Flexural Behavior of Steel I–Beams Bounded With Different Fiber Reinforced Polymer Sheets

Sadashiv Tavashi[1], V S Kshirsagar[2], Rahul Kapase[3], Avinash Thorat[4]

[1] PG Student SVERI's COE, Pandharpur, solapur Unversity solapur, Maharashtra, India.
[2]Assistant Professor SVERI's COE, Pandharpur, solapur University solapur, Maharashtra, India.
[3]Assistant Professor SVERI's COE, Pandharpur, solapur University solapur, Maharashtra, India.
[4]Assistant Professor SVERI's COE, Pandharpur, solapur University solapur, Maharashtra, India.

Abstract: *This paper focused on flexural behavior of steel I beams strengthened with carbon fiber reinforced polymer (CFRP) sheets and basalt fiber reinforced polymer (BFRP) sheets. The simply supported steel I beam in previous experimental work was modelled by using ANSYS finite element software. The parameters used in FEA are same as that of used in experimental work. Conventional strengthening technique for huge steel structures depends on enlarging the original steel section by welding additional elements such as steel plates or channels. In this conventional strengthening technique the dead load of the enlarged section becomes larger which may result in a reduction in its effectiveness and the added steel plates are also susceptible to corrosion if structure is situated in a corrosive environment. Also this technique requires heavy lifting equipment during the erection process. Due to these reasons considerable amount of research has been directed to the use of Fiber Reinforced Polymer (FRP) materials for strengthening and retrofitting of steel structures as FRP sheets are being used extensively from past two decades to rehabilitate concrete structures.*

Taking into account the various benefits of using FRP in strengthening process of structures it has become essential to study the flexural behavior of structural members, especially of steel structures, by making use of FRPs. Therefore, in this project work flexural behaviour of the steel I–beams using different types of FRP sheets namely carbon fiber and basalt fiber have been studied. The results obtained in experimental work have been validated from finite element model developed in ANSYS software.

Keywords: *CFRP, BFRP, ANSYS, flexural behaviour, I–beams.*

I. INTRODUCTION

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 very high stiffness-to-weight and strength-to-weight ratio, ease of their drilling and anchoring to an existing steel structure, high resistance against corrosion and chemical attacks. Another 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.

In this technique corrosion of steel is reduced if the structure is situated in corrosive environment. The various benefits of using FRP in strengthening process of structures it has become essential to study the flexural behavior of structural members, especially of steel structures, by making use of FRPs. Therefore, in this project work flexural behavior of the steel I–beams will be performed using different types of FRP sheets namely carbon fiber and basalt fiber. This is still quite new and needs to be researched further. There are several literature available on the use of FRP with RCC, but less are available with research and testing of FRP such as basalt fiber with steel sections. The FRP strips can be applied on the steel beam by using a most widely available resin named as "araldite" and its hardener.

II. METHODOLOGY

A. EXPERIMENTAL WORK

For the experimentation steel I-beam of total depth 100 mm, flange width of 50 mm, thickness of flange 4 mm and thickness of web 3 mm has been taken as shown in Fig.1 These beams were tested under four point bending test using Universal

Testing Machine (1000 KN capacity). Locally available steel I-beams were used to study the flexural behaviour bonded with and without FRP sheets. A beam section was chosen such that there will not be any local buckling and vertical stiffness. Basalt fibre sheets (BFS) having Young's modulus of 110 GPa, tensile strength of 4500 MPa, poisons ratio of 0.2 and Carbon fiber sheets (CFS) having Young's modulus of 200 GPa, tensile strength of 5500 MPa, passions ratio of 0.5 have been used for strengthening the I-beams having length of 1100 mm. The most widely used epoxy resin namely "araldite", available as resin and hardener in separate packages has been used. Before to the bonding of the BFS and CFS, the flanges of the beams roughened using sand paper to ensure rust free surface and to achieve proper bonding between steel beam and fibre sheet so as to avoid early de-bonding failure at the time of testing. The fiber sheets were cut into strips of width equal to the flange width of the beams (i.e. 50 mm). The Araldite epoxy resin AW106 and hardener HV953 are then mixed thoroughly (in proportion 1:1) till a uniform colour to the mixture is obtained. The uniform mixture of resin and hardener so obtained was then applied to the flange of I–beam. The strips of BFS and CFS were immediately bonded to the flange of steel I–beam using a hard roller to ensure the constant thickness of the epoxy coat along the bonding length and also to eliminate the presence of air pockets in between fiber strips and steel surface. Two different parameters were considered for bonding fibre strips. First beam was bonded with fibre strip on tension flange only while other beam was bonded with fibre strip on tension as well as compression flange to study the flexural behaviour.

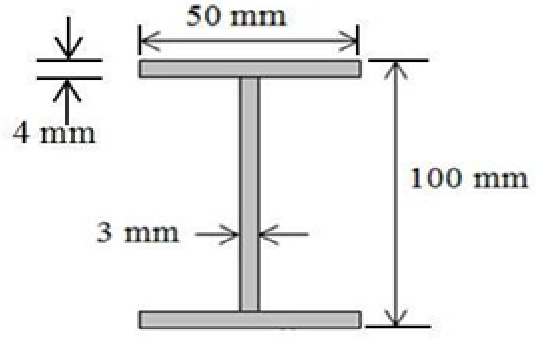

Fig1. Cross sectional details of the I-beam.

Fig.2 Basalt fiber sheet.

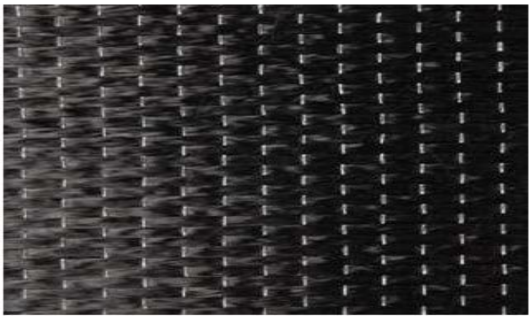

Fig.3 Carbon fiber sheet.

B. **Test setup**

The control beam and the beams bonded with strips of carbon fiber sheet and basalt fiber sheet on different flanges were tested in four point bending test on universal testing machine (1000 kN capacity) with two equally spaced concentrated loads as shown in Fig4.

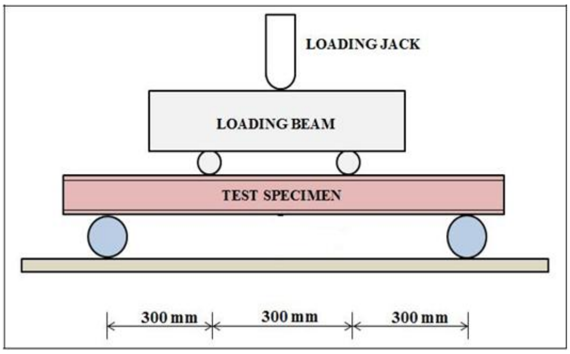

Fig4.Test setup

The load was transferred from the jack to the main specimen by using a loading beam. The middle of the loading beam was subjected to jack pressure from which the load was transferred to the test specimen through two point loads as shown in Fig.4

III. FINITE ELEMENT MODEL USING ANSYS SOFTWARE:

In the present study finite element program (ANSYS v.13.0) used to build three dimensional model of steel beam. Two type of element were used to represent the beam namely SOLID185 and SOLSH190. To develop precise model, the actual boundary conditions as well as loads were applied on 3D finite element model. Deformations at the mid-span of beam in finite element model are found to be similar as that of actual tested beam. Details of model development are given below. Fig7. Shows 3-D finite element beam of steel beam. In Fig.8 shows deformed shapes of control beams. In fig.9FRP bonded beam is presented.

a) SOLID185

SOLID185 is used for 3-D modelling of solid structures. It is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. Geometry of SOLID185 element is shown in fig.5.The element has plasticity, hyper elasticity, stress stiffening, creep, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyper elastic materials.

b) SOLSH190

SOLSH190 is used for simulating shell structures from thin to moderately thick. Geometry of SOLSH190 element is shown in fig.6. The element possesses the continuum solid element topology and features eight-node connectivity with three degrees of freedom at each node: translations in the nodal x, y, and z directions.

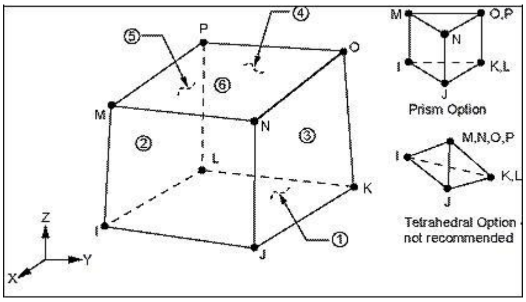

Fig. 5 Geometry of SOLID185 element.

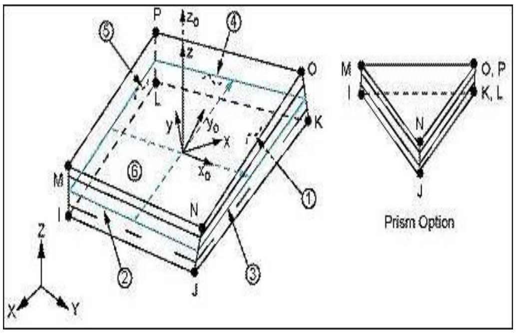

Fig. 6 Geometry of SOLSH190 element.

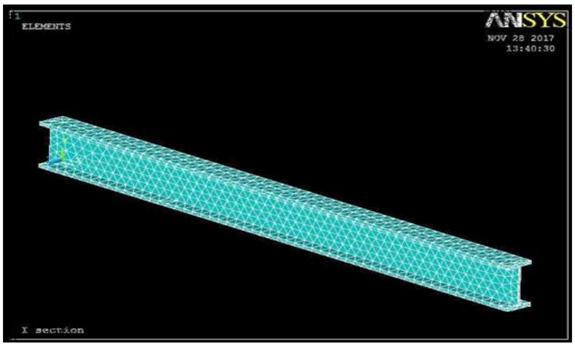

Fig7. Geometry of FE model.

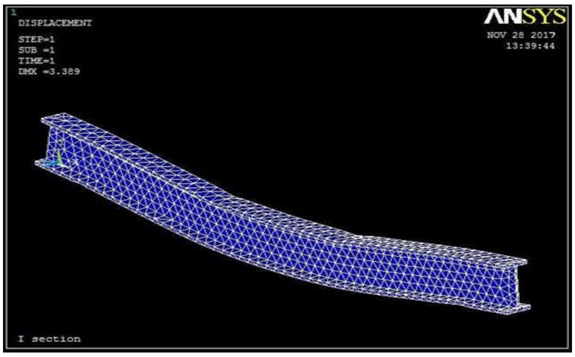

Fig8. Deflected shape of FE model

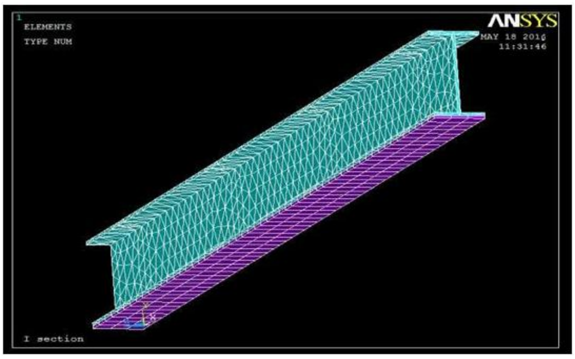

Fig.9 Fiber sheet bonded on tension flange in FE model.

IV. RESULTS AND DISCUSSION

From result table and Load vs. Deflection graph in Fig.10 we can say that load carrying capacity of 1st control beam is 47.1 kN. Beam showed elastic behavior up to 44 kN and then reached to yield point. Beam carried load of 47.1 kN and then failure occurred with deflection of 3.21 mm. Similarly from fig.2 shows load vs. deflection graph for 2nd control beam, which carried load of 46.5 kN and failed with deflection of 3.02 mm. From results obtained during the flexural test of control beams, we can consider average load carrying capacity of beam as 46 to 47 kN.

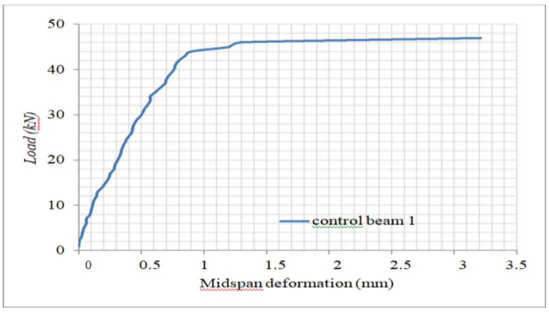

Fig10.Load vs. Deformation graph for 1st control beam.

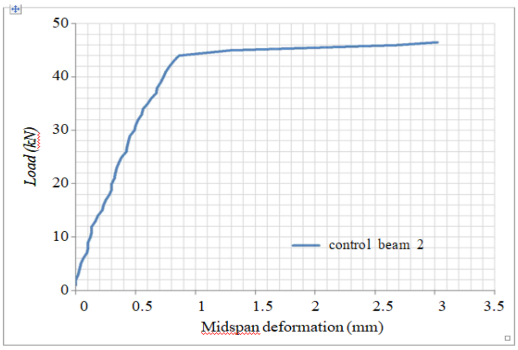

Fig. 11 Load vs. Deformation graph for 2nd control beam.

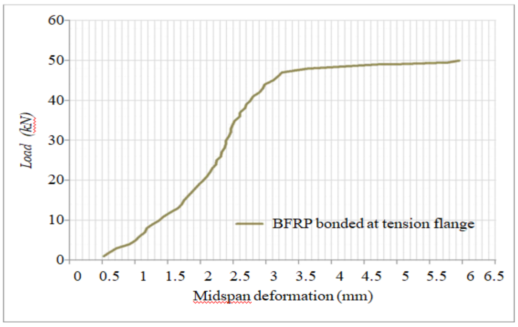

Fig 12. Load vs. Deformation graph for beam bonded with BFRP at tension flange.

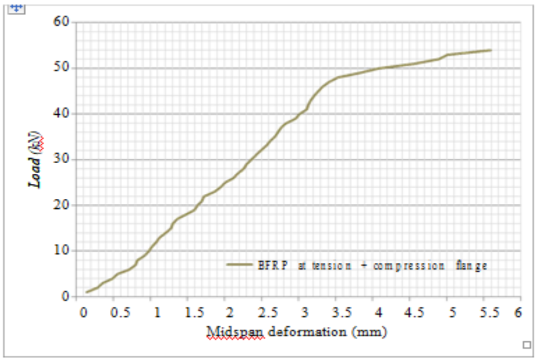

Fig13. Load vs. Deformation graph for beam bonded with BFRP at tension and comp. Flange.

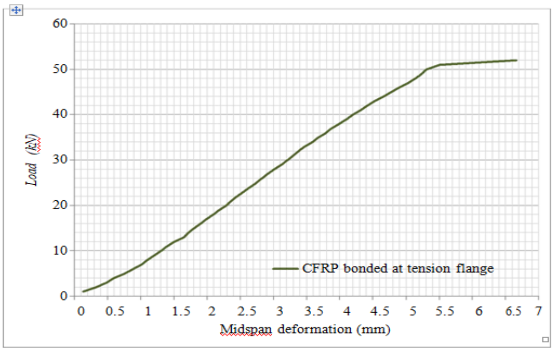

Fig. 14 Load vs. Deformation graph for beam bonded with CFRP at tension flange.

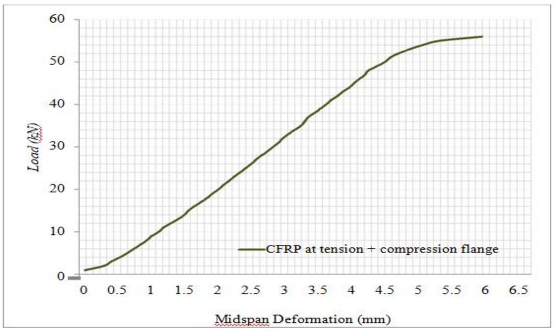

Fig. 15 Load vs. Deformation graph for beam bonded with CFRP at tension and comp. Flange.

From result tables and graphical presentation of beams bonded with BFRP we can observe that when BFRP was bonded at only tension flange, beam carried load of 50 kN and when BFRP was bonded at both the flanges, beam carried load of 54 kN. If the results are compared with control beam we can surely say that bonding of BFRP sheet affected increment in load carrying capacity. The elastic behavior of beam also seen to be increased than that of control beams which may have caused more deflection than control beam.

Fig14. Shows load vs. deformation graph of beam bonded with CFRP only at tension flange. A beam carried load of 52 kN and had deflection of 6.66 mm. When similar beam was then bonded with CFRP on both the flanges, it carried load of 56 kN and had deflection of 5.79 kN. Load vs. deformation graph for CFRP bonded on both flanges as shown in Fig.15 Elastic response of both CFRP bonded beams is found to be extended. For better understanding and comparison these plots are combined together as shown in fig16 and fig17.

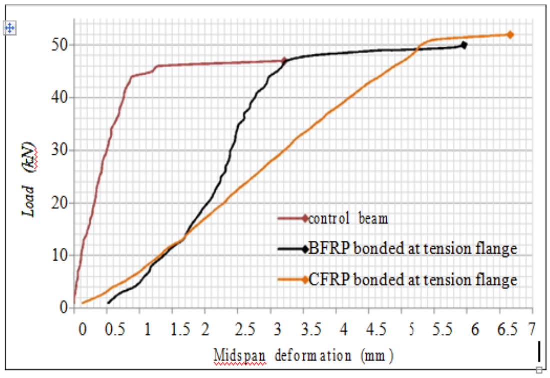

Fig 16.Comparative Load vs. deflection plot for beams bonded with FRPs (at tension flange).

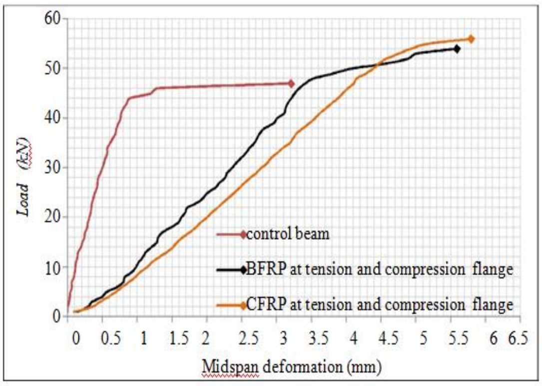

Fig17.Comparative Load vs. deflection plot for beams bonded with FRPs (at both the flanges).

From the combined graphs (fig.16 and fig.17), it is observed that all the strengthened beams shows better strength compared to control beam. However, CFRP bonded beam indicates more load carrying capacity as compared with the beam bonded with BFRP sheet. The elastic response of strengthened beams is also observed to be increased over the control beam. The Yield points of strengthened beams also indicated relatively higher magnitude of load than that of control beam. From the load vs deflection curve it is observed that the flexural behaviour of both the beams bonded with BFRP and CFRP sheet is somewhat similar in nature. Also, it can be said that bonding of FRP sheets on compression flange of beam in addition to tension flange definitely contribute to increased load carrying capacity of the steel beam.

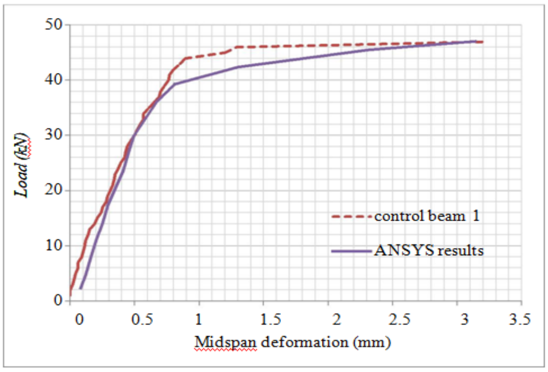

Fig 18. Load vs. Deformation graph for control beam from ANSYS finite element model.

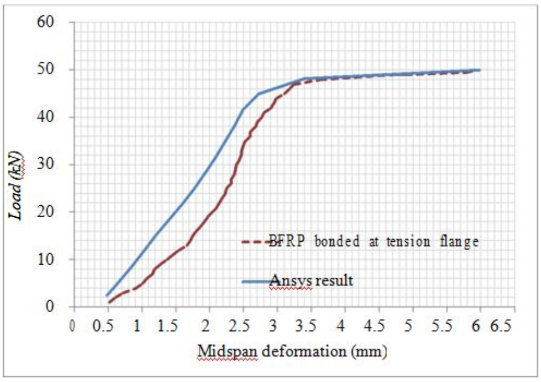

Fig19. Load vs. Deformation graph for beam bonded with BFRP at tension flange from ANSYS finite element model.

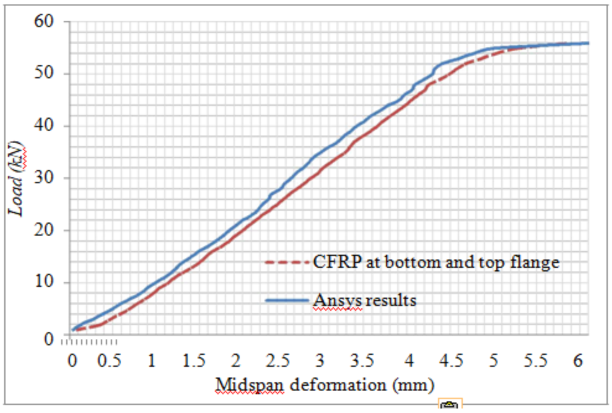

Fig 20. Load vs. Deformation graph for beam bonded with CFRP at tension and compression flange in ANSYS finite element model.

Fig.18 shows load vs. deformation graph for 1st control beam from ANSYS finite element model and Fig.19 shows load vs. deformation graph for beam bonded with BFRP at tension flange. Fig.20 shows plot for beam bonded with CFRP on tension and compression flanges. Results obtained from actual experiments and 3-dimensional finite element models in ANSYS software are found to be matching exactly. Thus, using properties of different FRP sheets for similar finite element 3-D model it is possible to find out exact deformation of that FRP bonded beam and to predict behaviour of that structural element.

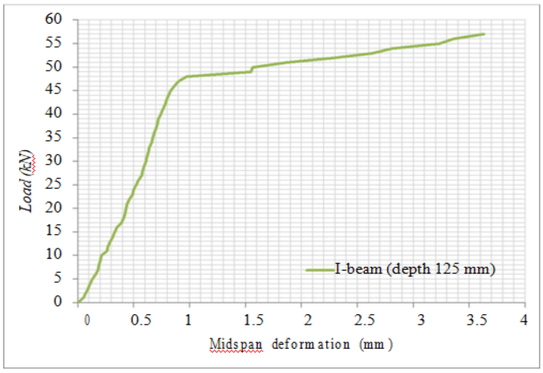

Fig 21. Load vs Deformation graph for beam having depth 125 mm.

Experimental data recorded for flexural test of steel I-beam without bonding FRP, having depth of 125 mm and fig.21 shows its load vs. deflection plot. From the observations we can say that load carrying capacity of beam is similar to that of beam having 100mm depth and bonded with CFRP on both the flanges. Thus it is possible to use such types of FRP bonded beams as equivalent beams and these beams will be able to carry the load which was carried by the larger section. This technique can also be used in case where there is a restriction for depth of beam.

V. CONCLUSIONS

Referring various experimental as well as mathematical studies it has been clear that the bonding of steel structures with different types of FRPs is a relevant technique to strengthen the existing steel structures. Various conclusions that can be drawn for the experimentation are listed below;

1) Bonding of FRP sheets on the flanges of the steel beam causes increment in elastic behavior of beam and ultimately gives higher yield point value.
2) Load carrying capacity of beam having depth 125 mm found to be equal (i.e. 56kN) to that of beam of 100 mm depth which was bonded with CFRP on both the flanges. Thus, it is possible to use smaller steel sections after bonding with FRP sheets as an alternative equivalent section for larger sections.
3) The load carrying capacity of the strengthened beam (BFRP bonded at tension flange) is found to be increased by 6.5% than that of control beam.
4) Beam bonded with BFRP at both the flanges carried load of 54 kN and it shows increment of load carrying capacity by 10.70%.
5) CFRP bonding at tension flange increased load carrying capacity of beam by 8.51%.
6) Beam bonded with CFRP at tension as well as compression flange mentioned increment of load carrying capacity by 20%.

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