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Investigation of Mechanical Properties of Hybrid Glass-Carbon Composites

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ABSTRACT: The use of composites has been rising for the last four to five decades from aircraft industries to other areas such as automobile industry, sports equipments, infrastructures, etc. Cost effective materials are required for sustainable development of aircrafts which are light in weight and also strong. In the recent years, the significance of fiber reinforced composites has significantly increased in the aerospace industry. These hybrid composites are light in weight, high corrosion resistant, high tensile strength, high temperature resistant which can be used both in commercial as well as military aircrafts. Required properties of the hybrid composites can be obtained by changing the choice of fiber and matrix. In this paper, main focus is to study and analyze the mechanical properties of hybrid glass-carbon fiber composites by fabricating it in different fiber orientation and testing the composite material in universal testing machine. Composites are tested for different mechanical properties such as tensile, compression and bending strength. Different mechanical behavior of the specimens has been observed due to different fiber orientation and type of glass and carbon fiber used in the process. Hand lay-up technique is used to fabricate the specimens.

KEYWORDS: Hand lay-up process, Carbon Fiber (SIKA WRAP-450C), E-Glass Fiber, Hybrid laminates, Tensile, compressive and bending properties

I. INTRODUCTION

Over the course of many decades, composites have undergone a drastic change in their behavior and properties. They were manufactured for applications such as automobiles, aviation industry, marine, etc [1]. The main research challenge of fiber reinforced composites was to match the material properties with original production process [2]. The glass fiber laminates have poor mechanical properties such as low Young's Modulus, Poisson's so there is a need to go for carbon and other fibers which have excellent properties but at the same time carbon fibers are expensive. So combination of carbon and glass fibers is essential to generate favorable outcomes [3]. The mechanical properties of hybrid laminates rely on fiber orientation, type of matrix used and length of fibers. The matrix provides the composites with required strength and stiffness [4]. Most commonly used matrix is epoxy. The main benefits of hybrids over ordinary laminates are excellent tensile and compressive strength, corrosion resistance, very light in weight, and good dimensional stability [5]. Since hybrid laminates are lighter in weight, they can be implemented in aircraft as lighter weight means good fuel efficiency [6]. Carbon fibers have low failure of strain which when combined with glass fiber provides good flexural properties [7]. The main focus of this study is to evaluate the tensile, compressive and bending properties of hybrid glass-carbon specimens and compare its properties with glass and pure carbon composites of different fiber layer and geometry.

II. EXPERIMENT DETAILS

Material selection

Reinforcements used in the fabrication process are E-Glass fiber (black and white) and unidirectional carbon fiber fabric (SIKA WRAP-450C). The matrix consisted of araldite (CY-230 IN) and hardener (HY 951 IN). I have used two types of glass fibers – White E-Glass unidirectional (0.18 mm thickness) and Black E-Glass unidirectional fiber (0.3 mm thickness)

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with density of 2.55g/cm^3 . Carbon fiber sheet used in the process has a thickness of 0.255 mm and density of 1.82g/cm^3 . Glass and carbon fiber used in fabrication process of hybrid laminates is depicted in figure 1.



Fig 1: White E-Glass (left) and black E-glass (right)

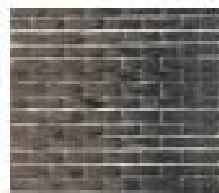


Fig 2: SIKAWRAP-450C unidirectional carbon fiber fabric

Composite Fabrication

Fabrication of laminates was carried out using Hand lay-up technique at room temperature. The fiber orientation was varied for all the specimens. Six specimens were fabricated with eleven fiber layers. Fiber sheets of different sizes were placed manually on the open mould. The ratio of hardener to araldite was taken as 1:10. Araldite was heated to a temperature of 110°C using a hot air oven. Once the araldite is heated to an optimum temperature, the hardener is placed along with it and oven is switched off and both are allowed to cool for about 30 minutes. The required mixture of epoxy and hardener is placed in a beaker and stirred using a glass rod. After casting process is carried out, a load of 10-15 Kg is placed over pre-fabricated specimen. The epoxy mixture is distributed evenly throughout the carbon and glass fiber layers using a brush. The air which is entrapped between fiber layers is removed manually by applying gentle pressure over each layer. The laminates are cured at room temperature of 23°C for 12-15 hours after which they are given proper shape.



Fig 3: Mould used for fabrication

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Specimen Preparation

Reinforced hybrid glass-carbon fiber composites along with only glass and carbon laminates are cut and removed from the mould and specimens of approved dimensions were prepared in form of slab and given a proper shape using a saw and a filing tool. Alternate layers of glass and carbon is used in fabrication of the hybrids. First three specimens were glass-carbon hybrid, fourth and fifth specimen was glass laminates and sixth specimen was pure carbon composite. The dimensions were considered according to Indian standards. Test method used was IS 1608 and IS 1599. Tensile and bending specimens have dimensions of length 50mm, width 20 mm. The thickness of each specimen varied. Specimens 1, 2, 3, 4, 5 and 6 have a thickness of 5.7 mm, 3.46 mm, 3.68 mm, 2.6 mm, 2.56 mm, and 8.3 mm. Compressive specimens have dimensions of length 50 mm, width 50 mm and thickness of 7.58 mm.

Table 1: Fiber orientation & nomenclature of different specimens

Specimen	Category	Fiber Orientation
1	Hybrid glass-carbon-I	All unidirectional
2	Hybrid glass-carbon-II	[90°,0°,90°]
3	Hybrid glass-carbon-III	All 45°
4	E-Glass (white)	All unidirectional
5	E-Glass (white)	All bidirectional
6	Carbon	All unidirectional

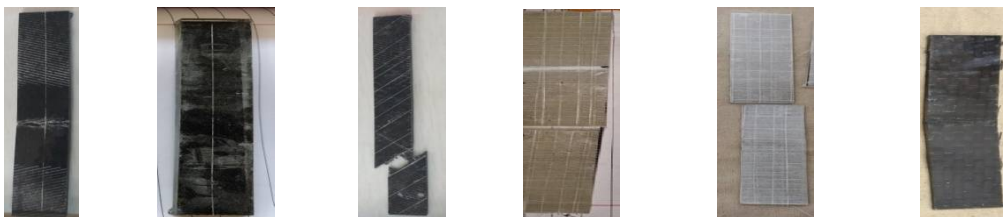


Fig 4: Tensile standard specimens from I to VI

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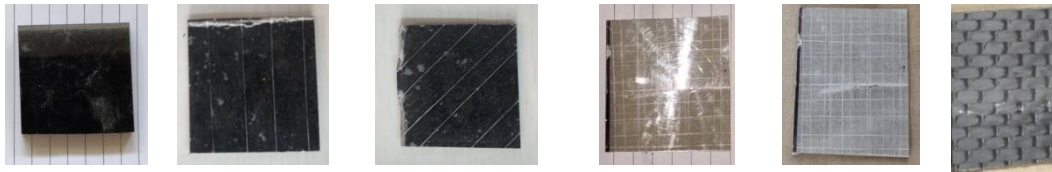


Fig 5: Standard compression specimens from I to VI

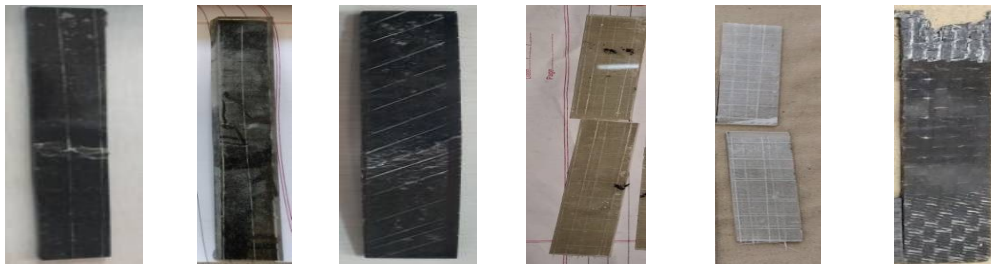


Fig 6: Standard bending specimens from I to VI



Fig 7: Hand lay-up process

Testing of specimens

Tensile, compressive and bending tests are carried out to evaluate various mechanical properties of the specimens. The tests were carried out using universal testing machine of 40 tonnes capacity provided by Inspection and Testing Engineers, Greater Noida. UTM is electromagnetically powered and fully computerized and has the ability to handle heavy external loads. Tensile specimen was placed between two mechanical grips and load was applied outwards from two sides until the point of fracture. During compressive testing, load is applied from two opposite sides until the point of deformation. In bending test, load is applied on the mid-point of the specimen such it forms a bend in the middle. Maximum load is observed in each specimen for all the tests.

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Fig 8: Tensile Test (top left), Compression Test (top right) and bending test (below)

III. RESULTS AND DISCUSSION

Tensile strength

From tensile tests, it was found out that maximum load before fracture was achieved in specimen-VI which is a unidirectional carbon laminate. It shows that carbon composites with unidirectional fiber orientation are much more strong compared to hybrids.

Table 2: Tensile test results for different specimens

Specimen	Maximum load (N)	Ultimate tensile strength (N/mm ²)
I	26200	220.99
II	21080	304.62
III	5980	82.49
IV	4300	82.69
V	4640	77.79
VI	47140	251.39

Lowest maximum load was experienced by specimen-IV which has unidirectional fiber geometry but lowest tensile strength was observed in specimen-III which is a hybrid glass-carbon composite with a 45° orientation. It shows that both carbon and glass fiber sheets at 45° fiber orientation doesn't provide good tensile strength. For hybrid specimens I, II and

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III the maximum load was observed in specimen 1 (unidirectional) but specimen-II had the maximum tensile strength which has bidirectional fiber geometry. This shows that both bidirectional carbon as well as glass fiber sheets contribute to good tensile strength. Since specimen III, IV and V has low maximum load before fracture, therefore ultimate tensile strength is significantly reduced. The variation of ultimate tensile strength for each specimen is shown in the figure below.

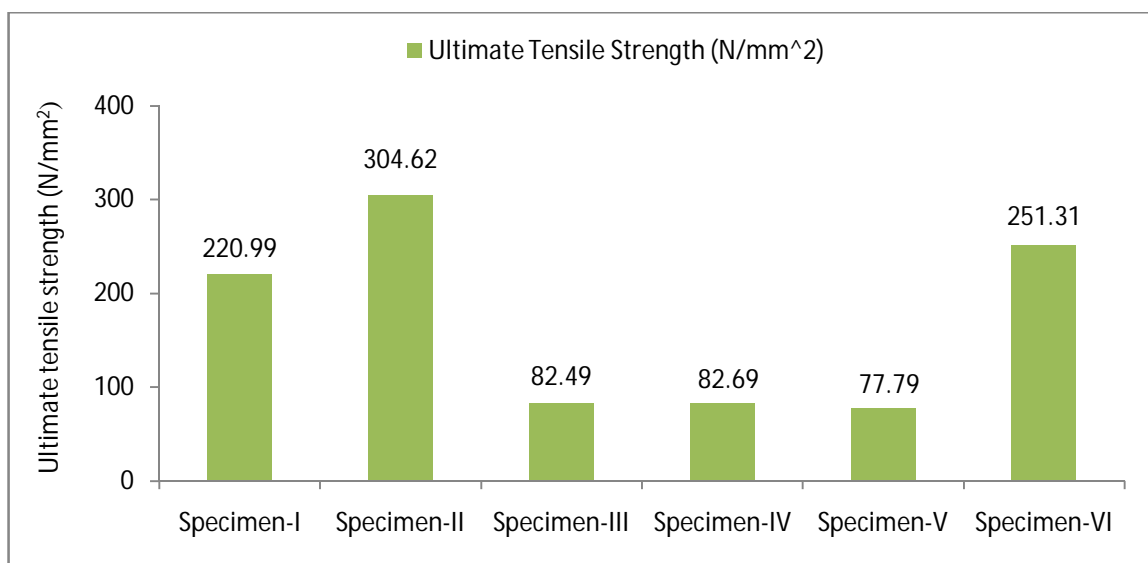


Fig 9: Ultimate tensile strength for different specimens

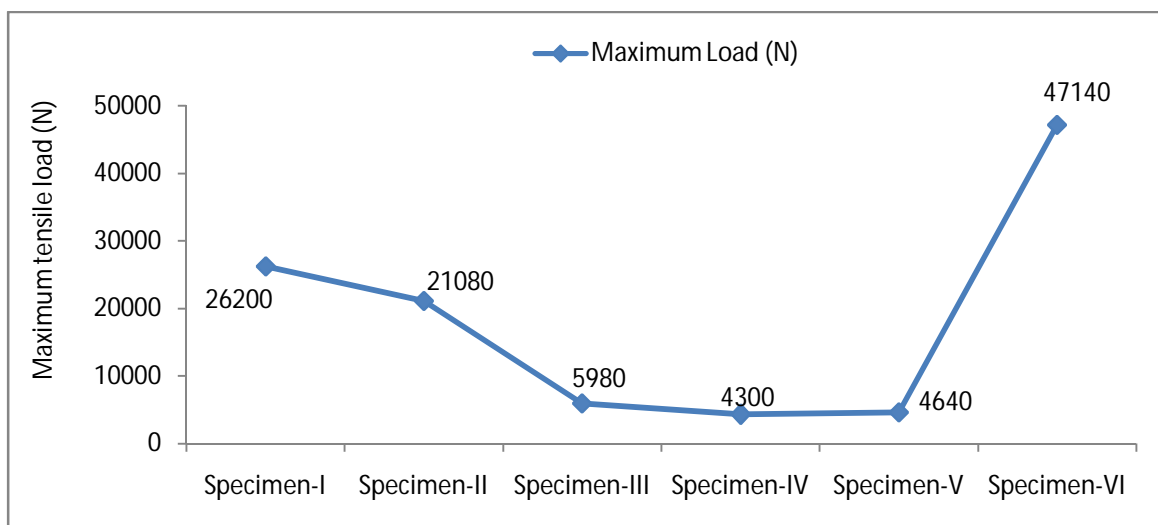


Fig 10: Maximum tensile load at which fracture takes place

Figure 7 shows the variation of maximum load for all the specimens at which deformation takes place.

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Compressive strength

Compression test was carried out successfully. Each composite has a different fiber orientation which is reinforced with araldite and hardener of varying quantity (1:10 ratio). After testing, maximum compressive load was observed in specimen-I which is a hybrid glass-carbon of unidirectional fiber orientation. It shows that both unidirectional glass and carbon fiber sheet provide good compressive strength to hybrid. Results of compressive strength are shown in the figure below.

Table 3: Compression test results for different specimens

Specimen	Maximum load (N)	Compressive strength (N/mm ²)
I	17680	102.30
II	14340	82.97
III	12820	74.17
IV	5720	33.09
V	4540	26.27
VI	7220	41.77

As it can be observed from the table above that lowest maximum loading and compressive strength was achieved in specimen-V which is white E-glass laminate of bi-directional fiber orientation. This shows that if glass fibers are used in 90° orientation, then it does not provide good compressive strength. Specimen-II also showed significant amount of compressive strength. Hybrid Specimen-I outperformed the other hybrids II and III. Specimen-III (45° Orientation) has the lowest compressive strength compared to I and II which shows that 45° fiber orientation is not suitable for good compression properties. The variation in compressive strength is due to the change in maximum load before fracture.

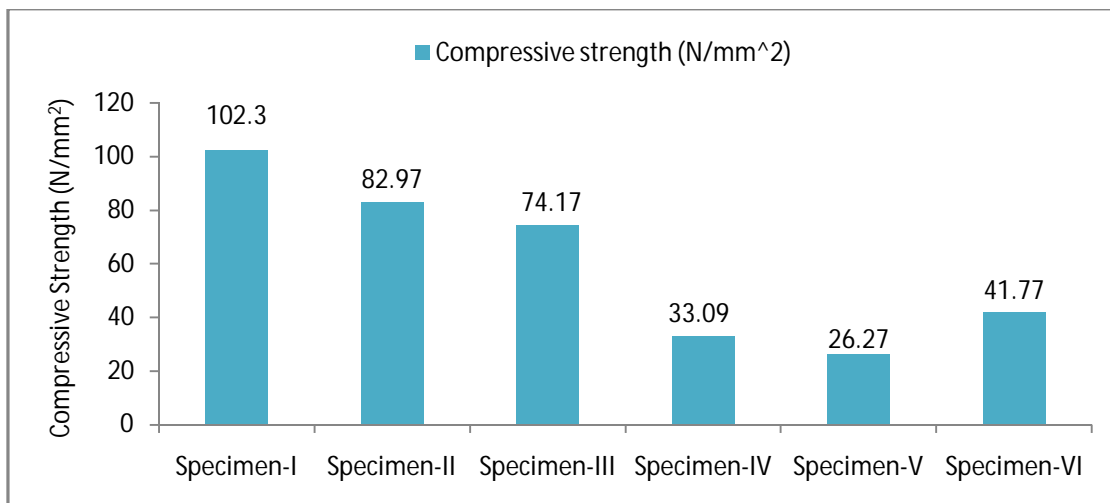


Fig 11: Compressive strength of different specimens

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Below figure shows variation of maximum fracture loads for all the compression specimens.

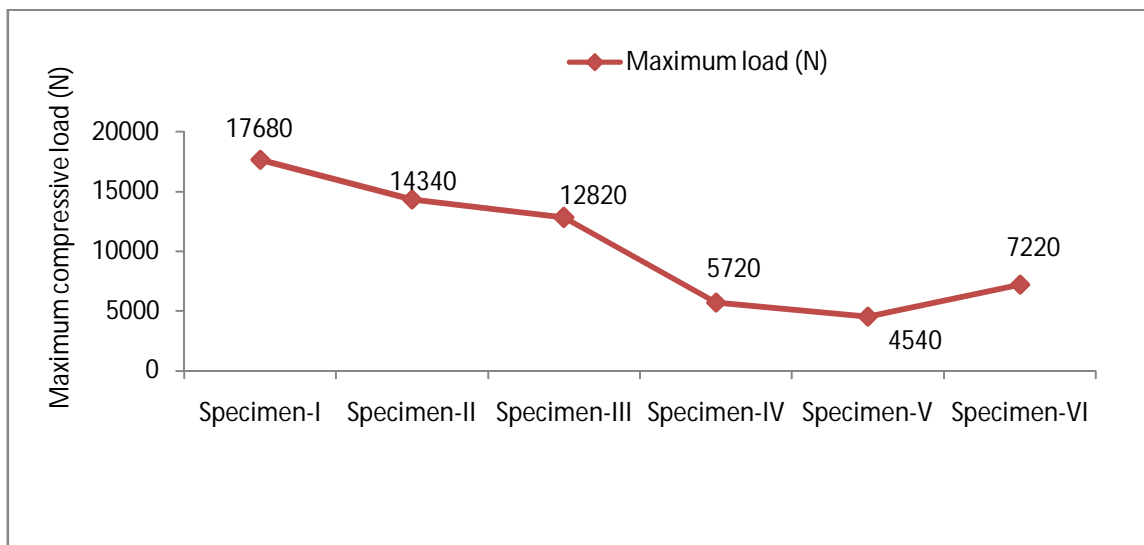


Fig 12: Maximum compressive load at which fracture takes place

Bending Strength

Three-point bending test was carried out on the six specimens of different fiber orientation and geometry reinforced with suitable quantity of araldite and hardener. The test is carried out to observe ductility in a material. The specimens are supported by two clamps on both ends and load is applied in the mid-point of the laminate. After testing it was found out that maximum load was achieved in specimen-V with a bi-directional fiber orientation and specimen-IV (white E-glass) had the lowest maximum load at which fracture occurred.

Table 4: Bending test results for different specimens

Specimen	Maximum load (N)	Bending strength (N/mm ²)
I	1160	9.78
II	480	6.93
III	1140	15.72
IV	420	8.07
V	3360	56.33
VI	1080	5.75

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From the above table, it can be observed that maximum bending is provided by specimen-V and second specimen which provides good bending strength is hybrid specimen-III which has fiber orientation of 45°.

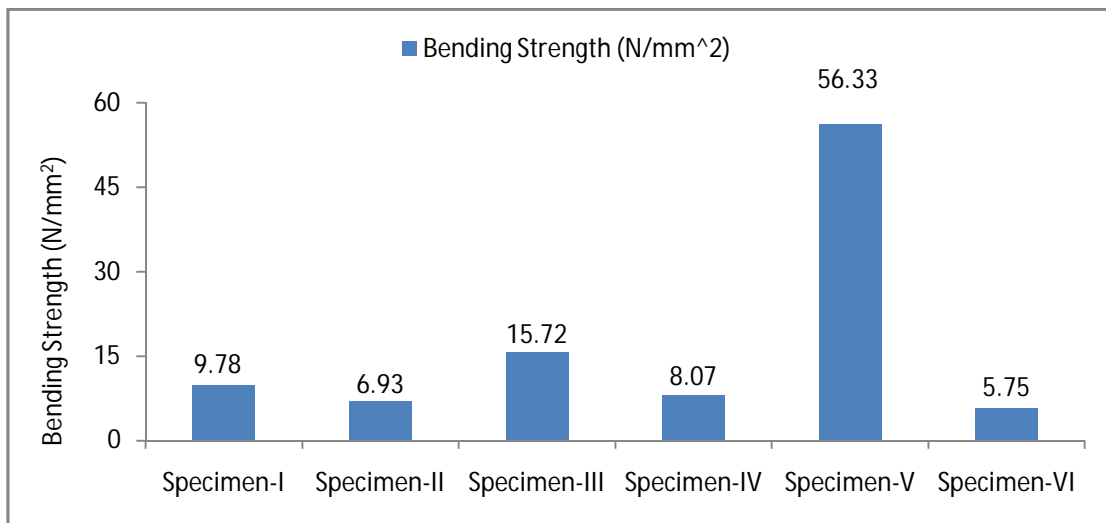


Fig 13: Bending strength of different specimens

The wide variation in bending strength is due to varying thickness and width of the specimens. Maximum bending strength in specimen-V was due to low cross sectional area compared to other specimens. Comparing the hybrid specimens I, II and III, it is observed that specimen-II has lowest bending strength. Below figure shows the variation in maximum load for bending specimens after which the laminates deform.

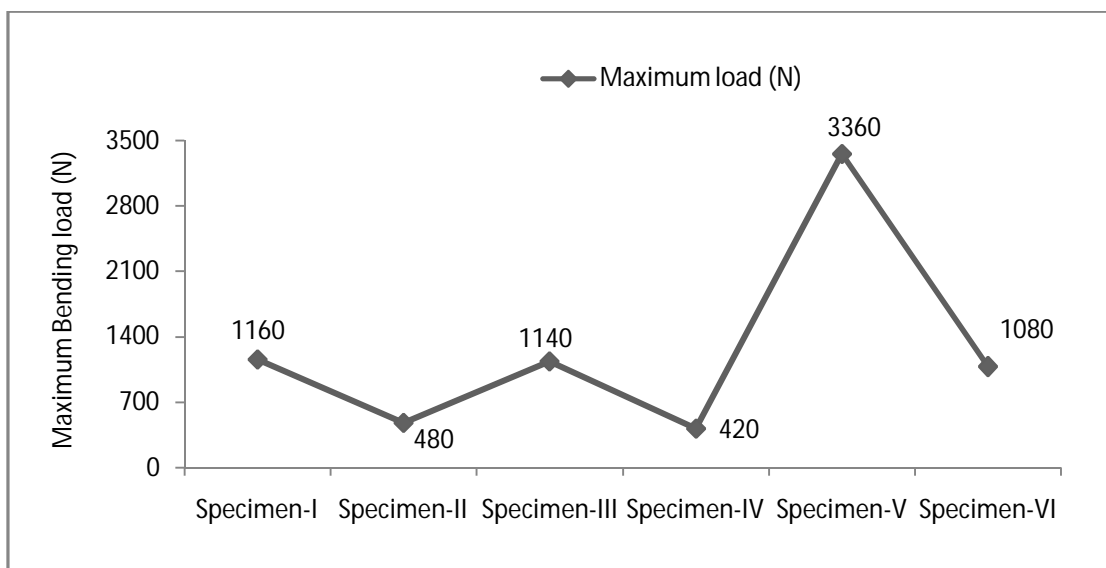


Fig 14: Maximum bending load at which fracture occurs

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IV. CONCLUSIONS

The glass and carbon hybrid laminates reinforced with epoxy are fabricated using hand lay-up technique. All the evaluation of mechanical properties such as tensile, compressive and bending strength has been successfully carried out using Universal Testing Machine according to proper Indian standards. Test method implemented is IS 1608 and IS 1599. The tensile and compressive strength of the specimens is significantly higher compared to the bending strength. Tensile properties have been evaluated and maximum breaking load has been measured for all the six specimens. Inclusion of SIKA WRAP-450C unidirectional carbon fiber fabric in the hybrid laminates improved the overall tensile strength and compressive strength of the specimens. When three hybrids I, II and III are compared with each other, maximum tensile strength is achieved in specimen-II [90°, 0°, 90°]_{WG, BG, C} and maximum compressive strength in specimen- I [unidirectional]_{WG, BG, C} where WG- white E-Glass, BG-black E-glass and C - carbon fiber. Maximum tensile load was experienced by specimen-VI (pure carbon laminate) of unidirectional fiber geometry. The ductility of the hybrid glass-carbon laminates improved significantly than the individual laminates.

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