Behaviour of Steel I-Beam With Aramid Fiber Reinforced Polymer

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Abstract- *Steel structures play an important role in civil industry and therefore more attention is required for strengthening and rehabilitation of such structures. Studies on enhancing structures have significantly increased recently. Different methods exist for strengthening various structures. Use of FRP appears to be an excellent solution. In this dissertation, the performance of steel I-beam with Uniaxial Aramid Fibre Reinforced Polymer (AFRP) is studied.Three different parameter of strengthening were considered. The first type of beams focuses on enhancing the strength of steel in flexure, the second focuses on increasing the shear strength while third focuses on increasing combined flexure-shear strength of the beams. Total ten beams were chosen having same length and properties. One of which was tested without AFRP to facilitate comparison of their behaviour to the other beams and remaining are strengthened beams. The results shows that there was slight increment in load resisting capacity as well as increase in deflection of steel beam.*

Keywords- FRP, Uniaxial Aramid fibre reinforced polymer, flexure, shear, flexure-shear.

I. INTRODUCTION

Fiber-reinforced polymer (FRP) structural composite technology dates back to the mid 1930s, when the first experimental boat hull was manufactured using fiber glass fabric and polyester resin. FRP composites with fibers/fabrics bonded together with the help of organic polymers (resin system) are being referred to as the materials of 21st century because of many inherent advantages. Some of the inherent advantages of FRPs over traditional materials are: superior thermo-mechanical properties such as high strength and stiffness, and light weight, excellent corrosion resistance, magnetic transparency, design flexibility (tailor ability), and long-term durability under harsh service environments. Composites can be three to five times stronger, two to three times stiffer, and three to four times lighter than metals such as steel and aluminium. In addition, composites are dimensionally stable, aesthetically pleasing and cost effective with better durability and lower maintenance than the conventional materials.

Common fibers used in FRP composites 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) and carbon fiber reinforced polymer (CFRP), while aramid fiber reinforced polymer (AFRP) and basalt fiber reinforced polymer (BFRP) are less frequently used. In particular, FRP, being a material of high tensile strength, can generally be used to its greatest advantages, when combined with concrete which is strong in compression but poor in tension. Therefore, the use of FRP in concrete structures has been a major focus of existing research. More recently, the use of FRP composites in combination with steel is in focus.

II.OBJECTIVES

The aim of this research is to study the flexural and shear performance of steel beam retrofitted by AFRP with following objectives,

1. The effectiveness of flexure, shear and combined flexure-shear strengthening on steel I-beams with single, double and triple layers of AFRP.
2. To examine the effects of single, double and triple layers of AFRP on steel I-beams.

III.METHODOLOGY

To study the flexural and shear behavior of steel beam retrofitted with AFRP an experimental program was conducted on steel beams ISMB 200 @ 25.9 kg/m of span 800 mm.The details about experimental program are given below.

1. For flexure

Four points loading test was done on steel beam with and without AFRP and then results are studied. The AFRP was applied on tension flange for full length. Four beams were tested out of which one was control beam for comparison of results of steel beam tested in all tests. And for remaining three, the FRP was applied in the increasing number of layers i.e. single, double and triple layer respectively.

2. For shear

For shear also four points loading test was done on steel beam with AFRP. The AFRP was applied on the either side of web for full length and three beams were tested. In this also AFRP was applied in the increasing number of layers i.e. single, double and triple layer respectively.

3. For combined flexure-shear

For combined flexure-shear, four points loading test on steel beam with AFRP was done. The AFRP was applied on the shear zone of web and on tension flange and three beams were tested. In this also AFRP was applied in the increasing number of layers i.e. single, double and triple layer respectively.

IV.MATERIAL

1. Steel Beam

In this research, steel I-sections ISMB200@ 25.9 kg/m were used. The dimensions and material properties of the steel beams are as follows:

Table 1: Details of Steel Beam used

Depth of section	200 mm
Sectional Area	32.3 cm^2
Width of flange	100 mm
Weight per meter	25.9 kg/m
Thickness of flange	10.8 mm
Thickness of web	5.7 mm

2. AFRP

In this research, Uniaxial Aramid Fiber Reinforced Polymer fabric of 240 gsm is used which was purchased from NickunjEximp Enterprises Private Limited, Mumbai.

Fig 1: Photograph of AFRP

3. Adhesive

The AFRP fabric was applied on the beam by using the epoxy named EPCO KP/HP - 350. It has high mechanical strength and strong in flexure, compressive, tensile and bond strength. Technical properties of epoxy are as follow:

Table 2: Details of Adhesive used

Epoxy resin	EPCO KP-350
Hardener	EPCO HP-350
Mix proportion (resin : hardener)	2 : 1
Setting time	12-16 hours
Curing	48 hours in air

V. PREPARATION OF THE SPECIMENS

Surface preparation is the key to a strong and durable adhesive bond. Since strengthening takes place onsite, surface treatment must also be environmentally friendly, and easily accomplished in field conditions. The following process was carried out for the preparation of the specimens. Firstly, surfaces were cleaned. Then, the cleaned AFRP fabrics were glue to the required portion of the specimens. After 48 hours, when the adhesive was hardened, the test procedures were carried out.Force transfer between FRP and steel takes place through bond at the interface between the two materials, which is influenced by several factors including bonded length, types of fiber and resin, surface preparation, thickness of adhesive and thickness of FRP laminate.

1. Flexure

The experimental setup is based on the four-points bending test on Universal Testing Machine (UTM). The load was applied by using a hydraulic jack via a load cell. 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, and two symmetrical point loads were applied to transfer the load's pressure to the main specimen (beam). Two roller supports carried the reactions; therefore, the loading states were four incremental bending points' loads. The deflection at the centre of web is measured by using dial gauge. For flexure AFRP is applied in increasing number of layer i.e. single, double, and triple layer on tension flange of beam for full length.

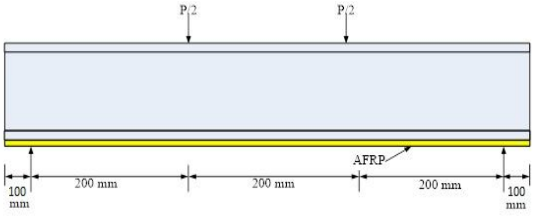

Fig 2: Specimen for flexure test

2. Shear

For tests setup, firstly, beams were placed on the rollers supports. Secondly, a loading beam was located over the main beam. Then, a load cell was placed at the mid span of the loading beam. The load was applied with a hydraulic jack. Here also the deflection of web is measured using dial gauge. For shear AFRP is applied in increasing number of layer i.e. single, double, and triple layer on either side of web of beam for full length.

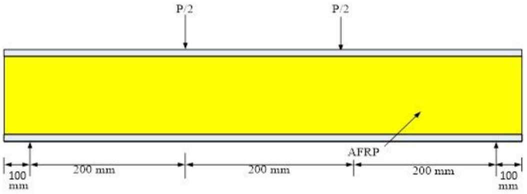

Fig 3: Specimen for shear test

3. Combined Flexure-Shear

The similar test setup that of flexure and shear test is used for these test also. For combined flexure-shear AFRP is applied in increasing number of layer i.e. single, double, and triple layer on tension flange and shear zone of web (for length of L/3 from both end supports) of beam.

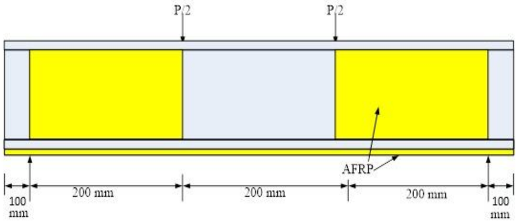

Fig 4: Specimen for combined flexure-shear test

VI.RESULT AND DISCUSSIONS

1. Flexure

For flexure, three different specimens strengthen with single, double and triple layer of AFRP were tested and compared with control specimen. The summary of results for flexure test is provided in Table 5.1. From observations, the ultimate moment of resistance of specimen was calculated. Also modes of failure observed during test were summarized in table.

Table 4: Results of flexure

Specimen designation	Ultimate load P (kN)	Ultimate moment (kN.m)	Failure mode
CB	466.00	46.60	Flexure
RBF1G	478.00	47.80	Web buckling
RBF2G	470.00	47.00	Debonding
RBF3G	472.00	47.00	Web buckling, debonding

The graph was plot from the observations to study the load-deflection behaviour. The load-deflection variation for CB, RBF1G, RBF2G and RBF3G are presented in fig 5.

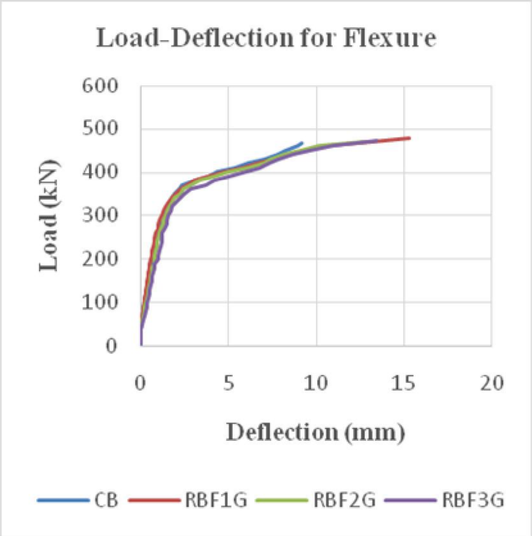

Fig 5. Load-Deflection for Flexure

2. Shear

For shear, three different specimens strengthen with single, double and triple layer of AFRP were tested and compared with control specimen tested in flexure test. Table 5.2 shows the summary of the results for the shear test. From observations, the ultimate shear of specimen was calculated. Also modes of failure observed during test were summarized in table.

Table 5: Results of shear

Specimen designation	Ultimate load (kN)	Ultimate shear (kN)	Failure mode
CB	466.00	233.00	Flexure
RBS1G	470.00	235.00	Web buckling, debonding
RBS2G	476.00	238.00	Web buckling, debonding
RBS3G	468.00	234.00	Web buckling

The graph was plot from the observations to study the load-deflection behaviour. The load-deflection variation for CB, RBS1G, RBS2G and RBS3G are presented in fig 6.

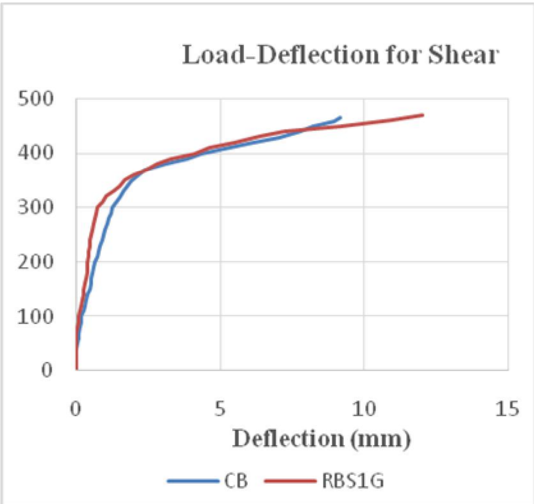

Fig 6. Load-Deflection for Shear

3. Combined Flexure-Shear

For combined flexure-shear, three different specimens strengthen with single, double and triple layer of AFRP were tested and compared with control specimen tested in flexure test. Table 5.2 shows the summary of the results for the combined flexure-shear test. From observations, the ultimate moment of resistance and shear were calculated. Also modes of failure observed during test were summarized in table.

Table 6: Results of combined flexure-shear

Specimen designation	Ultimate load (kN)	Ultimate moment (kN.m)	Ultimate shear (kN)	Failure mode
CB	466.00	46.60	233.00	Flexure
RBC1G	465.00	46.50	262.50	Flexure, web buckling, debonding
RBC2G	469.00	46.90	234.50	Flexure, debonding
RBC3G	476.00	47.60	238.00	Flexure, web buckling, debonding

The graph was plot from the observations to study the load-deflection behaviour. The load-deflection variation for CB, RBC1G, RBC2G and RBC3G are presented in fig 7.

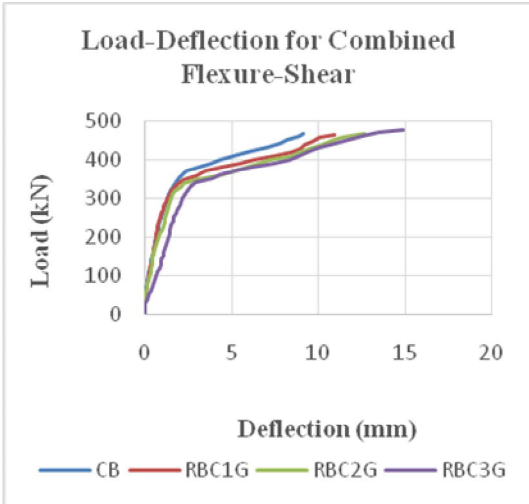

Fig 7. Load-Deflection for Combined Flexure-Shear

VII.DISCUSSION

1. Flexure

1. It was observed that the there is linear variation in load-deflection curve up to certain point and then deflection goes on increasing with increase in load, by reducing the slope of graph which indicate bilinear variations of deflection for retrofitted specimen.
2. It was seen that the control beam failed at a load of 466 kN. The control beam is considered to have failed when there is no appreciable increase in load. The beam RBF1G, RBF2G and RBF3G failed at a load of 478 kN, 270 kN and 472 kN respectively.
3. It was observed that deflection of the strengthened beams were almost same. There was sudden increment in deflection after 230 kN.

4. It was observed that deflection increases with increase in number of layers of AFRP.
5. Percentage increment in strength of specimen RBF1G, RBF2G and RBF3G was 2.57%, 0.85% and 1.28% as compare to CB.
6. Buckling of web was predominant in flexure strengthening as it is not strengthened in shear. On the other hand, the End-debonding was also observed.

2. Shear test

1. In this variations is linear up to certain point but that point is on lower side as compare to that of flexure test load-deflection curve. The slope of graph indicate bilinear variations of deflection for retrofitted specimen.
2. The beam RBF1G, RBF2G and RBF3G failed at a load of 470 kN, 476 kN and 468 kN respectively. The load carried by beams strengthened in shear is not much more than that of strengthened in flexure since the beams strengthened in flexure fails due to shear i.e. buckling of web which is prevented in shear strengthened beams.
3. The percentage increment in strength of specimen RBS2G was 2.14% but for specimen RBS1G and RBS3G there was only 0.85% and 0.42% increment in strength respectively.
4. It was not possible to record the deflection of specimen RBF2G and RBF3G because of debonding of AFRP on there centre part where the dial gauges were attached.
5. It was seen that in this also debonding and buckling of web was predominant but buckling of web was less as compared to buckling occurred in flexure and first debonding takes place and then web buckles.

3. Combined flexure-shear test

1. The load-deflection curve is linear up to a certain point. Three specimens CB, RBC1G, RBC2G have almost same variations till 350 kN load but RBC3G has less.
2. It was observed that in this test the beam RBC1G don't show much increase in load carrying capacity as compare to beam RBC2G and RBS3G, it failed at a load of 465 kN while RBC2G and RBC3G fails at a load of 469 kN and 476 kN respectively.
3. The deflection goes on increasing with increase in number of layers of AFRP as observed from graph and specimen having single layer AFRP has less deflection that that of double and triple layer specimen
4. The percentage increment in strength of specimen RBC2G and RBC3G was 0.64% and 2.14% respectively as compare to CB while specimen RBC1G was not able to withstand load equal to CB
5. As per observations during test it was clear that in this test debonding is predominant as compare to web buckle. And also failure in flexure was observed.

VIII.CONCLUSION

From the results of flexure test, shear test and combined flexure-shear test, we can conclude that application of AFRP slightly improve the flexural and shear performance of steel I-beam using AFRP. There was increment in load resisting capacity of all the specimens. Load carried in flexure as well as shear were nearly same.

After observing the failure mode it is clear that buckling of web is predominant. On the other hand, the end-debonding was more significant in more number of layers.

IX.FUTURE SCOPE OF PRESENT STUDY

1. The present study includes flexural and shear performance of steel I-beams for AFRP only. Further research can be done using different fibers like Basalt fiber.
2. Further research can be done using different adhesives as it plays an important role in load carrying capacity.
3. Effective length of applying FRP on steel I-beams for flexural and shear performance can be done in future.

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