INVESTIGATION ON FATIGUE STRENGTH OF THE JUTE FIBER REINFORCED HYBRID POLYMER MATRIX COMPOSITES

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The requirements of bio-composites for the structural applications are high strength and high stiffness. Due to the anisotropic nature of composite by the reinforcement of fiber, it is a challenging process to develop highly efficient composites. The optimized design criteria for the development of bio-composites depend on the life time expectancy of the components to be designed. Hence it is required to evaluate the composites failures at cyclic fatigue loading. In this work, fatigue failure of newly developed jute fiber reinforced hybrid polymer composites was analyzed to optimize the composition parameters. The hybrid polymer is prepared with the mixture of cashew nut shell liquid (CNSL) resin and polyester resin for the improvement of biocompatibility of the composite developed. The experimental investigations on various samples of composites give a promising solution for the fatigue failure of the specifically produced composite specimen.

Keywords: optimized design, fatigue failure, jute fiber, hybrid resin.

1. Introduction

There is a growing interest among engineering industries for the application of bio polymer composites as an alternate material for engineering materials [1]. Hence studies and investigation are being undertaken by researchers to develop new class of bio-composite materials. The bio-composites use natural fibers as reinforcement materials. The natural fibers are made up of cellulose, hemicelluloses, pectin, and lignin [2]. They are found in earth abundantly and its cost is less compared to the synthetic fibers of which some of them are hazards in nature [3]. Generally used matrix materials in bio-composites are petroleum based resins. There are certain limitations in mechanical properties of the composites while using natural resin as matrix materials [4]. Hence the present investigation is aimed to develop a new hybrid matrix material for the composite material. The hybrid matrix material will enhance the eco compatibility of composites without compromising the properties of the composite material [5].

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The property enhancement of polymer composites was achieved through controlling the reinforcement fiber parameter values and matrix composition [6] [7] [8]. Whenever developing a new class of materials for the properties enhancement, it is required to establish design criteria for the material development [9]. After development of material, the design criteria should be evaluated by the suitable experimentation [10]. The failure analysis of the material based on the experimental results will give the suitability of the material for the intended use. While designing a structure for the engineering use, it is mandatory to estimate the failure stresses and properties of the materials such as strength, stiffness, specific strength and specific stiffness, fatigue and toughness, etc. [11]. The properties of the composites can be enhanced by controlling the factors such as volume fraction of fibers, aspect ratio of fiber, dispersion of fibers and fiber orientation in matrix, volume fraction of matrix resin, etc. [12]

The composite materials are inhomogeneous in nature and are anisotropic. Hence the fatigue failure modes of the composites are complex in nature [13]. The number of cycles to failure depends on a number of variables such as stress levels, stress state, mode of cycling, process history, material composition and environmental conditions [14]. The fatigue tests on polymer composites are conducted for the recommendations of load level, allowable design stress and to find safety factors for a structure in defined or the predicted service life of the structure or the components [15].In this paper, fatigue strength of jute fiber reinforced hybrid polymer is investigated.

2.0 Experimental

2.1. Materials

2.1.1. Jute fibers

Bio composites are using natural fibers which are from the natural resources like plants (vegetable) or from animal as reinforcement fiber. The advantages of using natural fibers in composites are the cost of materials, eco-friendly, their sustainability, density, and available in abundant on earth. Some examples of natural fibers are cotton, coir, hemp, flax, jute, kenaf, sisal, and abaca. Of these fibers, jute, flax, hemp and sisal are the most commonly used fibers as reinforcement material in polymer composites [16].

The natural fiber chosen for the investigation as reinforcement material is jute fiber which is the cheapest and most abundantly available natural fibers in India. It is mainly composed of plant materials like cellulose and it can be spun into coarse or strong threads. Retting process is used to separate the fiber from the stem of the plant. The major types of retting are mechanical retting, chemical retting, steam retting, and water or microbial retting. The retted fibers are then dried in open air by using mechanical means [17].Further the jute fiber procured with above conditions is treated by alkali solutions like NaOH for the improvement of structural characteristics and is used in the composite as reinforcement materials.

2.1.2. Hybrid Polymer

Recent researches focus the use of thermosetting and a thermo polymer as matrix materials in bio-composites, as the natural resins availability is poor and its cost is high. One of the commonly used petroleum based polymer, used as matrix material in polymer composites is polyester resin. To improve the biodegradation of the polymer composite, various volume fractions of the natural resin extracted from cashew nut shell (cashew nut shell resin – CNSL) is mixed with polyester resin. This resin mixture mixed with hardener at room temperature to obtain optimum matrix composition and was used as the matrix material for the present research study.

2.2. Preparation of composites

The composites specimens are prepared by the conventional composite manufacturing process. Hand layup technique is followed for the preparation of composites. The fibers are knitted as shown in the figure 1.After the knitting of fiber in the mold, the resin mixture is poured in mold cavity. The mold is kept at room temperature up to cured stage.

Fig.1. Mold Preparation

Fig.2. Specimens for testing

The specimens for the testing are prepared with various constituents material parameter. The parameter values are determined by design of experiments procedure. The fiber and matrix composition of the specimens prepared are given in the table.1 and the molded specimen are shown in Fig. 2.

Table.1

Specimen Composition

Sample No	CNSL% in Matrix	Duration Alkali (NaOH)Treatment in hours	Fiber Volume Fraction (%)
1	5	6	5
2	5	12	10
3	5	24	15
4	10	6	10
5	10	12	15
6	10	24	5
7	15	6	15
8	15	12	5
9	15	24	10

The dimensions and size of the test specimens are prepared according to the ASTM standard D3479 M. The schematic diagram of the specimen is given in the Fig. 3.

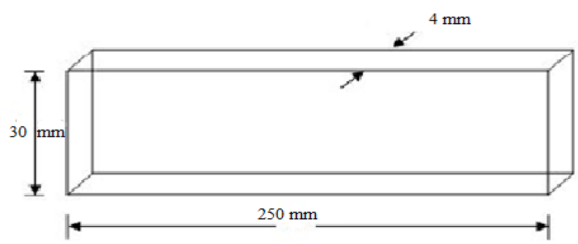

Fig.3. Specimen dimensions

2.3. Fatigue tests

The specimens for the fatigue test are prepared for the different composition and are tested using Instron universal testing machine as shown in figure 4. The test is conducted with the stress ratio of -1, amplitude of 5 kN and frequency of 5 Hz. The number of cycles of stress that a specimen sustains before failure occurs are recorded and given in the table 2.

Table 2.

No Cycles of load to the failure of samples

Sample No	No of cycles to Fail
1	5094
2	7175
3	7595
4	4113
5	4168
6	2869
7	2879
8	1723
9	2646

Fig.4. Fatigue test setup

3.0 Results and Discussion

3.1 Fatigue behavior of jute fiber reinforced hybrid matrix polymer composite

The objective of the study is to increase the fatigue life of composite with the suitable fiber and resin compensation. The fatigue behavior of the CNSL hybrid resin and jute fiber reinforced polymer composites followed the typical characteristics as given in the Fig. 5.

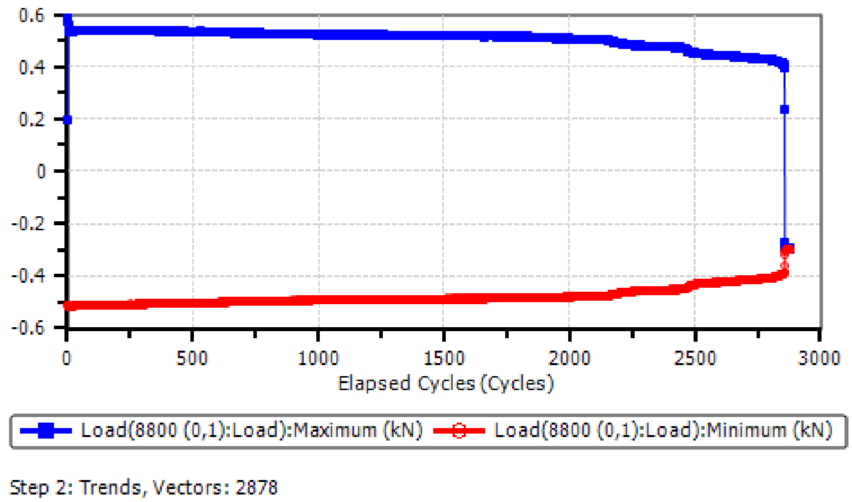

Fig.5 Fatigue characteristics of the hybrid polymer composite

Failure of materials at various cycles of load for the different material composition reveals that the composite material composition has significant influence on the fatigue life of materials. The comparisons of number of cycles of stress that a specimen sustains before failure occurs with different composite specimens are plotted as shown in the figure 6.

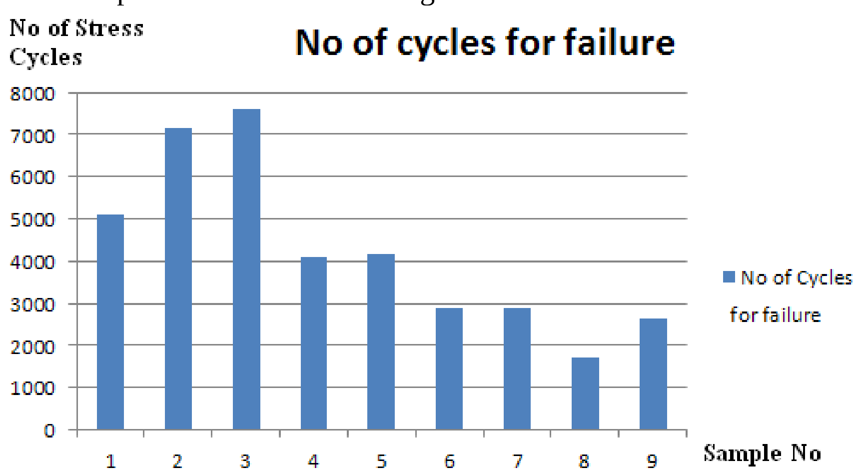

Fig.6. Analysis of Fatigue life of different composite specimens

The results of the fatigue test show that for the lower volume fraction of CNSL in resin matrix, higher fatigue life is achieved with increased fiber volume and fiber treatment duration. While increasing the CNSL percentage in resin matrix the fatigue life is decreased, but it is well compensated with increased volume of reinforcement fiber. Hence, it is found from the analysis that the loss of fatigue by the addition natural resin could be compensated by controlling various fiber parameters.

3.2 Study of influence of Resin and Fiber Parameters on Fatigue life by Taguchi's Design of Experiment techniques.

When a product or process design is influenced by various parameters, it can be optimized by different statistical techniques. Taguchi's model for the optimization is based on the loss function. Hence, the above composite composition is optimized for the better fatigue life by Taguchi's methods. The results obtained from the fatigue test are analyzed using Minitab software and results obtained are given in the figures 7 (a) – 7 (e).

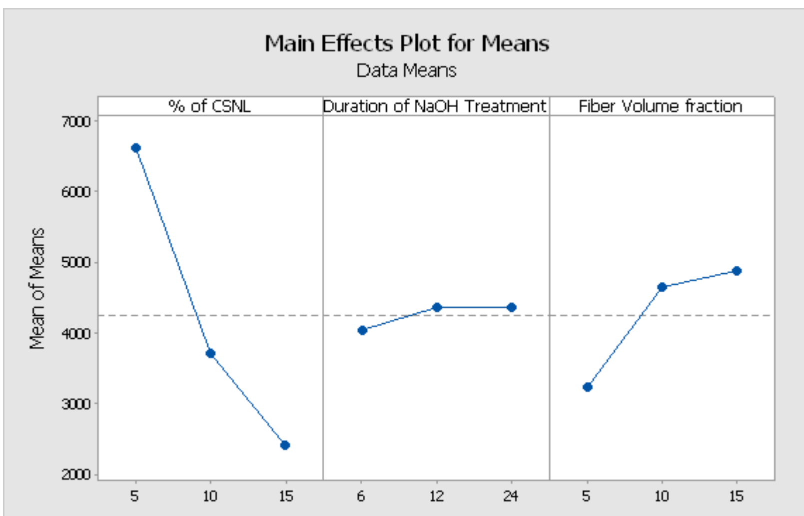

Fig.7 (a). Main Effects Plots for Mean Fatigue life

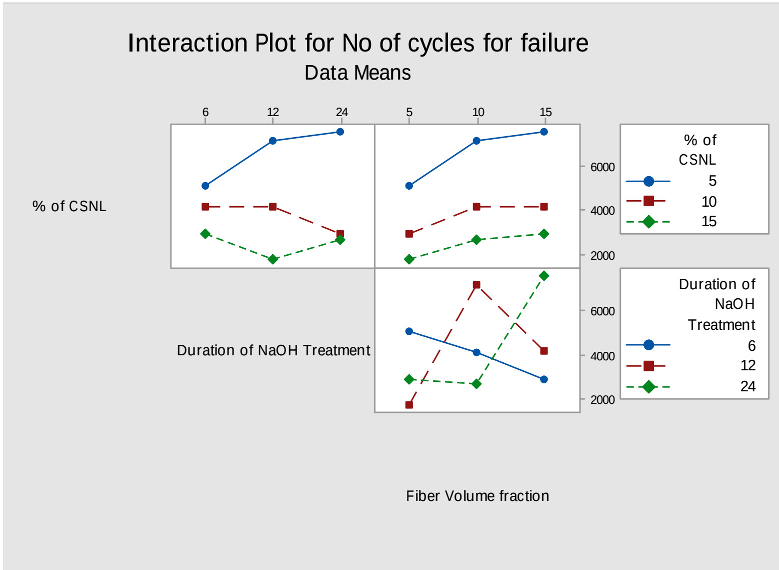

Fig.7 (b). Interaction Plots of fatigue life

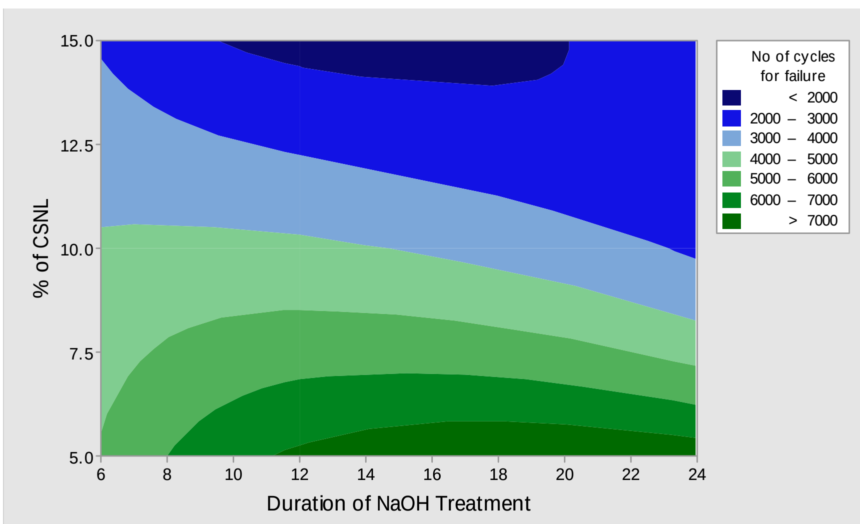

Fig.7 (c). Contour Plots for studying the influence of % of CNSL and duration of NaOH treatment on Fatigue life

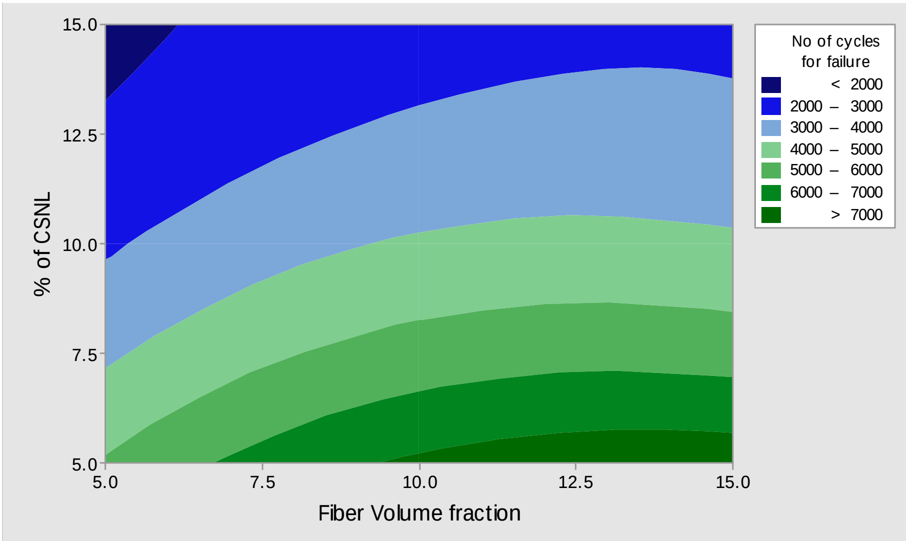

Fig.7 (d). Contour Plots for studying the influence of % of CNSL and fiber volume fraction on Fatigue life

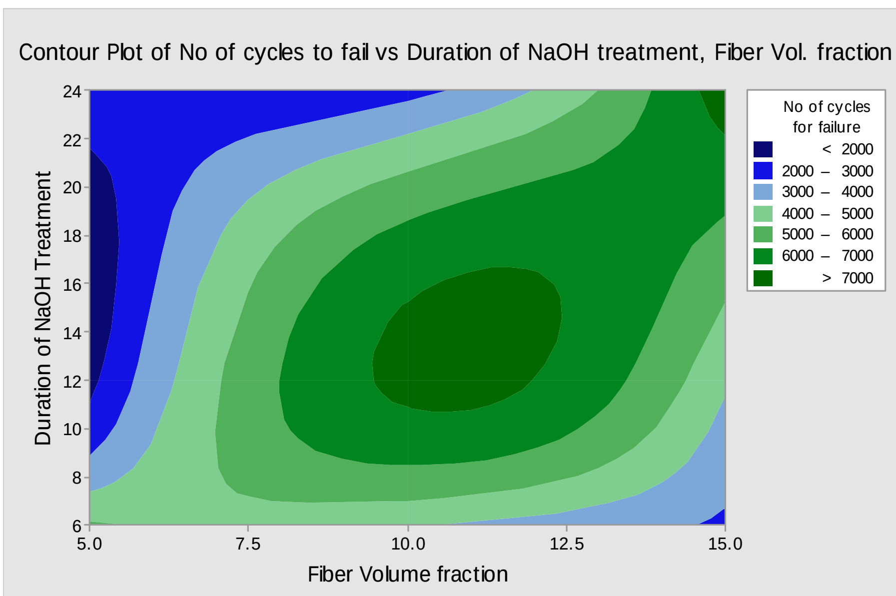

Fig.7 (e). Contour Plots for studying the influence of duration of NaOH treatment and fiber volume fraction on Fatigue life

The figure 7(a) shows that increase in CNSL fraction in hybrid polymer matrix reduces fatigue strength of the composite specimen. The average fatigue strength can be achieved with 5% to 10% CNSL composition in hybrid polymer matrix system. NaoH treatment of jute fiber influences less on fatigue strength. The fatigue strength of the composites is around the mean values with increase in NaOH treatment duration. The fatigue strength is above the average values for the fiber volume fractions of 10% and 15%.

The interaction plots between different design factors are given in the figure 7(b) and the following combinations of design factors are considered.

- % of CNSL and duration of NaOH treatment,
- % of CNSL and fiber volume fractions and
- Duration of NaOH treatment and fiber volume fractions.

It is found from the interaction plot that the fatigue life was increasing with hybrid polymer matrix composite of 5% CNSL concentration with increase of NaOH treatment duration. The fatigue life decreases considerably for 10% CNSL concentration hybrid polymer matrix with 24 hours NaOH treatment duration of jute fiber and also this value matches with the value of fatigue life for 15% CNSL concentration hybrid polymer matrix and 24 hours NaOH treatment duration of jute fiber. The analysis of interaction between fiber volume fraction and %CNSL reveals that the fatigue strength is increasing with the increase of fiber volume fraction for the all values of %CNSL. However, it is decreasing while increasing the %CNSL in hybrid polymer matrix. The study of interaction between duration of NaOH treatment of fiber and fiber volume fraction in composite reveals that the fatigue strength is high when duration of NaOH treatment is 12 hours with fiber the volume fraction of 10% and NaOH treatment duration of 24 hours with the fiber volume fraction of 15%.

The contour plots presented in figures 7(c) – 7(e) show the range of design factor values which gives higher fatigue strength. The fatigue strength is higher while the CNSL % in hybrid polymer matrix is 5% to 7% and duration of NaOH treatment is 8 hours to 24 hours. Similarly, it is higher while CNSL % in hybrid matrix is 5% to 7% and fiber volume fraction is 7.5% to 15%. It is evident from the contour plot between NaOH treatment duration and fiber volume fraction that the fatigue strength is higher for the jute treatment duration of 12 hours to 16 hours and 8 % to 12.5% volume fraction of jute fiber in the composite specimen.

In a nutshell, from the analysis it is found that lower the percentage of CNSL in hybrid polymer matrix and higher the duration of alkali treatments give higher fatigue life and lower the percentage of CNSL in the matrix phase and higher the fiber volume in the composite give higher fatigue life. The factors duration of alkali treatment and fiber volume have equal contribution for the enhancement of fatigue life of the composite specimen.

4. Conclusion

In this study, the fatigue behavior of the newly developed hybrid polymer composite is studied based on the Taguchi's design of experiment. The specimens made from hybrid polymer with jute fiber as reinforcement, are as tested for fatigue strength and are found that the fatigue could be improved by controlling the fiber constituent's parameters for the increased fatigue life. Also it is concluded that the hybrid polymer composite with jute fiber could be used in the industrial applications of automotive and consumer goods where the components are under the operation of moderate cyclic loadings.

R E F E R E N C E S

[1] *Akovali G.* Handbook of composite fabrication. United Kingdom: Rapra Technologies Limited; 2001.

[2] *Jaouadi Mounir, M'sahli Slah, Sakli Faouzi*. Optimization and characterization of pulp extracted from the Agave americana L. fibers. Text Res J 2009;79:110.

[3] *O_Donnell A, Dweib MA, Wool RP*. Natural fiber composites with plant oil-based resin. Compos Sci Technol 2004;64(9): 1135–45.

[4] *Joseph PV, Joseph Kuruvilla, Thomas Sabu*. Effect of processing variables on the mechanical properties of sisal-fiber-reinforced polypropylene composites. Compos Sci Technol 999;59: 1625–40.

[5] *Mahmoodul Haq , Rigoberto Burgueño , Amar K. Mohanty, Manjusri Misra*, Hybrid bio-based composites from blends of unsaturated polyester and soybean oil reinforced with nanoclay and natural fibers, Composites Science and Technology 68 (2008) 3344–3351

[6] *Ho M, Lau K*. Design of an impact resistant glass fibre/epoxy composite using short silk fibre. Mater Des 2012;35:664–9.

[7] *Imai M, Akiyama K, Tanaka T, Sano E*. Highly strong and conductive carbon nanotube/ cellulose composite paper. Compos Sci Technol 2010;70(10):1564–70.

[8] *Khalid M, Ratnam CT, Chuah TG, Ali S, Choong T.* Comparative study of polypropylene composites reinforced with oil palm empty fruit bunch fiber and oil palm derived cellulose. Mater Des 2008;29(1):173–8.

[9] *B. Csukás, M. Varga, S. Balogh, N. Miskolczi, A. Angyal, L. Bartha, H. Szakács, Cs. Varga*, Knowledge based model for polymer composite design and production Original Research Article, Materials & Design, Volume 38, June 2012, Pages 74-90.

[10] *M. Alemi-Ardakani, A.S. Milani, S. Yannacopoulos, G. Shokouhi* , A multi criteria experimental analysis of impact on fiber reinforced polymer composite laminates Original Research Article Materials Today Communications, Volume 4, September 2015, Pages 6-15

[11] *R.M. Guede*s, 12 - Time-dependent failure criteria for lifetime prediction of polymer matrix composite structures Creep and Fatigue in Polymer Matrix Composites, 2011, Pages 366-405

[12] *Hoi-yan Cheung , Mei-po Ho, Kin-tak Lau, Francisco Cardona , David Hui* , Natural fibre-reinforced composites for bioengineering and environmental engineering applications, Composites: Part B 40 (2009) 655–663

[13] Mechanical Testing of Advanced Fibre Composites, By J. M. Hodgkinson, Woodhead Publishing.

[14] *D Ray, B.K Sarkar, N.R Bose* Impact fatigue behavior of vinyl ester resin matrix composites reinforced with alkali treated jute fibres, Composites Part A: Applied Science and Manufacturing, Volume 33, Issue 2, February 2002, Pages 233-241

[15] *Jochen Gassan, Andrzej K. Bledzki,* Possibilities for improving the mechanical properties of jute/epoxy composites by alkali treatment of fibres, Composites Science and Technology, Volume 59, Issue 9, July 1999, Pages 1303-1309.

[16] *Nabi Saheb, D. & Jog, J.P.* Natural fiber polymer composites: Review. *Adv. Polym. Technol.*, 1999, **18**(4), 351-63.

[17] *Gowda, T.M., Naidu, A.C.B. and Chhaya, R.* (1999), some mechanical properties of untreated Jute fabric reinforced polyester composites, Composites: Part A, Vol. 30, pp. 277–284.