tensile strength, shape, and configuration of FRP composites of an adhesively bonded joint play an important role in respect of the fatigue strength and lifetime of reinforced steel beams and bridge girders.
2. The use of end anchorage prevented debonding of the CRRP strips at the beam ends by reducing the local interfacial shear and peel stresses.
3. Epoxy adhesive curing is needed for potential FRP strengthened structures. Cyclic loading during adhesive curing can decrease the fatigue life of the reinforced beam by reducing the bond strength.

Anirudh Chandrakant Dubal, Dr D.N Shinde (2015) Fiber Reinforced Polymer (FRP) sheets had been extensively used to rehabilitate concrete structures in the past two decades. This has allowed increase in the strength and ductility of these structures while benefiting the advantages such as high strength-to-weight ratio, ease of their drilling and anchoring to an existing steel structure, high resistance against corrosion and chemical attacks. Another significant advantage of FRP, which applies only to FRP laminates formed via the wet lay- up process, is the ability of such FRP laminates to follow curved and irregular surfaces of a structure. This is difficult to achieve using steel plates. The combination of adhesive bonding with shape flexibility makes bonded wet lay-up FRP laminates an attractive strengthening method in a number of applications. Needless to say, steel plates can also be adhesively bonded but bonding is less attractive for steel plates due to their heavy weight and inflexibility in shape. These uses of FRP sheets to upgrade the resistance of steel structures have recently been studied. The importance to rehabilitate ageing and deteriorated existing steel structures has motivated researchers to develop simple and efficient rehabilitation techniques.FRP sheets are formed by embedding continuous fibers in a polymeric resin matrix which binds the fibers together. Common fibers used in FRP sheet include carbon, glass, aramid and basalt fibers while common resins are epoxy, polyester, and vinyl ester resins. The most widely used FRP composites are glass fiber-reinforced polymer (GFRP) composites and carbon fiber-reinforced polymer (CFRP) composites, while aramid fiber-reinforced polymer (AFRP) composites and basalt fiber-reinforced polymer (BFRP) composites are less frequently used. Based on this following conclusion can be made.

1. It is observed that all the strengthened beams shows better strength compared to control beam.
2. BFRP bonded at both flanges of beam indicates more load carrying capacity as compared With the beam bonded with BFRP at Tension and Compression flange.
3. The elastic response of Strengthened beams is also observed to be increased over the control beam.
4. From the experimentation work carried out it can be concluded that BFRP may be an economical and possible alternative to strengthen the steel beams.

Mohammed Altaee, Lee Cunningham, Martin Gillie.(2017) studied about The introduction of web openings in existing steel floor beams is a common occurrence in practice. Such modifications are often necessary to accommodate additional services driven by a change of building use, thus extending the service life of the structure. Depending on their size and location, openings in the web can present a major challenge to the strength and stiffness of the beam. Strengthening around an opening is often necessary to maintain the required performance of the floor beam, traditionally this is affected via application of additional steel plate, either bolted or welded. This paper focusses on the novel application of carbon fiber reinforced polymer (CFRP) to the problem of strengthening web openings, taking advantage of the material's ease of handling, superior strength-to-weight ratio and corrosion resistance. An experimental study involving 4 full scale universal beams was conducted in order to investigate the ability of CFRP to recover the strength and stiffness of beams following the introduction of web openings. All the specimens were tested under 6-point bending in the experiments. For further comparison, the equivalent test series without the addition of strengthening was modelled numerically via finite element analysis. The effectiveness of the strengthening technique was demonstrated with increases in the load carrying capacity over the un-altered beam of between 5 and 20% being achieved. Based on this following conclusion can be made.

1. Strengthening method is likely to be a useful approach in practice for enhancing both serviceability and ultimate state the behavior of beams where in-service web openings are introduced.
2. The method has benefits over traditional methods such as applying additional steel plate that include lower self-weight, easier application and better corrosion resistance.
3. The failure mechanisms in the strengthened beams were not always the same as in the un-strengthened cases, or the control case. This highlights that if CFRP is used in design, care must be taken to identify and check potential failure mechanisms other than those that might be expected with strengthening.

Omar H. Elkhabeery a, Sherif S. Safar b, Sherif A. Mourad (2018). Studied about the use of modern Carbon Fiber Reinforced Polymer (CFRP) to strengthen and repair steel beams in flexure has been rapidly increased within the past few years. This technique benefits from light-weight and extra-strong CFRP material to enhance the flexural capacity of cross section. To study the reinforcing effect of CFRP, one hundred and seventy-eight models were analyzed to cover six variables representing the common problem parameters; the variables were the slenderness ratio of web (hw/tw), the mono-symmetric ratio of I-beam (ψ), the area of CFRP (Acfrp), the modulus of elasticity of CFRP (Ecfrp), the tensile strength of CFRP, and the length of CFRP sheet (Lcfrp). The adhesive properties used in parametric analysis were determined from experimental tests conducted for double-strap steel-to-CFRP joints with various bond lengths (50 to 200 mm), and the proposed model constructed using the general finite element program, ANSYS 17, was verified with experimental tests of full-scale steel beams reinforced with CFRP. The parametric study revealed that CFRP sheets were very efficient in reinforcing compact mono-symmetric sections, whereas the enhancement in beams with non-compact sections was very small. CFRP sheets were able to reach its ultimate strength provided that enough bond length was ensured. Analytical procedure to calculate the flexural strength of steel I-shaped beams reinforced with CFRP sheets at tension flange was presented. Based on this following conclusion can be made.

1. The enhancement in section capacity is generally pronounced at lower mono-symmetric ratios of beam.
2. Beams with compact cross sections can reach their plastic strength before onset of local buckling provided ensuring enough bond length for CFRP sheet. The ultimate strength of the composite section (Muc) can be analytically calculated using the plastic strength principles to locate the plastic neutral axis and calculate the cross-section strength.
3. For beams with noncompact sections, the enhancement in beam ultimate strength is very small regardless the strength of CFRP sheet. CFRP sheet attached to the tension flange will not reach its ultimate capacity since the failure due to buckling in noncompact elements will govern the analysis and hinder the redistribution of stresses along cross section after yielding of compression parts. Stress distribution along non-compact cross sections will be partial plastic stress distribution between yield and full plastic distribution depending on the slenderness ratio of compression elements.
4. The theoretical length of CFRP (Lt) was not sufficient to develop the shear induced from composite action in all cases. At CFRP ends, the maximum shear stresses exceeded the adhesive strength at corner regions; however, the overall section capacity was not far away from the reference value for CFRP sheet covering 80% of beam span.

III. Future work:

i. To study the flexural behavior of rolled steel I–beam of appropriate cross section for ultimate yield point, bonded with and without FRP sheets. .
ii. To compare load carrying capacities of steel I – beams, bonded with and without FRP sheet.
iii. To develop Finite Element Model using ANSYS software to validate the experimental results.

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