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Mechanical Characterization Of Polyurethane Foam And Hybrid Natural Fibre Based Sandwich Composite

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Abstract - The attention towards sandwich composites due to its enhanced strength and high stiffness to weight ratio is giving a new face to the era of modern engineering materials. Further, environmental issues have intended researchers to interchange synthetic fibres with natural fibres in the fabrication of polymer composites. This work makes an effort to synthesize and characterize the behavior of polyurethane foam core based sandwich composite. The specimens generated in this work to evaluate the properties are made to vary in terms of their core densities and skin configurations. The polyurethane foam based core has a uniform thickness and varying densities whereas the skin is varied by three different combinations which are completely natural using jute fibre, completely synthetic using glass fibre and a hybrid combination of natural and synthetic fibres. The mechanical characterization of the specimens involve tensile test, compression test and three-point bending test according to ASTM standards. The results from the investigation revealed that the strength of natural fibre could be enhanced by partially combining it with synthetic fibres and the mechanical properties of sandwich structures increases with increase in the polyurethane foam density.

Keywords - Polyurethane foam, Jute fibre, Glass fibre, Epoxy resin, Sandwich composites.

Introduction

In modern industries, the use of natural fibre composites as a replacement for most of the conventional materials is increasing due to its high strength to weight ratio, biodegradability, eco-friendly environment, etc. Moreover, natural fibres are easily available and they can be extracted from the plants. But their poor mechanical and thermal properties limit their different applications. Researchers have suggested the fabrication of hybrid composites so as to boost the mechanical and thermal properties of natural fibre-based composites. Hybrid composites are developed by using two or more fibres in one matrix or two polymers combined with one natural fibre reinforcement. The use of natural fibres such as coir, silk, jute, wool, sisal, flax, hemp, etc as reinforcements in composite materials has been a keen area of interest for researchers over the past decade. The possibility of developing a light weight material at low cost by separating two thin material with a relatively thick and lighter material is well known since a very long period of time. This distinctive character, in addition to many other advantages such as designing flexibility, efficient cost saving and favorable environment conditions are making sandwich composites a highly popular choice in the material selection process for product developments. Sandwich structure composite is a unique class of composite materials which is developed by joining two thin, strong and stiff skins to a light weight and relatively thicker core. This work made an effort to synthesize and characterize the behavior of natural hybrid fibre reinforcement and polyurethane foam based core sandwich composite. The fabrication of sandwich composites were with polyurethane (PU) foam as the core material and jute, glass and jute-glass hybrid fibres as the skin and epoxy polymer as resin by vacuum bagging technology. The laminates of jute, glass and jute-glass hybrid reinforcements with epoxy resin were fabricated and tested for tensile and flexural strength according to ASTM standards prior to the fabrication of sandwich composites with an aim to understand their behavior when placed as facings for the sandwich structure. The mechanical investigation of sandwich composites involved flatwise compression testing, edgewise compression testing and flexural testing, all according to ASTM standards.

Literature survey

The combination of jute and glass fibers is found to exhibit superior hardness and impact property associated to the commercial glass fibre composite material [1]. It thus shows that the natural jute fiber composites can undeniably replace the commercial glass fibre composites for automotive components. Natural fiber reinforced with higher fiber strength and modulus, stronger fiber-matrix adhesion or higher fiber fraction possess higher critical load for damage initiation and higher failure loads and reduced damage propagation on subjecting to fatigue loading [2]. The investigation on the effect of variation in fiber content weight revealed that the mechanical properties of polypropylene based composites substantially improved on the addition of the Jute fiber reinforcement [3]. The chemical treatment of jute fibre has a significant impact on the formation of voids in the composites as well as the mechanical properties of jute fibre composites [4]. The flexural and impact properties of jute fibre reinforced epoxy and polyester composite can considerably enhanced with increasing fibre volume fractions up to forty four percent [5]. Glass fibre composite held good properties such as high strength, low density and easy processing thus, widely used in automotive, aerospace and construction. Combining the glass fibre with other fibres into a single polymer matrix results in development of hybrid glass fibre composites [6]. Glass fiber-reinforced epoxy composites could be manufactured by hand lay-up technique at different degree of fibre loading and fibre orientation [7].

Incorporation of natural fibres with glass fibre reinforced polymer improved the properties and could be used as an alternate material for glass fibre reinforced polymer composites [8]. Jute fiber could partially replace glass fiber within the polymeric hybrid composites towards the production of more eco-friendly composites although there was a relative decline in composite's tensile properties and fatigue life [9]. Composite sandwich structures are highly proven materials that has high strength to weight ratio. Extensive research works are still being carried out in the area of impact characteristics of sandwich composites. The low velocity impact behavior of sandwich panels with PU foam core increases with increase in core density and core thickness[10]. Increase in the core thickness leads to a slight increase in specific strength of sandwich due to the decreases in the density of the sandwich composites and changing face sheet materials and thicknesses had limited effect on compression strength of sandwich composites [11]. Whereas the most significant factor for flexural strength is face sheet thickness. The maximum value of flexural strength can be achieved for the sandwich structure having greater face sheet thickness and lower core thickness values. During the flexural loading, the complete load is first taken by the face sheet and then gradually transferred to the core material. PU foam based sandwich composites has no water absorption found and hence shows good floatation property. It point towards the corrosive resistance property of material makes it possible to use in marine applications [12].

Materials and Methodology

Selection of materials play a very important role as it has a direct impact on the outcomes of the experimentation, The materials chosen as reinforcements for the skin for this work is bidirectional woven mat of jute and glass fibre. . The properties of jute and glass fibre is given in the Table 1 and Table 2. The Jute fibre mat was procured from a supplier in Chennai whereas the Glass fibre mat was obtained from a local supplier based in Bangalore. Epoxy resin of Araldite of grade LY 556 along with Hardener of grade HY 951 is used as the matrix. The ratio of binder to hardener used throughout this work is 1:10. Polyurethane is created when isocyanate and polyol is reacted in the presence of a catalyst. Foam is created when gas is introduced, either by the reaction of isocyanate with water, or using a blowing agents. Foams of the different density can vary considerably in mechanical properties. The specimens generated in this work to evaluate the properties are made to vary in terms of their core densities and hence the PUF based core has a varying densities of 60, 80 and 100 kg/m^3 and a uniform thickness of 10mm. The PU foams were readily procured from an industry based in Bangalore called Polynate Foams.

Fabrication of Laminates

In order to understand how the laminates behave when placed as skin on to the sandwich composites, it is important to study their behavior individually, hence laminates made of materials used for sandwich skin were fabricated and subjected to tensile and flexural test. The fabrication of the laminates begin with the preparation of the mould. A flat rectangular mould was selected for this process. The surface of the mould was first applied with polyvinyl chloride which enables easy removal of laminates after fabrication. Cross sections of fibre mat of 50mm x 50mm is the placed on top of the mould one by

Figure 1. Jute fibre mat

Weave Pattern	Bidirectional
Density (g/cm3)	1.3
Elongation (%)	3.8-4.8
Tensile Strength (Mpa)	390-720
Young’s modulus (Gpa)	28.5
Thickness	0.5

Table 1. Properties of Jute Fibre

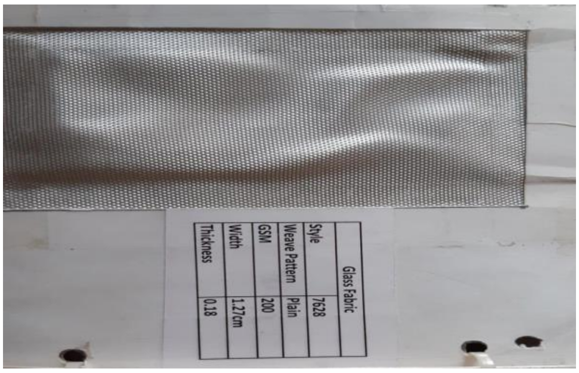

Figure 2. Glass fibre mat

Weave Pattern	Bidirectional
Density (g/cm3)	2.58
Elongation (%)	4.8
Tensile Strength (Mpa)	3.445

Young's modulus (Gpa)	72.3
Thickness	0.18
GSM	200

Table 2. Properties of glass fibre

one until the desire thickness is obtained. After the placement of each mat, a sufficient quantity of resin in applied to properly wet the fibres. A sealant is placed on the boundary and a vacuum bag is place on top of the wet fibres and press against the sealant to initiate vacuum bagging process. Vacuum bagging helps in the removal of excess resin, voids and ensure proper adhesion between the fibre an matrix. A release fabric is placed between the vacuum bag and laminate to prevent the sticking of vacuum bag with the laminate. It is subjected to a vacuum pressure of 0.5 bar. The laminates are then left to cure for a period of 24 hours. It is then put in a hot oven and post cured at 100°c for a period of 2 hours. The details regarding the laminate materials is shown in Table 3.

Fibre	**Reinforcement**	**Code**
100 % Jute	Epoxy	L1
100% Glass	Epoxy	L2
Hybrid (50% Glass + 50% Jute)	Epoxy	L3

Table 3. Laminate combination

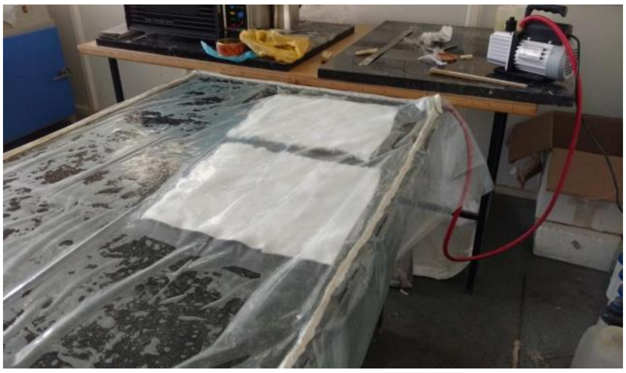

Fig 3. Laminate fabrication using vacuum bagging process

Fig 4. Composite laminates

Fabrication of Sandwich Composites

The sandwich composites in this study were fabricated using vacuum bagging technique. The fabrication of the sandwich composite begins with preparation of the mould. A flat mould was selected in this work for the fabrication of the sandwich composites. Polyvinyl chloride was first applied on top of the mould surface in order to facilitate the ease of removal of the developed part from the mould. In order to avoid any variations arising in the test specimens due to difference in the core densities and laminate thickness, sandwich panels of size 1000mm x 500mm of different skin combinations were fabricated at one. Once the jute fibre mats up to a desired thickness is laid on the mould. A sealant is then placed on the boundaries of the mat to create vacuum during the vacuum bagging process. The matrix is then applied on to the mat with the help of a brush. Once the mat is thoroughly wetted with the matrix, the foam cores of different densities are placed on top of it. In order to promote the penetration of matrix through the core, holes are pierces into the foam at distinct locations. This ensures a proper bonding between the skin and the core. A thin vacuum bag is then placed on to the core and pressed against the sealant too establish the vacuum bagging process. A release fabric is placed between the foam and the bag to ensure that the bag does not stick with the foam core. The vacuum pump is the connected to one of the corners of the sealant boundary with a vacuum pressure of 0.5 bar and left to cure for a period of 24 hours. After proper curing, the entire part in inverted to add skin on the other side of the foam in the same manner done earlier. Thus the sandwich panels with jute skin and PU foam core of densities 60kg/m^3, 80 kg/m^3 and 100 kg/m^3 is fabricated. The same procedure is used to fabricate sandwich panels of glass skin and jute-glass hybrid skin. The fabrication of hybrid skin involves alternative addition of jute and glass fibre mat until the desired thickness is obtained.

Fig 5. Sandwich composite fabrication by vacuum bagging process

Fig 6. Sandwich composite

Mechanical Characterization of Laminates

In order to understand how the laminates behave when placed as skin on to the sandwich composites, it is important to study their behavior individually, hence laminates made of materials used for sandwich skin were fabricated and subjected to tensile and flexural test. The laminates were cut according to the required size for the tensile test and flexural test. Tensile test is one of the most basic mechanical testing techniques used to determine how strong a material is and also how much it could be stretched out before it breaks. The geometry of the test specimens subjected to tensile testing were according to ASTM D3039. The dimensions of the specimen are length 250 mm, width 25mm, and thickness 2 mm. The ends of the specimen were thickened by 1.5 mm on both sides with a taper of 45° angle to ensure proper grip while stretching. The tensile test was done in computerized UTM (universal testing machine). The dimensions of the tensile test specimen is shown in figure 7. The flexural test on the other hand is a test to determine the flexural properties of a specimen which is a combined effect of tensile, compressive and shear stresses. The flexural test of the specimen in this study is done using a three-point bend setup as shown in figure 11 and the ultimate load-carrying capacity of the composite laminates is recorded following the ASTM D7264 standards. The dimensions of the specimen are length 140 mm, width 25mm, and thickness of 2 mm. The dimensions of the flexural test specimen is shown in figure 10.

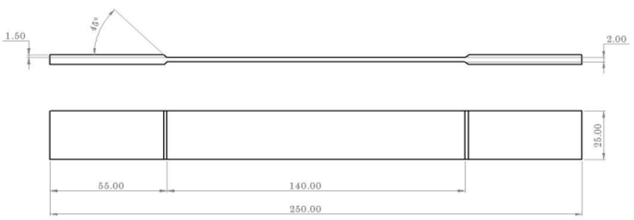

Figure 7. Dimensions of Laminate for tensile testing

Figure 8. Tensile test specimens

Figure 9. Tensile testing in UTM

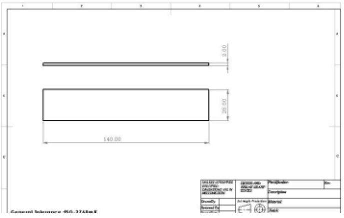

Figure 10. Dimensions of laminate for flexural testing

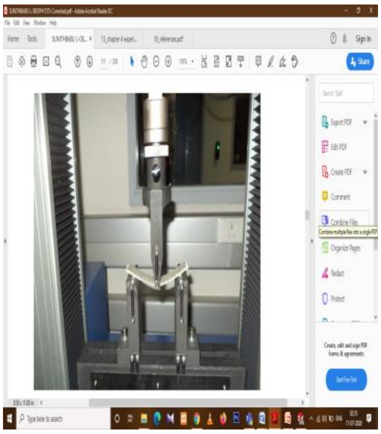

Figure 11. Flexural testing of laminate

Mechanical characterization of Sandwich composites

After the fabrication of sandwich composites, they were cut according to the dimensions of ASTM standards in order to carry out the mechanical characterization. The mechanical characterization involved flat wise compression test, edge wise compression test and flexural test. The specimens for flat wise compression test were designed according to the ASTM C365 standard which has a length of 50mm, breadth of 50mm and thickness of 14mm.The flat wise testing of sandwich specimen is shown in Figure 13. The test was conducted on a computer controlled test machine called Mecmisen-multitest10i. The specimens for edge wise compression test were designed according to the ASTM C364 standard which has a length of 90mm, breadth of 50mm and thickness of 14mm.The edge wise testing of sandwich specimen is shown in Figure 14. The edge wise test was also conducted on Mecmisen-multitest10i and the data was acquired. Flexural test was done using a three point bend setup with a high precision computer controlled testing machine. ASTM C393 is used as the standard test method for studying the flexural properties of sandwich composites. The test specimen geometry as specified in the above standard has a length 150 mm, width of 50 mm and thickness

14mm. The three-point bending test of sandwich composite is shown in Figure 15.

Specimen Skin	PU Foam Density	Specimen Code
Jute	60 kg/m^3	J1
Jute	80 kg/m^3	J2
Jute	100 kg/m^3	J3
Glass	60 kg/m^3	G1
Glass	80 kg/m^3	G2
Glass	100 kg/m^3	G3
Jute/Glass Hybrid	60 kg/m^3	H1
Jute/Glass Hybrid	80 kg/m^3	H2
Jute/Glass Hybrid	100 kg/m^3	H3

Table 4. List of Sandwich Specimens

The three point bend set up which tests the sandwich specimen imposes three different loads namely compressive, shear and Tensile. The former two appears on the top and the latter appear on the bottom side of the specimen. The flexural test results thus obtained is a combined effect of all the three forces. A total of 9 samples comprising one for each combination of skin and core were prepared for the mechanical characterization of sandwich composites whose details is given in Table 4.

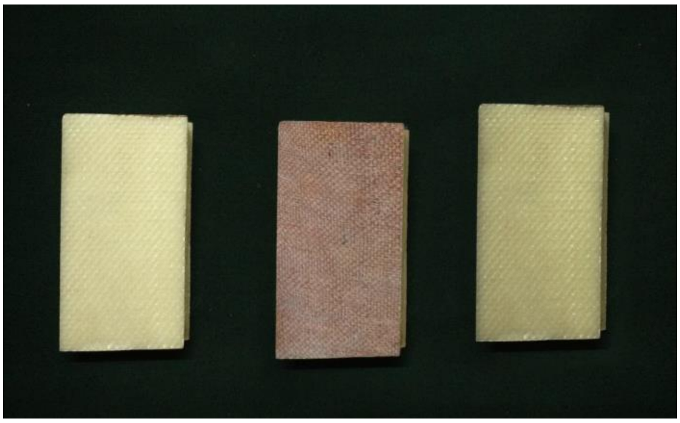

Figure 12. Sandwich specimens

Figure 13 Flat wise compression testing

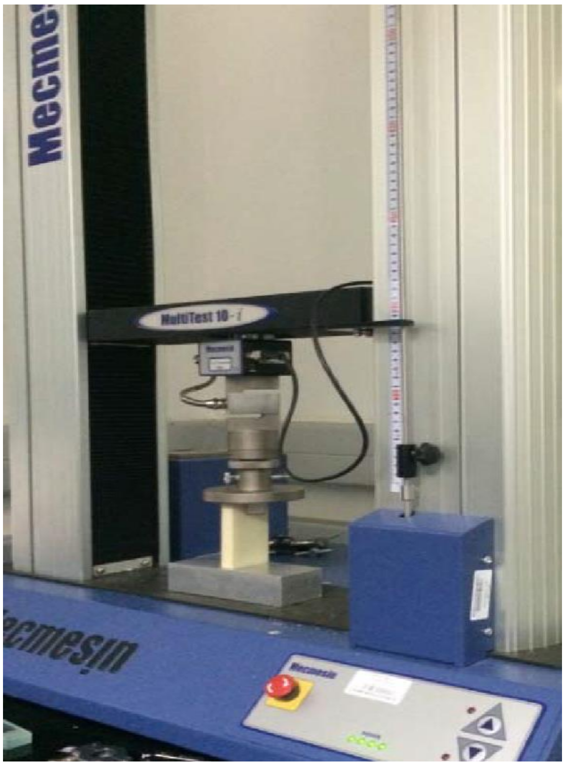

Figure 14. Edgewise compression testing

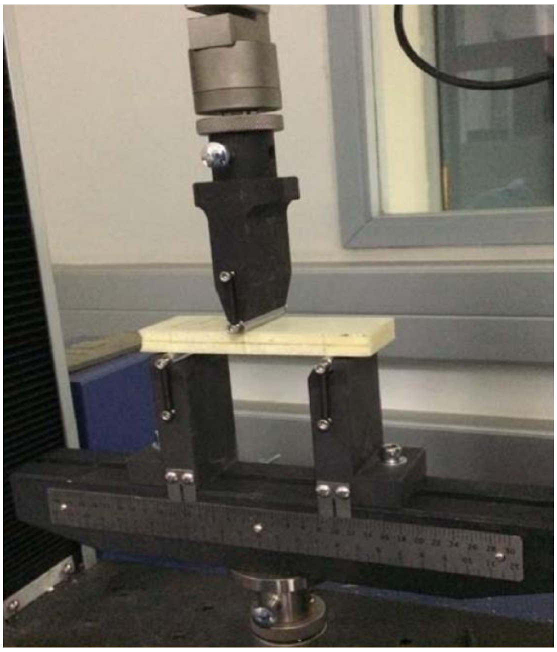

Figure 15. Flexural testing

Result

Mechanical Characteristics of Laminates

The results from the mechanical characterization of the composite laminates reveals that the Mechanical properties of glass fibre reinforced polymer laminate is significantly better that jute fibre reinforced laminates. The tensile test results show that the tensile strength of glass laminate is higher than jute laminate. Apparently the tensile strength of jute fibre laminates increase significantly on hybridizing it with glass fibre. Hybridization of jute fibres resulted in the increase of tensile strength by 88% compared with pure jute laminate and the tensile strength of hybrid laminate was 85% similar to that

Specimen Code	Tensile strength (MPa)	Flexural strength (MPa)
L1	36.85	64.32
L2	92.14	87.58
L3	70.28	80.76

Table 5. Experimental results of composite laminate testing

of glass. Similar results were obtained from the flexural test results. The flexural strength of glass fibre laminates were higher than jute but significantly increased on hybridizing it with glass. The flexural strength of glass laminates was found to be 36% greater than glass. On hybridizing jute fibres with glass, the flexural strength of the laminates increased by 25% and was closer to that of glass laminates. The outcomes of the laminate characterization indicates the capability of increasing the physical properties of natural fibre composites by hybridizing it with high strength synthetic fibre. Table 5 Shows the tensile and flexural test results for the composite laminates. The graph exhibiting the result comparison of the tensile and flexural characteristic of the laminates is shown in Figure 16.

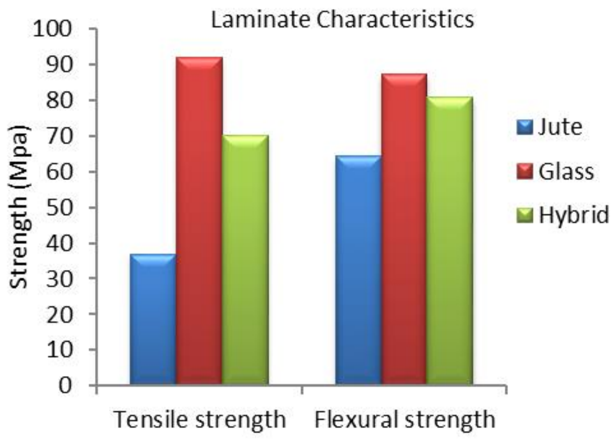

Figure 16. Test result comparison for laminates

Mechanical Characteristics of Sandwich Composites

The results from the mechanical characterization of sandwich composites reveals that natural Fibre based PU foam sandwich structures develops drastic enhancement in their physical properties on hybridizing the skin with high strength synthetic fibres. The results from flat wise compression test shows that the compressive strength of hybrid PU foam based sandwich composite was highest, greater than glass Based and Jute based sandwich composite. It was also seen that there was an increase in the strength with increase in the density of PU foam core. The hybrid sandwich composite with100kg/m3 core density showed highest value of compressive strength. Similar results were obtained from the edgewise compression test of sandwich composites. The compression strength of hybrid PU foam sandwich was seen to be the highest, greater than jute and glass based sandwich composites. these strengths increased with the increase in the core density in all the skin combinations. The result from flexural testing showed that the

Specimen Code	Compression strength(MPa)		Flexural strength(MPa)
	Flat wise	Edgewise	
J1	1.89	4.92	13.72
J2	2.4	6.9	19.54
J3	3.2	8.63	24.43
G1	2.14	7.92	27.28
G2	2.9	10.9	31.53
G3	3.7	13.73	39.41
H1	2.4	13.87	23.65
H2	3.1	19.14	30.58
H3	3.8	23.43	38.23

Table 6. Experimental results of sandwich composite testing

values of bending strength increases in the case of glass fibre sandwich combination. The sandwich composites made out of glass and PU foam combination had the highest values of flexural strength compared to all other combinations. The value of glass-PU combination is comparable with glass/jute hybrid-PU combination and is also environmentally more favourable. The flexural strength was the maximum for sandwich composite with glass reinforced skin and with the core density of 100 kg/m^3. The results of edgewise compression test, flat wise compression test and flexural test is given in Table 17. The graphs exhibiting the results of edgewise compression test, flat wise compression test and flexural test is shown in figure 17,18 and 19.

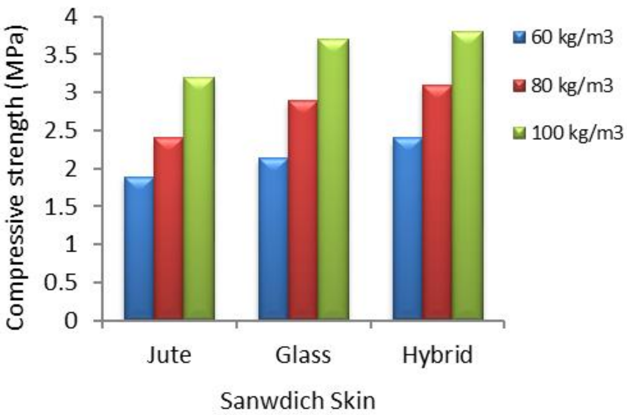

Figure 17. Comparison of Flat wise compressive strength for sandwich composites

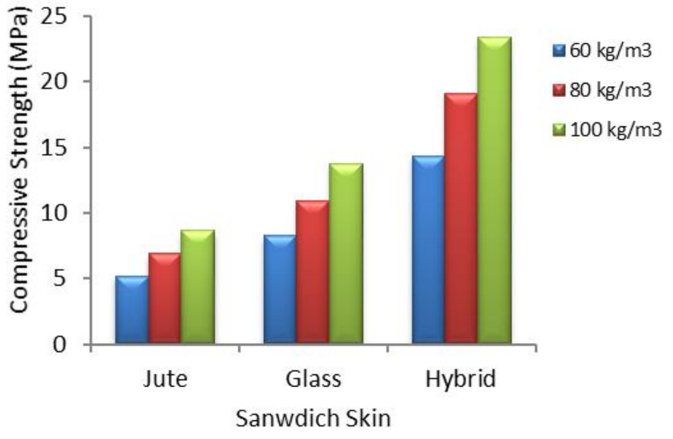

Figure 18. Comparison of Edgewise compressive strength for sandwich composites

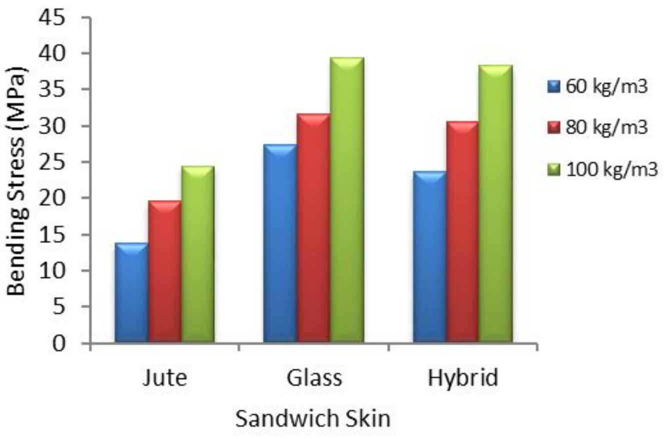

Figure 19 Comparison of Bending stress for sandwich composites

Conclusion

Sandwich composite is an assuring class of material among the engineering materials. The excellent mechanical properties in addition to the light weight structure caters sandwich composites as a replacement to conventional materials such as steel. This paves it applications towards most of critical engineering fields like aerospace, automotive, defense, construction and so on. This project made an effort to synthesize and characterize the behavior of natural hybrid fibre reinforcement and polyurethane foam based core sandwich composite. The fabrication of sandwich composites with PU foam as the core material and different combinations of skin such as jute skin, glass skin and jute-glass hybrid skin was successfully carried out by vacuum bagging technology. The laminates of jute, glass and jute-glass hybrid reinforcements with epoxy resin were fabricated and investigated prior to the fabrication of sandwich composites. The results from the mechanical characterization of the composite laminates reveals that the Mechanical properties of glass fibre reinforced polymer laminate is significantly better that jute fibe reinforced laminates and that improvement in the properties of jute laminates could be achieved by hybridization with high strength synthetic fibres. The overall results from the investigation of sandwich composites reveals that the physical properties of natural fibre and PU foam based sandwich composites could be enhanced by partially combining it with synthetic fibres along with using a core of higher density as the properties of sandwich structures increase with th increase in density.

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