International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Physical and Mechanical Behavior of Al_2O_3 Filled Jute Fiber Reinforced Epoxy Composites

Priyadarshi Tapas Ranjan Swain[Ȧ*] and Sandhyarani Biswas[Ȧ]

[Ȧ]Department of Mechanical Engineering, National Institute of Technology, Rourkela, 769008, Odisha, India

Accepted 16 January 2014, Available online 01 February 2014, **Special Issue-2, (February 2014)**

Abstract

Now-a-days, the use of natural fiber reinforced composites starts gaining popularity in many applications due to the fact that this material possesses characteristics that are comparable to conventional materials. Among natural fibers, jute has been widely used for many such applications due to its availability, low cost and satisfactory mechanical properties. The objective of the present work is to study the physical and mechanical behavior of jute fiber reinforced epoxy composites filled with Al_2O_3 particulate. The composites with different fiber and filler loading are fabricated using simple hand layup technique. Experiments are carried out to study the effect of fiber and filler loading on the properties of composites. The experimental result shows that the presence of Al_2O_3 content significantly influences the physical and mechanical behavior of composites. It is also observed that the composite with 30 wt. % fiber loading shows better strength properties.

Keywords: *Jute fiber, Al_2O_3, Epoxy, Mechanical properties*

1. Introduction

Over the past few decades, natural fibers have been receiving considerable attention as the substitute for synthetic fiber reinforcement in polymers. Compared with conventional glass fibers or carbon fibers, plant fibers have many advantages like renewable, environmental friendly, low cost, lightweight, high specific mechanical performance. Natural fibers such as kenaf (Nishino, *et al*, 2003), bagasse (Sousa, *et al*, 2004), jute (Gowda, *et al*, 1999), (Ray, *et al*, 2001),(Gassan, *et al*, 2002),(Khan, *et al*, 2006),(Khan, *et al*, 2006),(Khan, *et al*, 2005), ramie, oil palm (Wollerdorfer, *et al*, 1998) and hemp (Keller, *et al*, 1998) have been investigated as reinforcements for fiber reinforced polymers. Natural fibers can be used as an alternatives of synthetic fibers e.g. aramid, glass, carbon, etc. (Fardausy, *et al*, 2012). Among various natural fibers, jute has been widely used for various applications due to its many advantages. Jute seems to be a promising fiber due to its high aspect ratio and toughness in comparison to other natural reinforcement. Fabrics of jute fibers are easily available. Bi-directionality of the fabric offers resistance to transverse forces or cracking and hence stable properties are obtained. The incorporation of filler into polymer has been proved to be an alternative for the improvement of the performance the resultant composites. Hybridization of fiber with fillers has been used to enhance the properties of composites. A judicious selection of matrix and the reinforcing phase can lead to a composite with a combination of strength and modulus comparable to or even better than those of conventional metallic materials. The improved performance of polymers and their composites in industrial and structural applications by the addition of particulate filler materials has shown a great promise and so has lately been a subject of considerable interest. Specific fillers (additives) are added to enhance and modify the quality of composites. The objective of the present work is to study the physical and mechanical behaviour of jute fiber reinforced epoxy composites filled with Al_2O_3 particulate filler.

2. Experimental details

2.1 Materials

The bi-directional jute fiber and Al_2O_3 is taken as the reinforcement and epoxy is taken as matrix material in the present study. The jute fiber is collected from local sources and the Al_2O_3 is obtained from NICE Ltd India in a range of 80-100 μm. The epoxy resin and the corresponding hardener HY-951 is supplied by Ciba Geigy India Ltd.

2.2 Composite Fabrication

The fabrications of composite slab are carried out by conventional hand layup technique. The low temperature curing epoxy resin and corresponding hardener are mixed in a ratio of 10:1 by weight as recommended by the manufacturer. Composites with five different fiber loading

*Corresponding author: **Priyadarshi Tapas Ranjan Swain**

DOI: http://dx.doi.org/10.14741/ijcet/spl.2.2014.13

(0 wt. %, 10 wt. %, 20 wt. %, 30 wt. % and 40 wt. %) with four different filler loading (0 wt. %, 5 wt. %, 10 wt. %, 15 wt. %) were fabricated and subjected to post-curing at room temperature for 24 hours. The detail designation and composition of composites are given in Table 1. Finally, the composites were cut to the required dimensions as per the standards for the evaluation of physical and mechanical properties.

Table 1 Designation and detailed composition of the composites

Designation	Compositions
C1	Fiber (10%)+ Filler(0%)+Epoxy(90%)
C2	Fiber (20%)+ Filler(0%)+Epoxy(80%)
C3	Fiber (30%)+ Filler(0%)+Epoxy(70%)
C4	Fiber (40%)+ Filler(0%)+Epoxy(60%)
C5	Fiber (10%)+ Filler(5%)+Epoxy(85%)
C6	Fiber (20%)+ Filler(5%)+Epoxy(75%)
C7	Fiber (30%)+ Filler(5%)+Epoxy(65%)
C8	Fiber (40%)+ Filler(5%)+Epoxy(55%)
C9	Fiber (10%)+ Filler(10%)+Epoxy(80%)
C10	Fiber (20%)+ Filler(10%)+Epoxy(70%)
C11	Fiber (30%)+ Filler(10%)+Epoxy(60%)
C12	Fiber (40%)+ Filler(10%)+Epoxy(50%)
C13	Fiber (10%)+ Filler(15%)+Epoxy(75%)
C14	Fiber (20%)+ Filler(15%)+Epoxy(65%)
C15	Fiber (30%)+ Filler(15%)+Epoxy(55%)
C16	Fiber (40%)+ Filler(15%)+Epoxy(45%)

2.3 Physical and Mechanical Tests

For the composite materials, theoretical density can be obtained in terms of weight fraction calculated by the use of the following equation (Agarwal, *et al,* 1990).

$$\rho_{ct} = \frac{1}{(W_f/\rho_f)+(W_m/\rho_m)} \quad (1)$$

Where, W and ρ represent the weight fraction and density correspondingly. The suffix f, m and ct stand on behalf of the fiber, matrix and the composite materials respectively. The composites under this investigation consists of three components namely matrix, fiber and particulate filler. Therefore the modified form of the expression for the density of the composite can be written as

$$\rho_{ct} = \frac{1}{(W_f/\rho_f)+(W_m/\rho_m)+(W_p/\rho_p)} \quad (2)$$

Where, the suffix '*p*' indicates the particulate filler materials.

The actual density (ρ_{ce}) of the composite can be obtained experimentally by simple water immersion technique. The volume fraction percentage of voids (V_v) in the composites is calculated by the following equation:

$$V_v = \frac{\rho_{ct}-\rho_{ce}}{\rho_{ct}} \quad (3)$$

Leitz micro-hardness tester is used to found out micro-hardness measurement. A diamond indenter, in the form of a right pyramid with a quadrangular base and an angle 136° among reverse faces, is pressed into the material under a load F. Two diagonals X and Y of the indentation left on the surface of the material after removal of the load are measured and their arithmetic mean L is calculated. In the current study, the load considered F = 24.54N and Vickers hardness number is calculated using the following equation.

$$H_V = 0.1889\frac{F}{L^2} \quad \text{and} \quad L = \frac{X+Y}{2} \quad (4)$$

Where F is the applied load (N), L is the diagonal of square impression (mm), X is the horizontal length (mm) and Y is the vertical length (mm).

The tensile test is generally performed on flat specimens. A uniaxial load is applied through both the ends of the composite samples. The ASTM standard test method for tensile properties of fiber resin composites has the designation D 3039-76. The tensile test is conducted using universal testing machine Instron 1195 and results are analyzed to calculate the tensile strength of composite samples. The flexural strength of a composite is determined by the maximum tensile stress that it can withstand during bending before getting the breaking point. Three point bend test was performed to understand the flexural behaviour of composites using universal testing machine (Instron 1195). The span length of 40 mm of specimen and the cross head speed of 10mm/min are maintained. The short beam shear tests are performed on the composite samples at room temperature to evaluate the value of inter-laminar shear strength (ILSS). Inter-laminar shear test is also performed on Instron 1195. The flexural strength of any composite specimen is determined using the following equation:

$$FS = \frac{3PL}{2bt^2} \quad (5)$$

Where L is the span length P is maximum load, b is the width of the specimen, and t is the thickness of the specimen. The ILSS values are calculated as:

$$ILSS = \frac{3P}{4bt} \quad (6)$$

3. Results and discussion

3.1 Density

The theoretical and experimental densities of the composites along with the corresponding volume fraction of voids are obtainable in Table 2. It is observed that the composite density values are calculated theoretically from weight fractions by Eq. (1) are not equal to the experimentally measured values. This difference is due to the presence of voids and pores in the composites. The observation shows that more voids are found in the composites with the addition of fiber as well as filler material.

As the fiber content increases from 0 wt.% to 10 wt.% , 10 wt.% to 20 wt.%, 20 wt.% to 30 wt.% and 30wt.% to 40 wt.% the volume fraction of void is found to be increasing. Similar trend is also noticed in case of increasing filler content.

Table 2 Comparison between Experimental density and Theoretical density

Fiber Loading (wt. %)	Filler Loading (wt. %)											
	0			5			10			15		
	ρ_{ct} (gm/cc)	ρ_{ex} (gm/cc)	Δv (%)	ρ_{ct} (gm/cc)	ρ_{ex} (gm/cc)	Δv (%)	ρ_{ct} (gm/cc)	ρ_{ex} (gm/cc)	Δv (%)	ρ_{ct} (gm/cc)	ρ_{ex} (gm/cc)	Δv (%)
10	1.163	1.145	1.569	1.206	1.165	3.432	1.253	1.188	5.175	1.304	1.226	5.981
20	1.177	1.155	1.889	1.221	1.178	3.519	1.269	1.197	5.646	1.321	1.237	6.359
30	1.191	1.164	2.267	1.236	1.188	3.982	1.285	1.21	5.768	1.339	1.245	7.02
40	1.205	1.173	2.656	1.252	1.195	4.536	1.302	1.221	6.221	1.357	1.258	7.295

Density of a composite material depends on the relative proportion of reinforcing and matrix materials and it is one of the key factors in determining the properties of the composites. The void content is the reason for the difference between the values of theoretically calculated density and experimental one. The voids considerably affect some of the mechanical properties and even the performance of composites in the workplace. It is understandable that a good composite should have fewer voids. Presence of void is unavoidable in composite making particularly through hand-lay-up route.

3.2 Micro-hardness

Fig. 1 depicts an increase in hardness value of composites with the increase in fiber as well as filler loading. Presence of fiber in the matrix body results in improving the hardness of the composites (Gupta, et *al*, 2011), (Oksman, *et al*, 2000). This is because hardness is a function of the relative fiber volume and modulus (Ferrigno, *et al*, 1978). The increase in hardness value with the filler loading is reported by researchers in case of glass-epoxy hybrid composites reinforced with SiC particles (Satapathy, *et al*, 2010). It can be explained as in case of hardness test, a pressing or compression stress is in action.

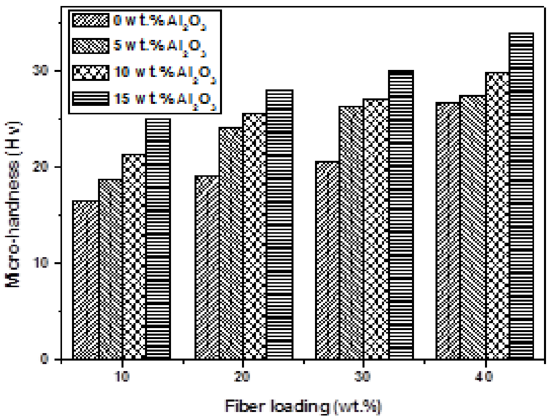

Fig.1 Effect of fiber and filler loading on hardness of composites

Thus, the polymeric matrix phase and solid filler phase would be pressed together and touch each other more closely. Therefore the interface can transfer pressure more efficiently although the interfacial bond may be weak. This may resulted in improvement of hardness.

3.3 Tensile strength

It is well known that the strength properties of composites are mainly determined by the fiber content and the fiber strength. Thus, deviation in composite strength with different fiber loading is understandable. The tensile strength increases with the increase in fiber loading upto 30 wt. % fiber loading then decrease with further increase in fiber loading, as shown in Fig. 2. This increased strength clearly indicates the improvement in load bearing capacity of the composites up to 30 wt. %. It may be due to the fact that the epoxy resin transmits and distributes the applied stress to the jute fibers resulting in higher strength.

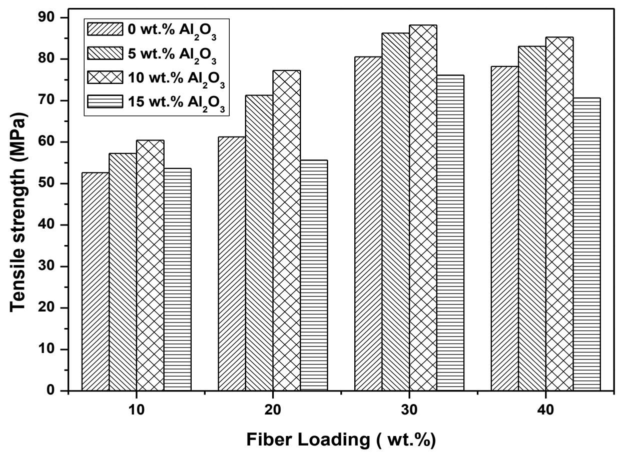

Fig.2 Effect of fiber and filler loading on tensile strength of composites

The decrease in tensile strength beyond 30 wt. % fiber loading is due to increased interaction between the fibers inside the composites i.e. there will be higher fiber to fiber contact which leads to poor interfacial bonding between the matrix and the fiber. Because of the poor interfacial bonding effective load transfer will not take place and lead to quick failure. Fig. 2, also indicates an improvement in tensile strength of the composite with the addition of filler upto 10 wt. %. At higher wt. % of filler i.e. 15 wt. %, a decrease in tensile strength of composites in noticed this may be due to improper bonding resulting in poor interface adhesion between the epoxy matrix and filler. The higher filler content also leads to difficulty in stirring process and hence uniform distribution of filler in the laminate cannot be confirmed.

3.4 Tensile Modulus

From Fig. 3, it is observed that the tensile modulus of composites increased with an increase in fiber loading. This is because with an increase in fiber loading, the brittleness of the composite increased and stress/strain curves becomes steeper. Poor interfacial bonding produces partially separated micro spaces which hinder stress propagation between the matrix and the fiber (Siddika, *et al*, 2013). As the fiber content increases, the degree of hindrance increases, which in turn results in increased stiffness. The tensile modulus of Al_2O_3 filled jute-epoxy composites increases as the wt. % of the filler increases. Tensile modulus increases with the addition of filler in hybrid composite (Raju, *et al*, 2012). As Al_2O_3 filler is hard and brittle there may be a reduction in the elongation at break of composites with increase in the weight fraction of the filler. Thus, the increase in weight fraction of filler leads to increase in the tensile modulus of the jute-epoxy composites, but at the same time the system becomes more brittle.

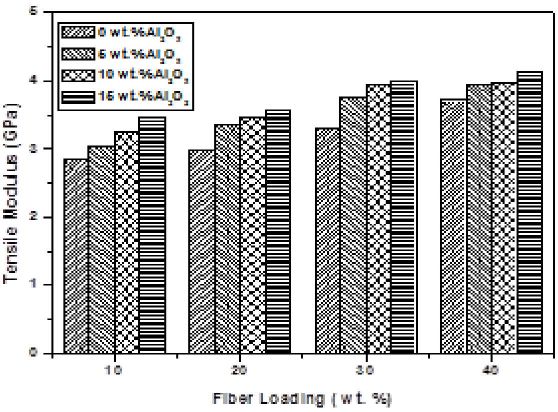

Fig.3 Effect of fiber and filler loading on tensile modulus of composites

3.5 Flexural Strength

The flexural strength of composites increases up to 30 wt. % fiber loading and further increase in fiber loading it decreases as shown in Fig. 4. Similar results are reported elsewhere for jute/ low density polyethylene composites (Miaha, *et al*, 2011). The initial increase in the flexural strength upto 30 wt. % fiber loading is mainly attributed to reinforcing effect imparted by the fibers, which allowed a uniform stress distribution from continuous matrix phase to dispersed fiber phase (Bozlur, *et al*, 2010). Above 30 wt. % fiber content, flexural decreased. This decrease in the flexural strength at high fiber content implied poor fiber-matrix adhesion which promoted micro-crack formation at the interface.

On the other hand the decrease in flexural strength at high fiber content (i.e. 40 wt. %) is due to poor fiber matrix

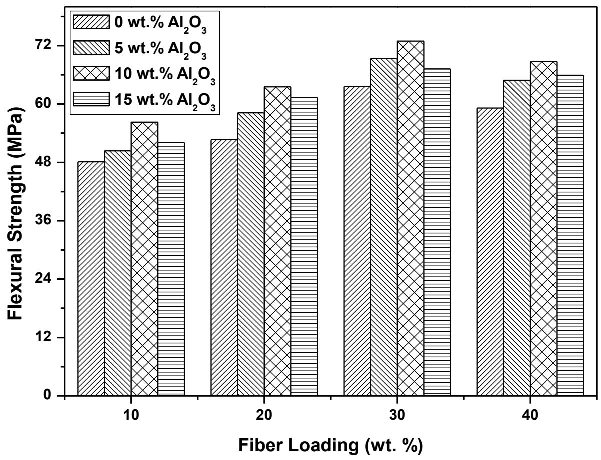

Fig.4 Effect of fiber and filler loading on flexural strength of composites

adhesion. The trend of increased flexural strength with increased filler content is similar to the result from tensile strength. Composite with 10 wt. % Al_2O_3 filler shows higher flexural strength than unfilled composites. The property of fillers to offers greater resistance to crack initiation and propagation in the composites may lead to the increased flexural strength in filled composites (i.e. upto 10 wt% filler). During flexural testing, different mechanisms like compression, tension, shearing etc. takes place simultaneously. In case of higher filler content the resistance to shearing decreases due to poor interfacial adhesion and the failure takes place due to shear (Ahmed, *et al*, 2011). The decrease in flexural strength at 15 wt% filler content is a signal of shear failure.

3.6 Inter-Laminar Shear Strength (ILSS)

Inter-laminar shear stress happens due to the stresses acting on the interface of two adjacent laminas. The stresses cause relative deformation between the lamina and if these are adequately high, they may cause failure along

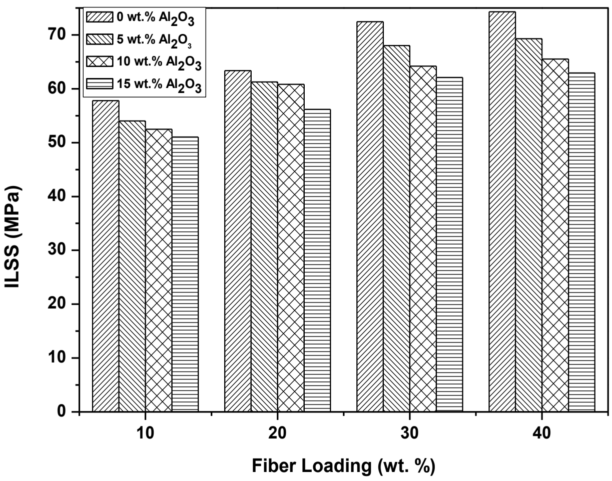

Fig.5 Effect of fiber and filler loading on ILSS of composites

the common plane between the laminar (Patnaik, *et al*, 2009). It is therefore of considerable interest to estimate inert-laminar shear strength through tests in which failure of laminates starts in a shear (delaminating) mode. From the Fig. 5, it is noticed that the ILSS of the composite increase with increase in fiber loading. But, with increase in filler content the ILSS of the composite decreases. This reduction may be due to the formation of voids in the matrix which is generally located at the inter-laminar region of composites.

Conclusions

The experimental study on the effect of fiber and filler loading on physical, mechanical behaviour of jute-epoxy and Al_2O_3 filled jute-epoxy composites leads to the following conclusions:

1) The successful fabrications of epoxy based composites reinforced with jute fiber and Al_2O_3 have been done.
2) The present investigation reveals that fiber and filler loading significantly effect on the different properties of composites.
3) The void content of composites increased with increase in fiber and filler loading. . The composite with 10 wt. % jute fiber shows minimum void content.
4) The hardness of the composites increased with the increase in fiber and filler loading. It has been observed that composite with 40 wt. % fiber and 15 wt. % filler exhibits maximum hardness value.
5) The experimental result reveals that the composite with 30 wt. % fiber loading shows better strength properties. The tensile modulus of composite increase with the increase in fiber as well as the filler loading.
6) It has also been observed that the ILSS of the composite increases with the increase in fiber loading. However, addition of filler results in poor ILSS shear strength of composites, as it decreases with increase in filler content.

References

T. Nishino, K. Hirao, M. Kotera, K. Nakamae, H. Inagaki, (2003), Kenaf reinforced biodegradable composite, *Composites Science and Technology*, Vol. 63, pp.1281–1286.

M.V. de Sousa, S.N. Monteiro, J.R.M. d'Almeida, (2004), Evaluation of pre-treatment, size and molding pressure on flexural mechanical behavior of chopped bagasse-polyester composites, *Polymer Testing*, Vol. 23, pp.253–258.

T.M. Gowda, A.C.B. Naibu, R. Chhaya, (1999), Some mechanical properties of untreated jute fabric-reinforced polyester composites, *Composites A*, Vol.30, pp.277–284.

D. Ray, B.K. Sarkar, A.K. Rana, N.R. Bose, (2001), The mechanical properties of vinylester resin matrix composites reinforced with alkali-treated jute fibres, *Composites A*, Vol. 32, pp.119–127.

J. Gassan, (2002), A study of fiber and interface parameters affecting the fatigue behavior of natural fiber composites, *Composites A*, Vol.33, pp.369–374

M. A. Khan, N. Haque, A. A. Kafi, M. N. Alam and M. Z. Abedin, (2006), Jute Reinforced Polymer Composite by Gamma Radiation: Effect of Surface Treatment with UV Radia-tion, *Polymer Plastic Technology and Engineering*, Vol.45,no.5, pp.607-613.

M. A. Khan and M. M. Hassan, (2006), Effect of γ-aminopropyl Trimethoxy Silane on the Performance of Jute-Polycar-bonate Composite," *Journal of Applied Polymer Science*, Vol.100,no. 6, pp. 4142-4147

M. A. Khan, M. M. Hassan and L. T. Drzal, (2005), Effect of 2-Hydroxyethyl Mathacrylate(HEMA) on the Mechanical and Thermal Properties of Jute-Polycarbonate Compos-ites," *Composites Part A*: *Applied Science and Manufac-turing*, Vol.36,no.1, pp.71-81.

M. Wollerdorfer, H. Bader, (1998), Influence of natural fibers on the mechanical properties of biodegradable polymers, *Industrial Crops and Products*, Vol. 8, pp.105–112.

A. Keller, (2003), Compounding and mechanical properties of biodegradable hemp fiber composites, *Composites Science and Technology*, Vol. 63, pp.1307–1316.

A. Fardausy, M.A. Kabir, H. Kabir, M.M. Rahman, K. Begam, F. Ahmed, M.A. Hossain, M.A. Gafur, (2012), Study of physical, mechanical and thermal properties of unidirectional jute fiber reinforced PVC film composites, *International Journal of Advanced Research in Engineering and Technology*, Vol.3,no.2, pp.267-274.

B.D. Agarwal, L.J. Broutman, (1990), Analysis and performance of fiber composites, *Second edition, John wiley & Sons, Inc*, pp.2-16.

A. Gupta, A. Kumar, A. Patnaik, S. Biswas, (2011), Effect of Different Parameters on Mechanical and Erosion Wear Behavior of Bamboo Fiber Reinforced Epoxy Composites, *International Journal of Polymer Science*, pp.1-10.

K. Oksman, (2000), Mechanical properties of natural fibre mat reinforced thermoplastic, *Applied Composite Materials*, Vol.7, pp.403–414.

T.H. Ferrigno, (1978), Handbook of Fillers and Reinforcements for Plastics, *Van Nostrand Reinhold, New York, NY, USA.*

A. Satapathy, G. Kranthi, S. Mantry, and S.K. Singh, (2010), Mechanical Characterization Of Glass-Epoxy Hybrid Composites Reinforced with SiC Derived From Bamboo Leaves, *Proceedings of Recent Advances in Fluid and Solid Mechanics*, 27-28.02, NIT Rourkela.

S. Siddika, M. Mansura, and M. Hasan, (2013), Physico-Mechanical Properties of Jute-Coir Fiber Reinforced Hybrid Polypropylene Composites, *World Academy of Science: Engineering and Technology*, Vol.73, pp.1145-1149.

B. R. Raju, R. P. Swamy, B. Suresha, K. N. Bharath, (2012), The Effect of Silicon Dioxide Filler on the Wear Resistance of Glass Fabric Reinforced Epoxy Composites, Advances in Polymer Science and Technology: An International Journal, Vol.2,no.4, pp.51-57.

M.J. Miaha, M.A. Khan, R.A. Khan, (2011), Fabrication and Characterization of Jute Fiber Reinforced Low Density Polyethylene Based Composites: Effects of Chemical Treatment, Journal of Scientific Research, Vol.3,no.2, pp.249-259.

R.M. Bozlur, S. Sibata, S.F. Diba, M. Uono, (2010). Effect of holding time and the amount of fiber content on the flexural properties of Bagasse/bamboo fiber reinforced biodegradable composite, Proc. of International Conference on Environmental Aspects of Bangladesh (ICEAB10), Japan, pp.51-54.

K.S. Ahmed, V. Mallinatha, S.J. Amith, (2011), Effect of Ceramic Fillers on Mechanical Properties of Wove Jute Fabric Reinforced Epoxy Composites, Journal of Reinforced Plastics and Composites, Vol. 30,no.15, pp. 1315-1326.

A. Patnaik, A. Satapathy, S.S. Mahapatra, R.R. Dash, (2009), A Comparative Study on Different Ceramic Fillers Affecting Mechanical Properties of Glass−−Polyester Composites, Journal of Reinforced Plastics and Composites, Vol.28,no.11, pp.1305-1318.