Investigation of Optimum Parameters for Mechanical Properties of Ecofriendly Molded Plant Fibre Polymer Matrix Composite by Experimental Methods

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Abstract—Natural fibre composites are mainly price-driven commodity composites, which have useable structural properties at relatively low cost. The manufacture of such types of composites are environmentally sustainable alternative to conventional composites made of glass, carbon and aramid fibres which are considered critical because of the growing environmental consciousness. Fibres derived from plants are renewable and have low levels of embodied energy compared to synthetic fibres. Therefore this research work explains the development of natural fibre composite, [9] to attain the optimum mechanical property parameters which are equivalent and better to the traditional reinforcing fibres such as glass and carbon.

The research work illustrates the manufacture and tested values of one such composite manufactured from a plant fibre which is used as green manuring plant called Crotalaria juncea. Retted fibres after alkali treatment [17] is taken and plate preparation is done using polyester resin mixed with random orientation of the fibre of lengths 20,30,40 and 50mm to a weight of 21,28,31,35,42 and 45 grams as the first part. In the second part of the work woven orientation of biaxial, biaxially stitched and unidirectional mat in 2 layer and 3 layer separately and they are mixed with polyester resin and plates are prepared. Both the stages are tested for mechanical properties [10,16] such that the breakeven value of each property is analyzed, and the results acquired derive the usefulness of the material for required application.

Keyword- Polyester resin, Sunnhemp, Alkali treatment, Fibre orientation, ASTM standards

I. Introduction

The use of polymer matrix composite has been in the use with various fibres, as it can be easily manufactured, environmental friendly and also has the advantage of having properties which are equivalent and even more than expectations, to the traditional materials by strength and usage. In the recent years industry is attempting to decrease the dependence on products due to the increased environmental consciousness. This is leading to the need to investigate environmentally friendly, sustainable materials to replace existing ones. The tremendous increase of production and use of plastics in every sector of our life, has lead to huge plastic wastes. Disposal problems, as well as strong regulations and criteria for cleaner and safer environment, have directed great part of the scientific research toward ecocomposite materials. Among the different types of eco-composites, those which contain natural fibers (NF) and natural polymers have a key role. Currently the most viable way toward ecofriendly composites is the use of natural fibres as reinforcement. Natural fibres represent a traditional class of renewable materials which, nowadays, are experiencing a great revival. Although thermoplastics have the added advantage of recycling possibilities, thermosets are targeted to obtain much improved mechanical properties [1,4] as compared to thermoplastics in the resulting composites. In the presented paper, one such plant fibre is taken for preparation of composite plate by compression molded layup method and the prepared plates are tested for mechanical properties [13] as per ASTM standards, so that the values for which the mixture of the fibre and the matrix showing the desired value is derived. Investigation of properties for its better value of composites is the main purpose of presented work.

Fig. 1. (a)-Sunnhemp plant (b)-Sunnhemp Fibre (c)-Retting Process

II. EXPERIMENTAL MATERIALS

Sunnhemp [7] is a green manuring plant as shown in Fig. 1(a) used in agriculture called by botanical name as "Crotalaria juncea". The plant at its full growth stage is taken and fibres as shown in Fig. 1(b) extracted from them by retting process as shown in Fig. 1(c). Matrix material is general purpose Polyester resin[1], Catalyst used is Methyl Ethyl Ketone Peroxide (MEKP), Accelerator used is Cobalt naphthenate[6], Equipment for plate fabrication is Compression test rig and die made of steel of 3 pieces(top plate, bottom plate and the middle plate) as shown in Fig. 2(a) such that when the pieces are closed the required cavity of sizes 150*150*3.2, and 250*250*3.2mm is achieved, since this is the size from which the required specimen size can be cut as per ASTM standards.

A. Sunnhemp Fibre

Retted fibres are being procured for use as the composite fibre. It has a Fibre diameter of 48 µm, its apparent Density is 1.34 g/cm3, Its Ultimate tensile strength is 200-300 Mpa, its Modulus is 2.68 GPa, and its Extension at breakage is 2.5-3.5% (Details Procured from Central research institute for jute and allied Fibres (ICAR), West Bengal.). Sunnhemp as a fibre and green manure crop is cultivated in all states of India. It also serves as a good fodder crop in many parts of the country and is the largest producer of sunnhemp fibre followed by Bangladesh and Brazil. Of late, China is the highest yielder of sunnhemp fibre in the world. The strength of cordage fibre of sunnhemp is 185 kg as compared to 157 kg for cotton rope, 132 kg for hemp and 102 kg for coir.

B. Matrix Properties

Properties of Polyester resin [14] used for research is, its Density is 1.16 g/cm3, its Ultimate tensile strength being 8-9 Mpa, its Modulus is 0.58 GPa, and its Elongation at break is 1.6 % procured from the manufacturer.

C. Orientation of Fibre in the Mould

Orientation is termed as the alignment of fibre [15] in the mould along with the resin mix. The orientation used for the research is random orientation, [2,8] keeping the length of the fibre as a standard value and chopping the fibres for a required quantity by weight [3] as discussed later in the paper. The second part of the work is preparing woven fibres of different types as Biaxial, Biaxial stitched and unidirectional orientations [15] from fibre design centre where the fibres were given to be woved.

TABLE I: LIST SHOWING THE PLATES FABRICATED

S.No	Fibre Parameter	Fibre Weight in grams for the fibre parameter	No. of Plates Fabricated	Total Plates
1	20 mm Chopped length	21, 28, 31, 35, 42 & 45	3 plates each	18
2	30 mm Chopped length	21, 28, 31, 35, 42 & 45	3 plates each	18
3	40 mm Chopped length	21, 28, 31, 35, 42 & 45	3 plates each	18
4	50 mm Chopped length	21, 28, 31, 35, 42 & 45	3 plates each	18
5	Biaxial Woven	2layer	3	3
6	Biaxial Woven	3layer	3	3
7	Biaxially Stitched	2layer	3	3
8	Biaxially Stitched	3layer	3	3
9	Unidirectional	2layer	3	3
10	Unidirectional	3layer	3	3
			Total plates fabricated	90

D. Fibre Length and Weight Fraction

In the first stage Composite plate fabrication were carried by chopping the fibres to 20, 30, 40, & 50 mm separately and kept ready. These chopped fibres are taken in weights of 21, 28, 31, 35, 42 & 45 grams for each fibre length separately. So, for each fibre length the above said six weights are mixed with resin and fabricated and hence it gives a total of 4x6 = 24 plates. To arrive at an average value three plates are fabricated for each combination. In the second part the fibres were woven [16] to three different orientations as biaxial, biaxial stitched and unidirectional types and plates were fabricated for the three woven types by placing 2layer and 3layer of the woven mat which gives 3*2=6 plates. Even here to arrive at an average value three plates are fabricated for each combination and the total plates fabricated are as shown in table1.

III. EXPERIMENTAL METHODOLOGY

A. Sequence of investigation

The procedure used for fabrication is as followed by various PMC's, and the adopted procedure is as detailed below

a) Preparation of the Fibre
b) Alkali treatment of the Fibre
c) Preparation for orientation
d) Preparation of mould
e) Post curing of the mould
f) Removing specimen from mould & cleaning
g) Test for Mechanical properties.

B. Preparation of Fibres

- Dry retted fibres are washed with detergent solution, and cleaning the Fibres with deionised water for the removal of oily and foreign matter present in it and again dried. The dried Fibres are designated as untreated Fibres.
- The fibres are dewaxed by soaking, batches of fibres in 1:2 mixture of ethanol and benzene [2] for 72 hours at room temperature, initially by slight heating followed by washing with deionised water and then air dried.
- The dewaxed fibres are immersed in 5 to 10% NaOH solution for 1hr at room temperature, then washed thoroughly with deionised water and air dried to get alkali treated[11,12] fibres respectively.

C. Fabrication Procedure

- After the fibres are treated and dried thoroughly these fibres were cut into required length as per the table 1 shown above for fabrication, and the fibres are separated loose and ready to be weighed such that it can disperse in the resin to mix evenly at the time of fabrication.
- To maintain an even distribution of the weighed fibres, a GI tray of size equal to the size of mould cavity (150*150 and 250*250 mm) and which is also dependent upon the size of the specimen to be fabricated, is made and the weighed fibre is evenly distributed and pressed, such that it forms a thin layer of evenly distributed random oriented mat and kept ready to be used in fabrication.
- A transparency sheet of 150*150 and 250*250 as required is placed on the die bottom plate such that the resin mix can be poured on the sheet.
- Now the middle plate is placed on the bottom plate such that it is aligned exactly with the help of alignment pin provided in the bottom plate of the die.
- The resin mix(mixture of resin, catalyst and accelerator) which is mixed with proportion is poured slowly in the cavity, then the random fibre mat prepared earlier is transferred to the die and placed over the poured resin. The balance resin is now poured to fill the mould cavity and care is taken such that the resin is evenly distributed on the random mat.
- The above process has to be done faster as the resin mix starts to polymerize when the catalyst and accelerator are added to the resin.
- Another transparency sheet of the same size is taken and placed on the poured mix. This is done such that the piece got can be released easily and also a glossy finish of the plate can be achieved.
- The top plate of the die is closed and aligned. The die is placed in compression test rig and is loaded with 20 tons such that it compresses.
- Now the excess resin if available in the mould cavity oozes out of the cavity and the balance forms a required plate needed. This load is maintained for an hour for the complete curing to take place.

Similar procedure is followed for woven fibre fabrication also replacing the random oriented fibre mat with the woven mat, and care is taken such that woven mats are placed in 2 layers as well as 3 layers to the size required such that the placement of the mat is done alternatively with the pour of the resin. The setup of the experiment is as shown in Fig. 2.

Fig. 2. (a) Die used for plate fabrication (b) compression molding machine (c) Fabricated composite plate

D. *Post Curing and Finish of the Mould*

When the required time for curing is over the die is removed from the compression test rig and it is opened up. Care is taken in removal of the composite from the die. The die is washed thoroughly and dried. The removed composite plate is washed with deionised water for dirt sticking to it and dried. Then the fabricated plates are cut into required sizes and tested for its mechanical properties as per ASTM standards. To arrive at the result every tests are done in three specimens cut from different plates fabricated from same weight fractions and is averaged.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The following are the test conducted, tensile test [5] as per ASTM D3039, Flexural stress [18] as per ASTM D790, Impact testing as per ASTM 256 and Shear testing as per ASTM D35185 were done and the results are graphically represented further in this paper.

A. *Tests on Random Orientated plates*

1) Tensile Strength: As shown in the Table 1 after fabrication of the plates, test specimens were cut as per standards having 25mm wide and 50mm gauge length in all the three plates fabricated of the same weight fraction. The tested values are taken average and noted for graphical prediction. When comparing the tensile strength of random orientation of fibres, it is noted that the tensile stress is increasing from 20mm length of fibre up to 40mm for all fibre weights and then starting to decrease, when noted for 50mm fibre length showing a highest value of 62.28Mpa for 40mm fibre length and 42gms fibre weight as shown in Fig 3. The corresponding elongation noted is 3.9mm, and the corresponding load is 4980N. Taking into account the stress and strain values, another comparison is done between stress-strain.

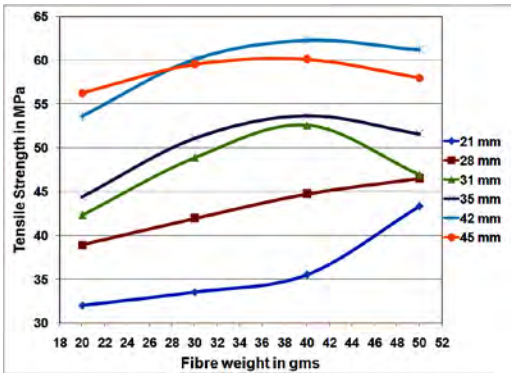

Fig.3 Comparison of Fibre length with tensile strength for various Fibre weights

2) Stress-Strain analysis: From the stress-strain curve shown in Fig. 4, it is observed that for lower value of fibre weight it is noted that there is a drastic change in the linear pattern of the curve for a fibre length of 40mm. This pattern is noted in almost all the fibre weights, but when the curve is seen for the 42gms fibre weight it shows a straight linearly increasing pattern, which is almost different from the other fibre weights such that it doesn't follow the same pattern. When the fibre weight is increased to 45gms, the same pattern is observed again as noted for the lower weights. So to conclude, the change in pattern is occurring in the 42gms fibre weight and fibre length of40mm as well as there is change in the pattern observed for the 40mm fibre length for all fibre weights.

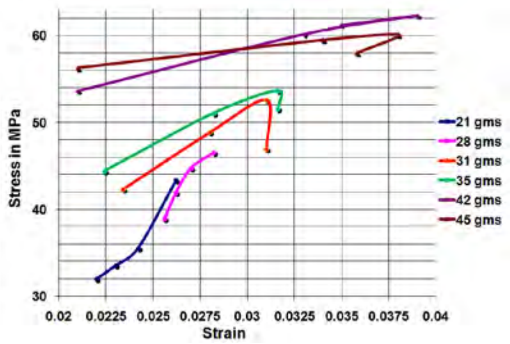

Fig. 4 Stress-strain curve of random Oriented Fibre.

3) Flexural Strength: When comparing the flexural strength test for random fibre orientation almost all fibre weights are showing increase in value in the range of 5-10Mpa for increase in random lengths from 20mm and reaches a maximum value of 92.27Mpa for 50mm length of fibre and 42gm weight, and when it is increased to 45gm the strength value reduces as shown in Fig. 5. It is observed that the more the fibre weight the more is the flexural strength for all lengths of fibre. It is also observed that for 42gms weight only, the maximum value is achieved as for as this research is done, and the corresponding load is 64N and elongation at deflection at break is 12.8mm.

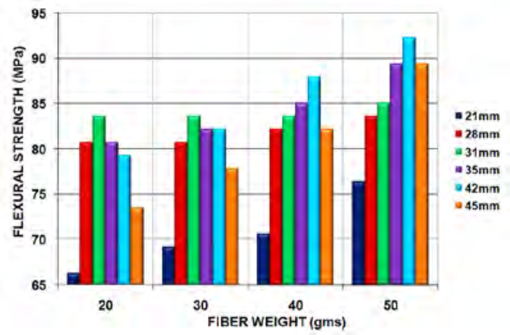

Fig. 5 Comparison of Fibre length with flexural strength for various Fibre weights

4) Impact Strength: In the impact test conducted the maximum value that the composite achieved is 4.96 J/cm at 50 mm fiber length and 42 grams of fiber weight where the energy value is 1.49 Joules as shown in Fig. 6, also bringing about the same percentage of fiber as bending stress. It is also noted that the impact strength is lower for small fibre length and lesser weight and as the fiber weight increases the impact strength also increases. It is also clearly shown in that for 30 to 40 mm of fibre length the impact strength is almost the same for all fibre weights.

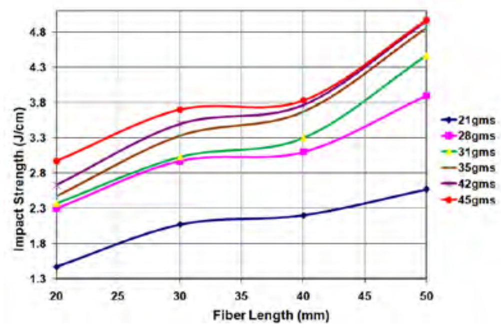

Fig. 6 Comparison of Fiber length with Impact strength for various Fiber Length

5) Shear Strength: In the shear stress conducted the results prove to be higher at the same values say 40 mm of fiber and 42 grams of fiber weight giving a stress value of 11.23 MPa which is also at 52.5% weight fraction as shown in Fig. 7. In this case also it is noted that as the fiber weight increases the shear stress value also increases and vice-versa.

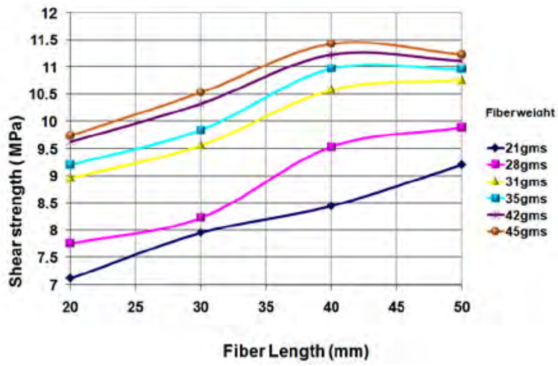

Fig.7 Comparison of Fiber length with Shear strength for various Fiber weight

B. Tests on Woven Orientated plates

1) Tensile Strength: Similar to the random orientation after the fabrication of the composite plates with woven mats specimens were cut to the sizes for testing. Here also three specimens with the same combination were tested to get the average value. When comparing the tensile strength of tested values of woven fibre using 2layer and 3layer composite for all the biaxial, biaxial stitched and unidirectional mat orientations showed drastic improvement in the values of strength for 3layer than that of 2layer fabrication. The increase in strength value accounted to 60%, 53%, and 50% for biaxial, biaxial stitched and unidirectional mat respectively. The maximum tensile strength value of 86.9Mpa is achieved for 3layer unidirectional mat, withstanding to a load of 1107Kgf the details of which are shown in the Fig. 8.

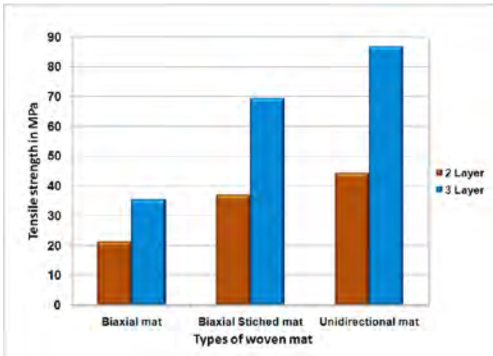

Fig.8 Comparison of tensile strength of woven fibre composite

2) Flexural Strength: The specimen with the given span is supported between two supports as a simply supported beam and the load is applied at the centre by the loading nose producing three point bending at a specified rate. The parameters for this test are the support span, the speed of the loading, and the maximum deflection for the test.

When comparing the flexural strength of woven fibre of 2 layer and 3 layer composite both the biaxial and biaxial stitched mat orientations are almost showing the same value in the range of 30-35Mpa and for biaxial and 70-80Mpa for biaxial stitched mats, in which the 3layer is slightly better than 2 layer, but whereas in the unidirectional mat the 3layer has the highest value of 126.8Mpa than that of 84.3Mpa for 2layer mat when tested along the direction of orientation. The difference in the pattern was noted for the unidirectional mat that as the layer increased the flexural strength increased than that of the other two woven mats. This is graphically presented in Fig. 9.

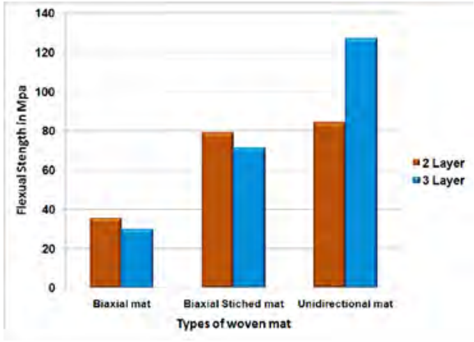

Fig.9 Comparison of flexural strength of woven fibre composite

3) Deflection: Comparing the deflection of the specimen for the above two at break during tensile loading unidirectional woven mat withstands better than that of the other two types of woven orientations and also increase in the number of layer shows better withstanding values which is shown in Fig. 10.

When comparing the deflection at break values at bending, the biaxially stitched woven mat has better withstanding capability than the other two woven types as shown in Fig. 11 and it deflects up to around 11mm for both 2layer and 3layer types than that of around 4mm for biaxial mat and around 6mm for unidirectional mat. The increase in withstanding capability is 30-35% more than the biaxial mat and that of 50% for unidirectional mat.

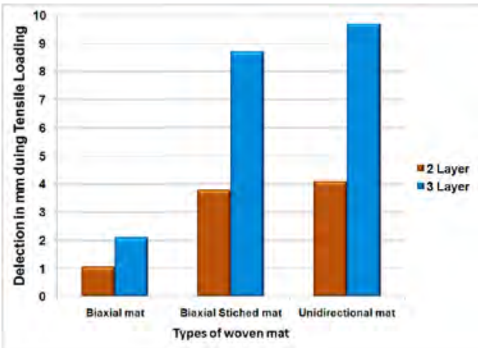

Fig.10 Comparison of Deflection of Woven Fibre composite during tensile loading

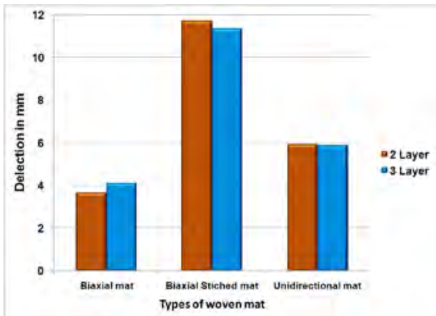

Fig.11 Comparison of Deflection of Woven Fibre composite during bending

4) Impact Strength: Impact strength is better for biaxial stitched mat orientation when compared to biaxial and biaxial stitched mat woven fibre of 2 layer and 3 layer composite. Both the 2layer and 3layer biaxial stitched woven orientation are showing better results than the other two woven types as shown in Fig. 12. The values of impact strength are 0.27J/mm and 0.45J/mm for 2layer and 3layer biaxial stitched respectively. This clearly indicates as far as impact property is concerned biaxial stitched woven orientation is better than the other orientations.

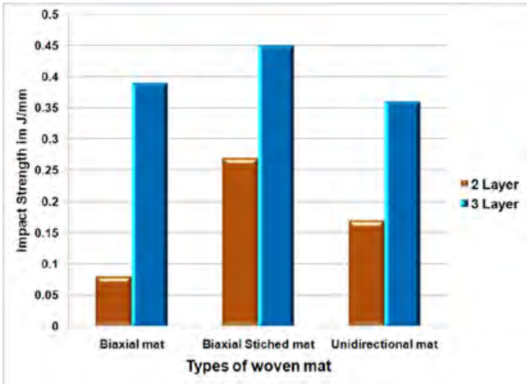

Fig.12 Comparison of Impact strength of Woven Fibre composite

CONCLUSIONS

The objective of this study is to define the benefits of bringing about a composite which posses superior properties for the correct mix of the fibre and the matrix. Significant conclusions which are obtained in this research are as follows:

- For a particular random length of fibre of 40mm and a weight of 42 grams the composite possessed the vital behaviour as for as strength is concerned.
- Three point bending method probably provides a better estimate of the actual material behaviour under flexural loading.
- There is a significant improvement in strength of the composite prepared as compared to the banana, bamboo, flax fibres for same thicknesses under test. This may be due to good adhesion between sunnhemp fibre and matrix under compression molding layup technique.
- When the same fibre is tested by woven orientation, similar to random orientation the tensile strength increases with the increase in woven fibre layers i.e., 3 layers.
- It is also noted that the unidirectional woven orientation posses highest strength when measured along the direction.
- For all other properties the biaxially stitched mat is better when 3 layer mat is used compared to 2 layer mat.
- These results are applicable to treated fibres only and when the same test is initially conducted for untreated fibres the results were very low and not even reaching the lowest grade of polymer matrix composite.

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