Comparison of mechanical properties of fiber reinforced plastic laminates compose with different thicknesses, manufacturing techniques and structures

[1] Harita Zikre[#], [2]Alpa Bhatt[*]

[#] *School of science and engineering, Mechanical department, Navrachana University*

[1]zikreharita@yahoo.in [2]alpab@nuv.ac,in

Abstract — **In recent era the demand of Fiber Reinforcement Plastics (FRP) is increasing day by day due to its high strength to low weight ratio, thermal stability and long life. From small toys to aerospace parts, defense applications, aircraft industries, name it and one will find the application of composites. It is time to invest, invent, innovate and introduce this material at a high level of development, to compete with the universe. The constrain with synthetic fibers and resin is its non-biodegradability. Researchers are working to search solution to this problem by replacing with natural materials without losing the strength to weight ratio. In this article the author has put efforts to make laminate with hybrid structure, that is putting alternating layers of glass and bamboo and other laminate with only natural fabric as jute and has checked mechanical properties for comparison. It has been concluded that the hybrid structure gives better mechanical properties than monolithic laminate. The authors have made laminates with different thickness to observe the impact of thickness increased in the laminate structure. It is noticed that, as the thickness increases the strength of laminate reduces. For all laminates, the author has used polyester resin with hand lay-up technique and curing is done at room temperature. However, during curing either compression molding tool or vacuum bagging is being used to control the part thickness during curing.**

***Keywords* — Fiber Reinforcement plastics, Composite, Manufacturing, Synthetic fibers, Natural fibers, Mechanical property.**

I. Introduction

Composite material forms a material system composed of a mixture or a combination of two or more macro constituents that differ in form and in chemical composition, when they combined. They are insoluble in each other and give better mechanical properties than the individual one. Basically composite have two essential parameter matrix and reinforcement. Composite matrix can be classified based on the matrix as metal matrix, ceramic matrix and polymer matrix. Based on reinforcement they can be classified as natural fiber and synthetic fiber reinforced composites.

Natural fibers are renewable and biodegradable, which consists low density as well as low machining cost, less irritating to human skin and having efficient thermal and mechanical properties [3, 4, 5, 6, 7]. At the present time natural fibers such as Banana[2,11], Coir[11], Sisal[11], Jute[3,13], Cotton Lycra[13] are being more preferred as reinforcement for composite production with thermoplastic and thermosetting resin[8,9] due to their eco-friendliness. Glass fabrics are used as fabric [1, 10, 20] due to their excellence mechanical property in unidirectional and bidirectional orientation [16].

If layers of different reinforcement materials are combined together to form laminate, they are called hybrid structure. This hybrid structure can be the product combination of layers of different synthetic and natural fabric or it can be prepared by combing layers of different kinds of synthetic and different kinds of natural fabrics. Hybrid structures of natural fibers such as banana-coir [17] and synthetic fibers such as glass and carbon [21] have been used previously for the development of better mechanical properties.

Though, there are plenty of methods to build composite structure, hand lay-up is one of the basic and oldest methods to make composite products for study the composite laminate properties during the research stage. This process is cheap, easy to do and no specific machine is required. In this method reinforcement is first placed on the mold surface and the resin is applied to the fabric. As this method is very preliminary, the distribution of resin through laminate is uneven due to which it is difficult to have a uniform part thickness and fiber-resin volume ratio.

After lay-up the component needs to be cured at room temperature or at elevated temperature based on resin system used. The part can be cured with compression molding or vacuum bagging to give more compaction during curing.

In this paper the authors have used both natural and synthetic fibers for manufacturing composite laminate. Natural fiber, such as Jute, Bamboo and Glass fabric as synthetic fibers have been used for laminate preparation.

Hand lay-up followed by vacuum bagging or compression molding to make laminates ensured controlled part thickness. Four different laminates are being manufactured. The details of these laminates are furnished below.

TABLE I
LAMINATE DETAILS

Sr. No	Material	No of Layers	Process Used	Fiber – Resin volume fraction ration (Assumed)	Final Part Thickness Achieved	Laminate Type
1	Jute + Polyester resin	9	Hand lay-up + Vacuum bagging	20:80	3.45	Monolithic
2	Glass + Bamboo + Polyester resin	6 Bamboo 7 Glass	Hand lay-up + Vacuum bagging	60:40 for glass 80:20 for Bamboo	3.60	Hybrid
3	Jute + Polyester resin	17	Hand lay-up + Compression molding	20:80	7.15	Monolithic
4	Glass + Polyester resin	28	Hand lay-up + Compression molding	50:50	7.85	Monolithic

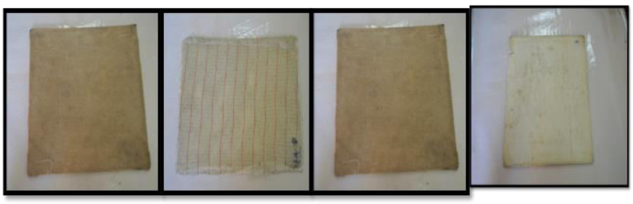

Fig 1: Laminates (i) jute with 9 layers, (ii) hybrid with 13 layers of bamboo and glass (iii) Jute with 17 layers (iv) Glass with 28 layers

II. MATERIAL

In this paper the author has used jute and bamboo as natural fiber and glass as synthetic fiber. Polyester resin has been used with a hardener and accelerator. Refer Table 2 for fabric and Table 3 for resin material details.

TABLE II
FABRIC MATERIAL PROPERTIES [24]

Material	Fabric thickness (mm)	Density (gm/cc)	Young's modulus (GPa)	Tensile stress (MPa)	Elongation (%)
Jute	0.45	1.44	10-30	393-773	1.5-1.8
Bamboo	0.26	0.6-1.1	11-17	140-230	-
Glass	0.3	2.5	70	2000-35000	2.5

TABLE III
RESIN PROPERTIES [25]

Material	Viscosity (cp)	Density (g/cm^3)	Flexural modulus (MPa)	Tensile stress (MPa)	Maximum elongation (%)
Polyester resin	250 - 350	1.09	45	40	1

III. MANUFACTURING

There are several types of manufacturing methods available to develop composite products. In this paper hand lay-up with vacuum begging and hand lay-up with compression molding have been used. Hand lay-up is the primary method to produce composite. It is the most traditional method for the manufacture of fiber-reinforced, thermosetting and thermoplastic resin. This method is most preferable method to produce prototype. To ensure uniform distribution of resin, vacuum begging and compression molding methods have been used to cure the part after lay-up. The mold is of 260×260 mm in size with variable depth created by compression plates from the mild steel material. The mould was cleaned with acetone to remove dust particles and then mould release liquid was applied to ensure easy removal of the laminate after curing.

Fig 2: Hand Lay-up

As shown in the figure, the reinforcements and matrix were laid on mould surface after applying mold release. The number of fabric layers built is as per table 1. After hand layup, to remove extra resin and to compact the fabric to get uniform thickness vacuum bagging or compression molding was done. Refer to table 1 for details.

For making hybrid laminate, glass and bamboo layers were placed alternately. It was ensured that the last layer of glass fabric is available at both the ends. This will ensure better strength of laminate. However, Effect of stacking sequence on the flexural properties of hybrid composites reinforced with carbon and basalt fibers [23] indicated that, to get good mechanical properties it is better to put synthetic material at the ends of the laminate while deciding the stacking sequence.

Compression molding is a closed mold process which is used to produce complex profile parts. In this method male and female die merges together by applying pressure. The combination of pressure and heat (not always) produces a composite part with low void content and high fiber volume fraction—a near net shape finished component.

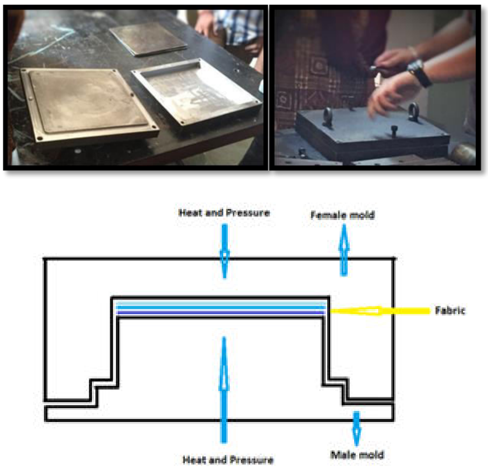

Fig : 3 Compression molding

Compression molded parts are prefect in size and shape, having excellent surface finish on both the side of the parts, and have very good part to part repeatability. The post processing like trimming and finishing costs are very nominal.

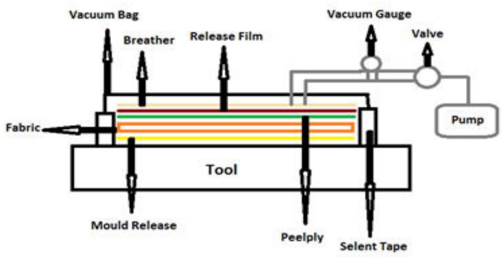

Fig: 4 Vacuum bagging

Vacuum bagging is a technique employed to create mechanical pressure on a laminate during its cure cycle. This process consists four different layers of bagging material to secure laminate such as peel ply, bleeder/breather, release film and vacuum bag. The peel-ply will be used to generate a rough surface of laminate and will be removed after the laminate has been cured. On peel ply released film will be laid to separate laminate from other bagging materials. Sometimes these films are perforated to ensure removal of excess gasses during the curing process. After this, breather or bleeder will be laid to absorb excess resin from the laminate and to ensure uniform vacuum distribution within the system. The sealant tape is used to seal the vacuum bag. Make sure there is no leakage during vacuum. Uniform vacuum has to be maintained and should be monitored by the vacuum gauge during the process. Sometimes pressure plates are used to have a uniform part thickness during curing.

IV. TESTING

After preparing laminate, laminate has to be cut according ASTM standard and need to be tested using universal testing machine. In this paper, the dumbbell shape five test coupon were cut per laminate with jigsaw machine. Refer figure 5 and 6 for test coupon before and after testing. Refer table 4, 5, 6 and 7 for the tensile test results of different laminates.

TABLE IV
TESNILE TESTING FOR HYBRID LAMINATE (3.6mm)

Bamboo + Glass (Hybrid)-3.6mm(vacuum begging)		
Sr. No.	LOAD(KN)	STRESS(MPa)
1	5.04	119.6582
2	5.86	139.1263
3	5.59	132.7160
4	5.69	130.4088
5	5.45	124.9083

TABLE V
TENSILE TESTING FOR JUTE LAMINATE(3.45mm)

Jute -3.45mm(vacuum begging)		
Sr. No.	LOAD(KN)	STRESS(MPa)
1	4.66	98.5930
2	4.96	102.6915
3	5.03	103.4022
4	4.98	103.1056
5	4.85	102.6129

TABLE VI
TENSILE TESTING FOR JUTE LAMINATE (7.15mm)

Jute- 7.15mm(compression molding)		
Sr No.	LOAD(KN)	STRESS (MPa)
1	8.4	61.8374
2	7.89	57.4737
3	7.44	55.0560
4	8.08	59.4773
5	7.65	55.7255

TABLE VII
TESTING DATA OF GLASS MATERIAL (7.85mm)

Glass- 7.85mm(compression molding)		
Sr No.	LOAD(KN)	STRESS (MPa)
1	23.96	171.5169
2	21.16	151.3846
3	28.11	188.4679
4	28.71	194.5385
5	24.40	164.4593

Tensile Test

The test was conducted according ASTM D638 standard with type-I of total length of the specimen 165mm with 50mm gauge length for laminate thickness less than 7 mm. This test was carried out by using a universal testing machine (UTM) and the result was noted for five different specimens. A test was conducted for hybrid and jute laminates with thickness 3.6 and 3.45 respectively. For Glass and jute with greater than 7 mm thickness specimens were cut and tested according to ASTM D638 type-III.

Fig: 5 Test sample of hybrid and jute laminate

Fig: 6 Test coupons before and after

V. RESULT AND DISCUSSION

a. Jute Laminate with 3.14 mm thickness:

Figure 7 depicts the tensile stress of samples which were vacuumed bagged for eight hours after wet lay-up. Fiber volume ratio to build laminate was 20:80. That means, 20% jute fabric and 80% polyester resin were used to prepare this laminate. The resin to hardener ratio was 100:1. Behavior of the graph shows, tensile stress varying between 98 MPa to 103.5 MPa.

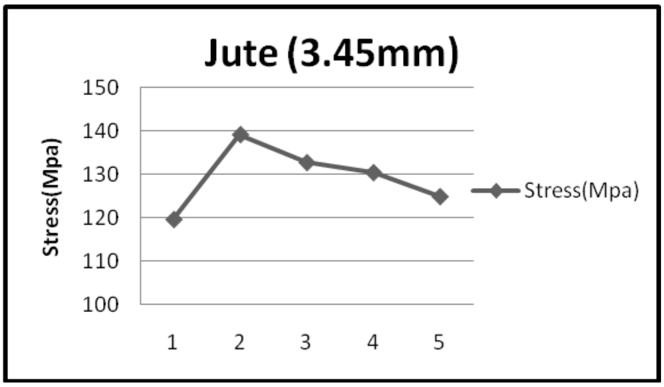

Fig: 7 Jute laminate stress values in MPa

b. Hybrid laminate structure with 3.6 mm thickness:

Figure 8 shows the tensile stress of hybrid laminate specimen. The reinforcement to matrix ratio is 20:80 for bamboo and 60:40 for glass fabric. The graph depicts better strength than jute material for the same thickness. The values are varying from 119 to 139MPa.

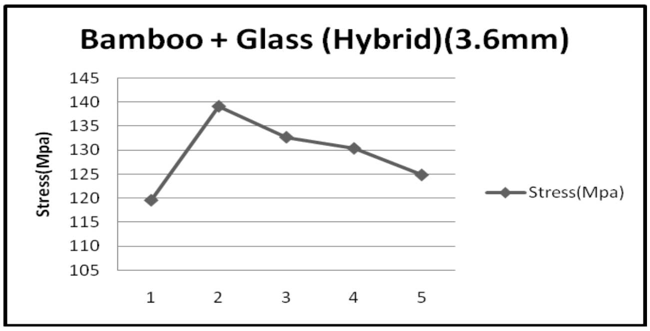

Fig: 8 Hybrid laminate stress values in MPa *c. Jute laminate with 7.15 mm thickness:*

Figure 9 shows the tensile stress of jute laminate specimen with 7.15 mm thickness prepared by compression molding. The reinforcement to matrix ratio is 20:80. The graph depicts less strength than jute material for less thickness. The tensile stress value varies from 55.05 MPa to 61.83 MPa.

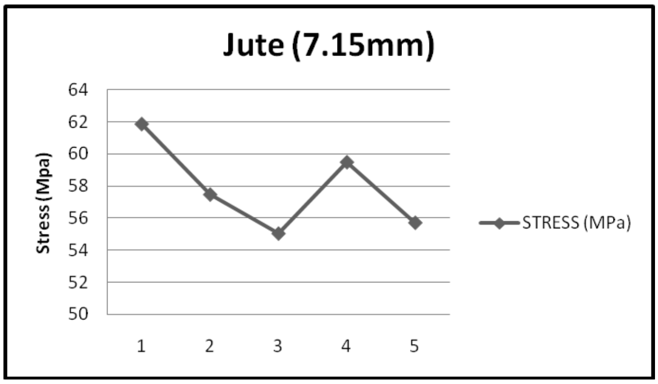

Fig: 9 Jute laminate stress values in MPa

d. Glass laminate with 7.85 mm thickness:

Figure 10 shows the tensile stress of jute laminate specimen with 7.85 mm thickness prepared by compression molding. The reinforcement to matrix ratio is 60:40. The graph shows higher strength than any other material. The tensile stress value varies from 164 MPa to 194MPa.

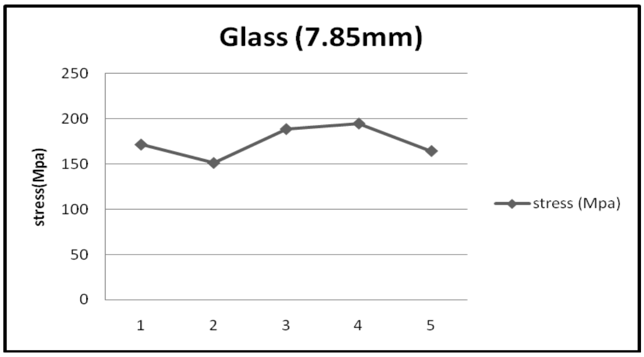

Fig: 10 Glass laminate stress values in MPa

VI. CONCLUSION

In this paper author as prepared laminates with different reinforcement materials, manufacturing methods and thickness and concluded following points.

1) The synthetic fibers give best strength than natural fibers and hybrid sturcture. Refer figure 11 showing same thickness, same manufacturing process, but different fabric as reinforcement. The synthetic fiber gives much better mechanical properties than natural fibers.

2) However, as synthetic fibers are not biodegradable the solution would be to go for hybrid structure to reduce the use of synthetic fibers. Refer figure 12 showing comparison of strength of hybrid laminate vs. monolithic natural fiber laminate for the same thickness and manufacturing process.

3) As the thickness of laminate reduces strength increase as the number of defects reduces. Also, it has been observed that the vacuum bagging gives better result than compression molding. Refer figure 13 which explains this point.

4) At last, the figure 14 compares result of all four laminates and from this we can conclude that the strength in the laminate is governed by reinforcement hence the highest strength we get with synthetic fibers, then hybrid structure and then natural fibers.

5) If we compare manufacturing techniques for curing after wet layup, it is observed that the strength is better achieved with vacuum bagging and with less thick laminate.

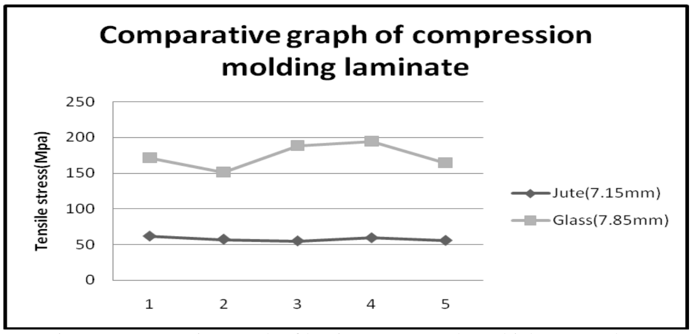

Fig: 11 Comparative graph of laminate stress value which prepare by compression molding

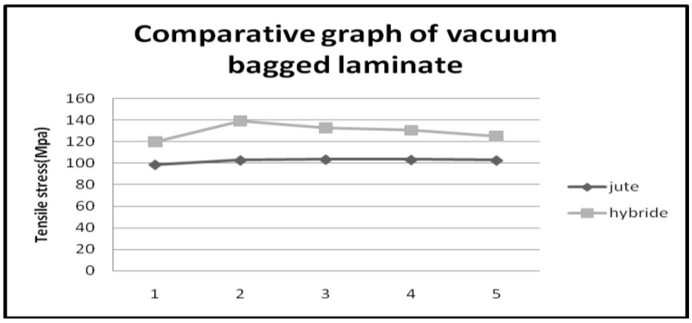

Fig: 12 Comparative graph of vacuum bagged laminate

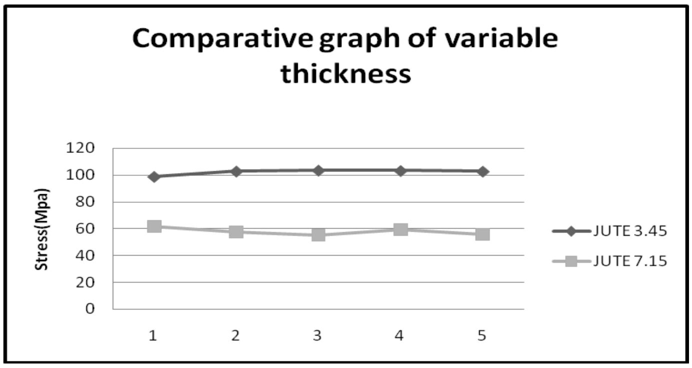

Fig: 13 Comparative graph of variable thickness for same material (Jute)

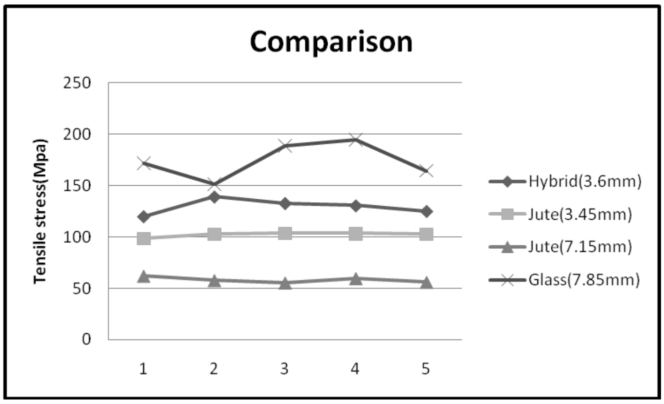

Fig: 14 Comparison of all stress value

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