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Finite Element analysis of jute and banana fibre reinforced hybrid polymer matrix composite and optimization of design parameters using ANOVA technique

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Abstract

During last few years, the interest in using natural fibers as reinforcement in polymers has increased significantly. Natural fibers are not only strong and lightweight but also relatively very cheap and bio-degradable. In this work, an investigation is carried out on jute fiber, a natural fiber. Jute fiber has gained interest in the composite field due to its superior specific properties compared to manmade synthetic fibers like glass, Kevlar, asbestos, etc. The present work describes the development and characterization of natural fiber based composites consisting of jute fiber as reinforcement and hybrid resin consisting of general purpose resin and cashew nut shell resin as matrix material. The composites are fabricated using hand lay-up technique. The tensile strength is studied using experimental and numerical analysis. The nature of hybrid matrix at different composition is also studied. The commercial Finite Element Analysis software ANSYS is used for numerical study.

Keywords: Natural fibre, hybrid matrix, finite element analysis.

1.Introduction

Jute and banana fibres, due to its ease of availability and increasing demand in environmental friendly materials, marked its importance in composite engineering. Focus on natural fibres is increased as its cost is less when compared to synthetic fibres which are petroleum based products. Natural fibre composites are manufactured using natural or synthetic resin with reinforcement as natural fibres [1].

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High specific properties, low density, light in weight and renewable in source are its highlighting advantages [2-7]. Natural fibre reinforcement in traditional thermoplastic polymers finds its application in automobile industries. Influence of surface treatment on natural fibres improves the interfacial bond between fibre and resin thereby increases its mechanical properties [8-9]. For traditional fibre reinforced composites, even though it has advantages, one of its main disadvantages is its disposal that causes environmental problems in disposal by incineration [10]. Some of the recent research works show that increase in fibre length and fibre volume fraction in composites improves its mechanical properties [11-12]. Alkali treatment of jute and banana fibre reinforced composites with 5% NaoH improves the mechanical properties of composites [13]. High level of moisture absorption, poor wettability, inadequate adhesion and debonding are the main disadvantages of natural fibre reinforced composites. But the alkali treatment of fibres reduces its disadvantages. Alkali treatment removes the lignin and hemicellulose content in the fibre, also reduces the spiral angle so as to increase the molecular orientation thus increasing the elastic modulus of fibre [14-16]. Improvement of interfacial bonding is important in improving mechanical properties [17-20]. Alkali treatment provides finer fabric, increase crystallinity, reduction in amount of defects, superior bonding and reduced moisture absorption [21].

2. Experimental

2.1 Fabrication method

Jute and banana fibre hybrid polymer matrix composite are manufactured separately in laboratory. Cashew Nut Shell Resin Liquid [CNSL] is mixed with General purpose resin to get hybrid polymer and used as matrix for both jute and banana fibre composites. Varying CNSL percentage in hybrid polymer from 5% to 40% is carried out to fabricate composites so as to study the effect of the influence of CNSL in the hybrid polymer matrix composites. Figure 1 shows the specimen prepared for experimental studies.

(a) (b)

Fig. 1. Jute fibre (a) and Banana fibre (b) made hybrid polymer matrix composites at varying CNSL % prepared.

Tensile test is conducted using Instron machine with strain rate of 2mm/min.
Figures 2-4 present the tensile test and specimens after failure.

Fig. 2. Testing of specimen in Instron machine

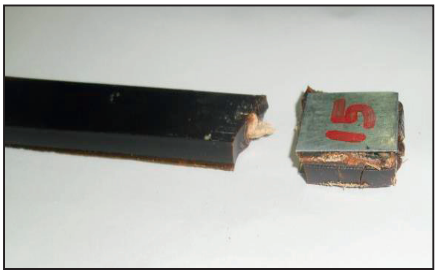
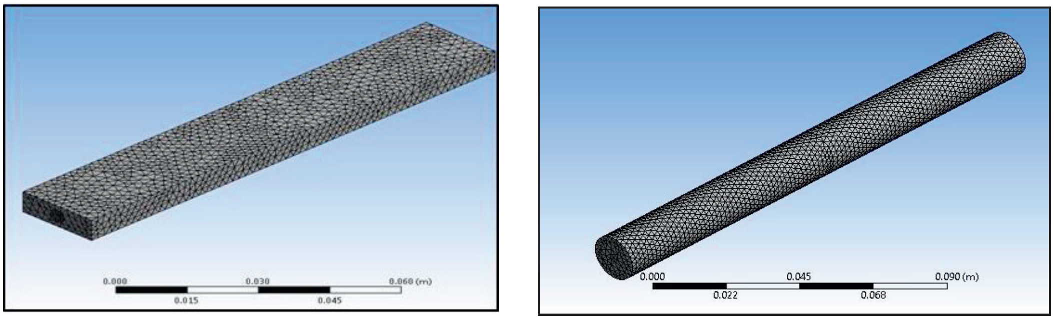


Fig. 3. Jute fibre composite after failure

Fig. 4. Banana fibre composite after failure.

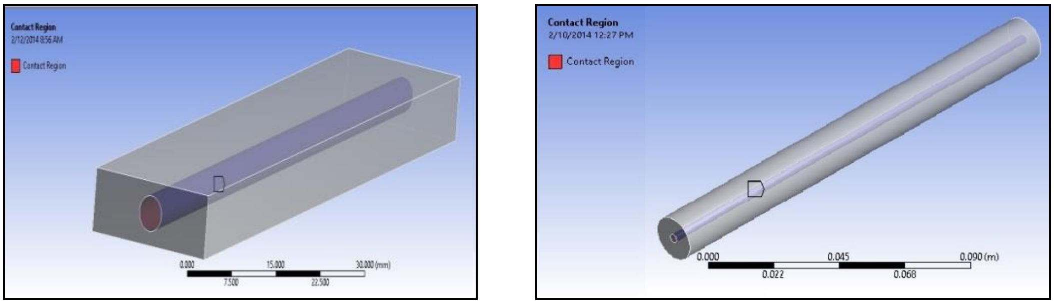
3. Finite Element Analysis

Modeling of jute and banana fibrse reinforced composite materilas are carried out in Solidworks and imported to ANSYS. The model was meshed using element type solid 187. Boundary conditions are applied for uniaxial tensile test conditions. Contact between fibre and matrix is assigned as bonded conditions. Material properties, obtained from experiments for matrix and for jutre fibre from literature[22], are assigned to respective models.



(a) (b)

Fig. 5. Meshing done to (a) jute and (b) banana fibre hybrid polymer matrix composites.



(a) (b)

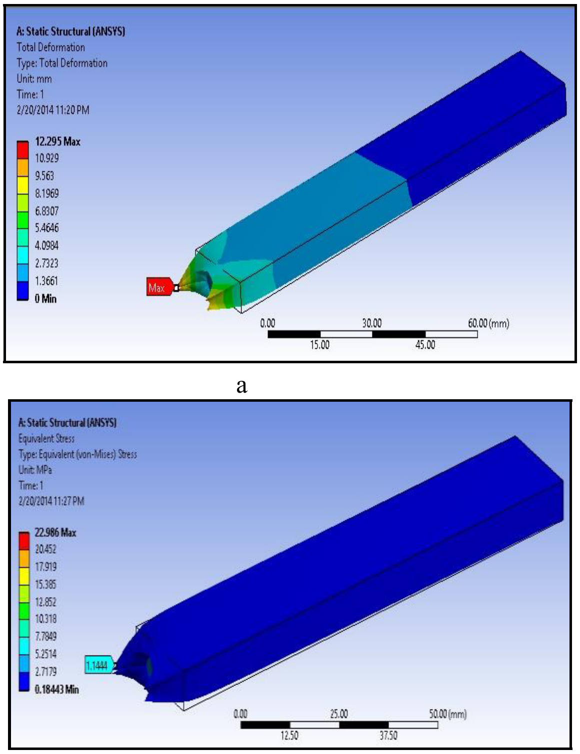
Fig. 6. Contact between fibre and matrix for (a) jute and (b) banana fibre hybrid polymer matrix composites.

4.Results and Discussions

Tensile test results,obtained from experiments, are compared with Finite element analysis results. Both results are found to be closer. Maximum load and maximum stress as well as load versus deformation results of each cases of jute and banana fibre hybrid polymer matrix composites with varying CNSL % when compared with experimental and Finite element analysis results have closer values, [23] and [24].

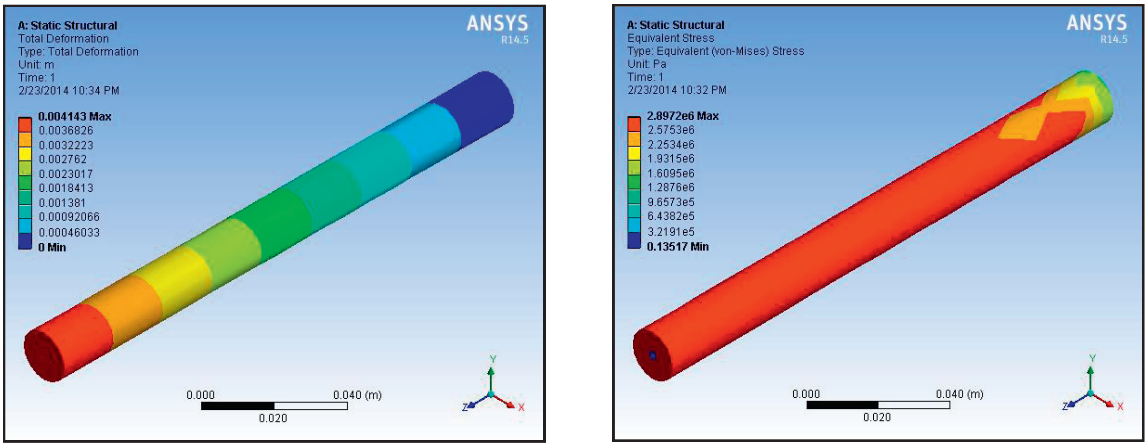
From the comparison, it is concluded that further analysis can be carried out for different fibre lengths, fibre volume fractions and effect of alkali treated fibres in hybrid polymer matrix composites numerically using finite element analysis.

Figures 7(a)- (b) shows the tensile test conducted using finite element analysis for jute and banana fibre hybrid polymer matrix composites. Effect of alkali treated jute and banan fibre in hybrid polymer matrix composites are analysed numerically using ANSYS. Figure 8 represents the comparison of the effect of alkali treated and untreated jute and banana fibres reinforced hybrid polymer matrix composites. It is evident from the figure that treated jute and banana fibres carried more load when compared to untreated jute and banana fibres for same CNSL %.



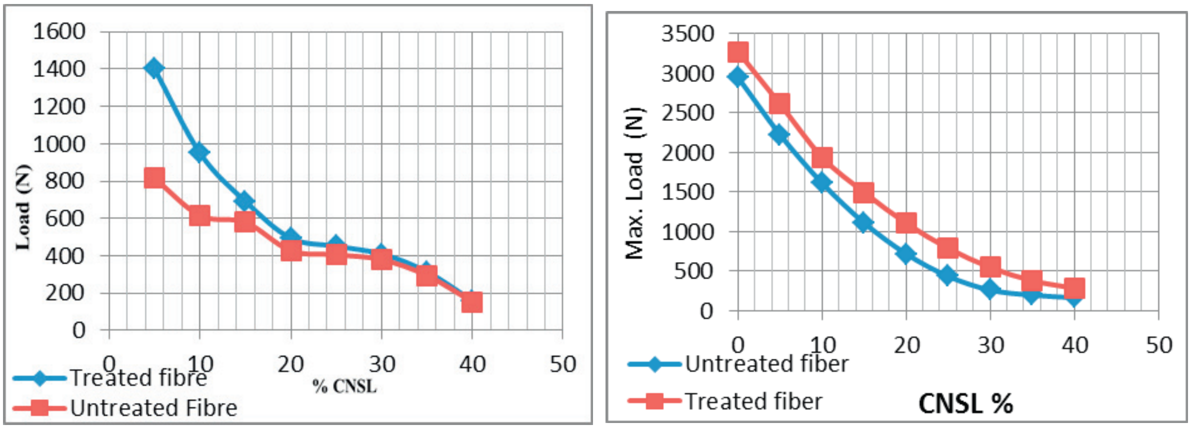
a

b



c d

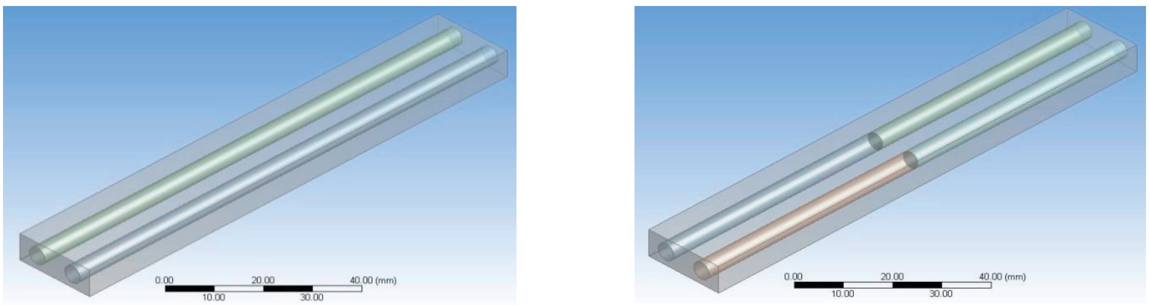
Fig. 7 Finite element analysis contour plots for (a)(c)deformation (c)(d) von mises stress



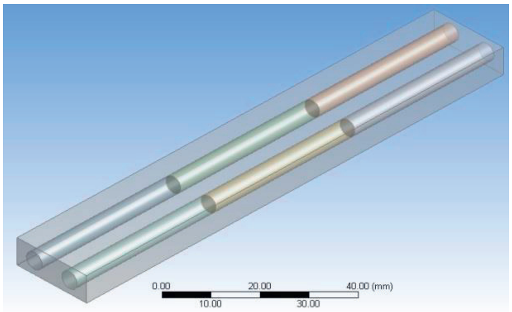
a b

Fig. 8(a)-(b). Comparison of maximum load for treated and untreated jute fibre composites.

Fibre lengths at 3 different levels i.e. long, medium and short are modeled in ansys and maximum load bearing is found. Figures 9(a)-9(c) show the model for 3 cases of fibre length for 20% fibre volume fraction and figure 10 represents the graph showing the effect of fibre length for 3 cases each for varying CNSL % for maximum load carrying conditions. It is concluded that influence of fibre length on maximum load bearing is insignificant.

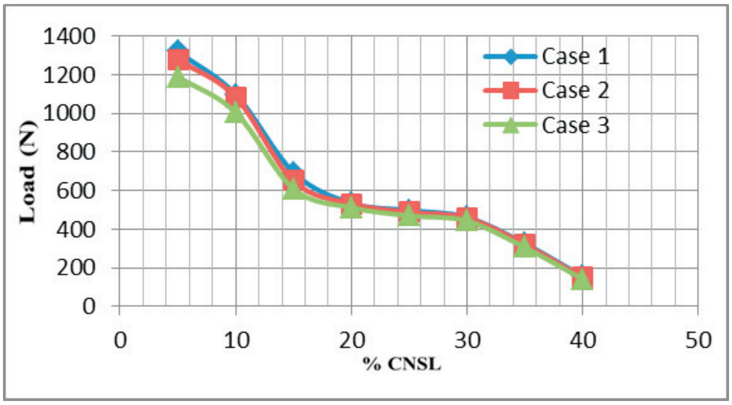


a b

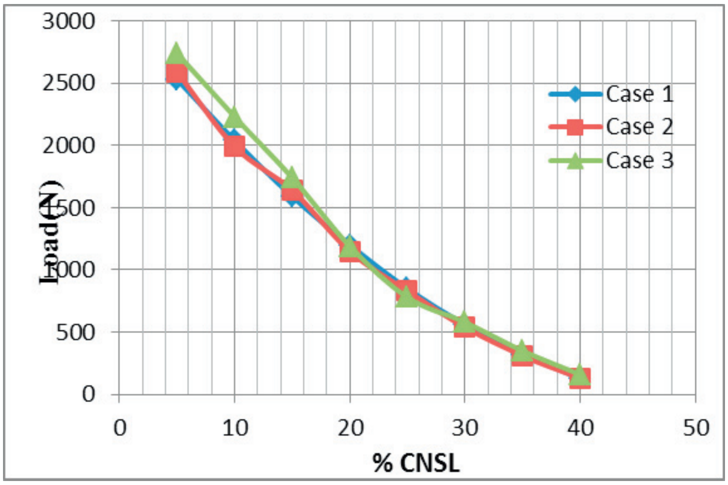


c

Fig 9(a)-(c). 3 cases of fibre length for 20% fibre volume fraction



a



b

Fig. 10 Comparison of maximum load for 3 different fibre length for (a) jute fibre with 20% fibre volume fraction (b) banana fibre composites with 3.5% volume fraction.

Composites are prepared for various volume fraction of fibre from 10 % to 40 % to study its influence. It is concluded from figure 11 that as volume fraction of fibre in composite increases, maximum load at which composites can bear also increases. The results can be validated from the literature which concludes that as fibre vlume fraction increases upto 47% the mechanical property of fibre reinforced composite increases and hence load at break also increases [11].

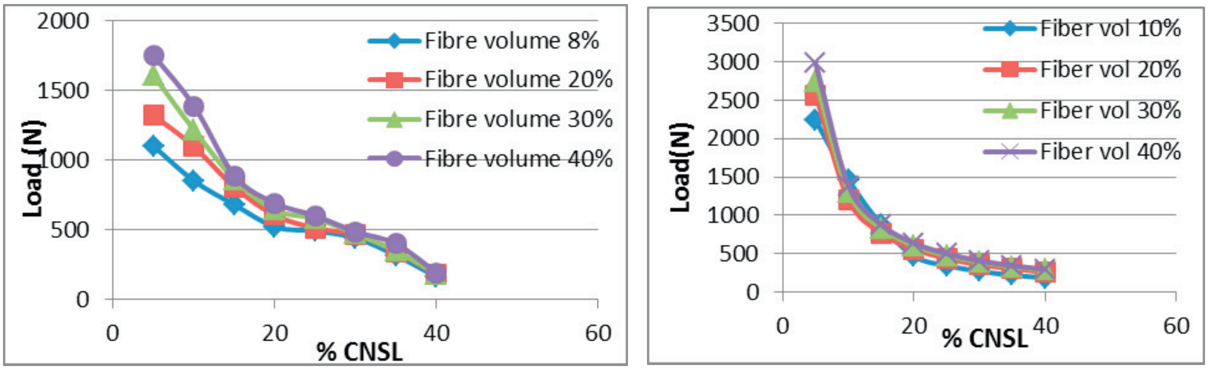


Figure 11. Comparison of Maximum load cases for varying Fibre volume fraction in composite for (a) jute fibre composites (b) banan fibre composites.

5.Optimization of Parameters by ANOVA technique

Optimization technique is carried out to find the optimum combination of parameters giving the best result of maximum load withstanding capacity at break, by considering 3 factors such as fibre volume fraction with 3 levels 20%, 30% and 40%, CNSL% with 3 levels 5%,10% and 15% and also 3 levels of fibre length. Design and analysis of experiments (DOE) using Taguchi method is followed to find the number of analysis. L9 orthogonal array is taken, as given in table 1 and table 2. Minitab software is used to obtain the regression equation and corresponding plots.

L9 Array	**Factor 1** CNSL%	**Factor 2** Fibre volume fraction %	**Factor 3** Fibre length	**Response** Maximum load (N)
1	5	20	1	1321
2	5	30	2	1560
3	5	40	3	1630
4	10	20	2	1085
5	10	30	3	1050
6	10	40	1	1388
7	15	20	3	660
8	15	30	1	862
9	15	40	2	880

Table1. L9 orthogonal array with 3factors, 3 levels each and response.

L9 Array	Factor 1 CNSL %	Factor 2 Fiber Vol. fraction	Factor 3 Fiber length	Response Max. Load(N)
1	5	10	1	2245
2	5	20	2	1578
3	5	30	3	1289
4	10	10	2	1200
5	10	20	3	991
6	10	30	1	525
7	15	10	3	814
8	15	20	1	635
9	15	30	2	520

Table 2. L9 orthogonal array with 3factors, 3 levels each and response.

Figures 12 and 14 present the main effect plot for SN ratios, which is selected by recommending higher the best results for jute and babana fibre composites. It is palpable from these figures that the combination of lowest CNSL%, maximum fibre volume fraction and first case of fibre length directs to maximum load where composite fails. Figures 13 and 15 explain the contour plot with fibre volume fraction in x axis and CNSL % in y axis, which also infers that lowest CNSL% with highest fibre volume fraction has highest maximum load at failure capacity for jute and banana fibre composites. From the regression equations (1) and (2), maximum load for different parameters at 3 different levels can be obtained.

Maximum Load (N) = 1388 - 70.3 *(% CNSL) + 13.9*(Fibre volume fraction %) + 0.799*(Fibre Length (mm)). (1)

Maximum Load(N)= 2882-105*(%CNSL)+32.1*(Fibre volume fraction%) -51.8*(Fibre Length (mm)). (2)

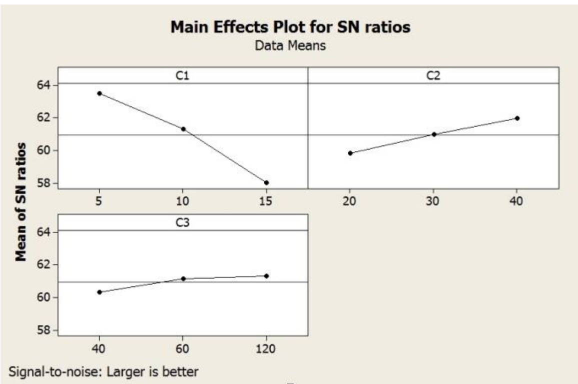


Fig. 12. Main effect plot for SN ratios

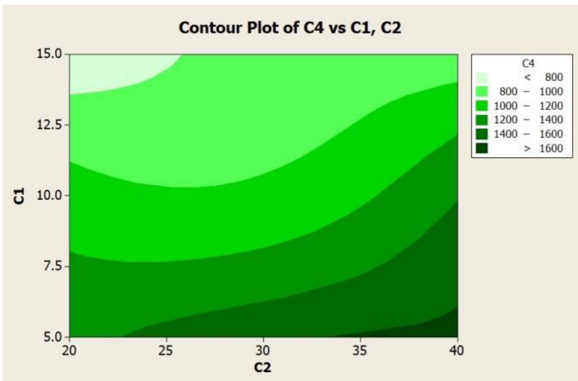


Fig. 13. Contour plot showing maximum load carrying level for selected factor.

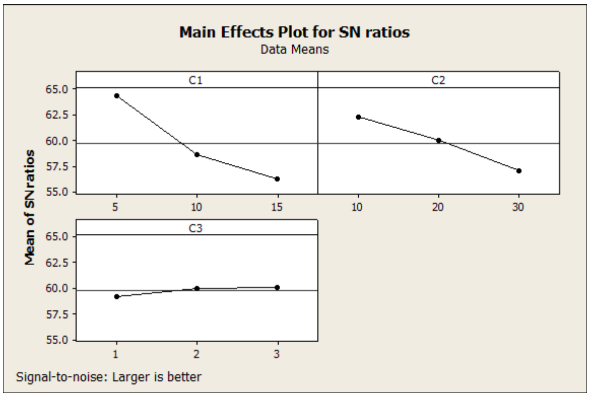


Fig. 14. Main effect plot for SN ratios

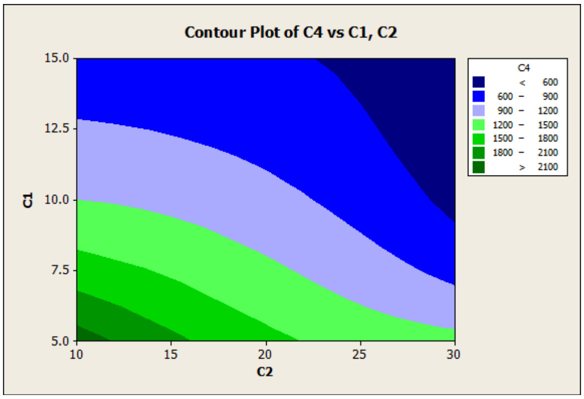


Fig. 15. Contour plot showing maximum load carrying level for selected factor.

6.Conclusions

A new set of jute and banana fibre hybrid polymer matrix composite, combination of varying CNSL and general purpose resin matrix is obtained whose tensile strength is calculated at various combinations and best results are obtained using ANOVA technique. This natural fibre hybrid polymer matrix can replace many synthetic resin composites considering the recyclability and cost factors.

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