Research article

polymers advanced technologies

Received: 18 January 2016, Revised: 22 February 2016, Accepted: 24 February 2016,

(wileyonlinelibrary.com) DOI: 10.1002/pat.3798

Mechanical property evaluation of glass–jute fiber reinforced polymer composites

Md. Rafiquzzaman*, Md. Maksudul Islam, Md. Habibur Rahman, Md. Saniat Talukdar and Md. Nahid Hasan

The natural fibers such as jute, coir, hemp, sisal etc. are randomly used as reinforcements for composite materials because of its various advantages such as low cost, low densities, low energy consumption over conventional fibers. In addition, they are renewable as well as biodegradable, and indeed wide varieties of fibers are locally available. In this study, glass–jute fiber reinforced polymer composite is fabricated, and the mechanical properties such as tensile, flexural and impact behavior are investigated. The materials selected for the studies were jute fiber and glass fiber as the reinforcement and epoxy resin as the matrix. The hand lay-out technique was used to fabricate these composites. Fractured surface were comprehensively examined in scanning electron microscope (SEM) to determine the microscopic fracture mode. A numerical procedure based on the finite element method was then applied to evaluate the overall behavior of this composite using the experimentally applied load. Results showed that by incorporating the optimum amount of jute fibers, the overall strength of glass fiber reinforced composite can be increased and cost saving of more than 30% can be achieved. It can thus be inferred that jute fiber can be a very potential candidate in making of composites, especially for partial replacement of high-cost glass fibers for low load bearing applications. Copyright © 2016 John Wiley & Sons, Ltd.

Keywords: polymer composite; glass fiber; jute fiber; mechanical property; finite element analysis

INTRODUCTION

A composite is a material which is manufactured by combining two or more dissimilar materials in such a way that the resultant material is endowed with properties superior to any of its original ones. Fiber reinforced composites, owing to their enhanced properties, are normally applied in different fields like defense, aerospace, engineering applications, automotive, sports goods, etc. Hence natural fiber composites have gained increasing interest due to their eco-friendly nature. Naturally available fibers like jute, coir, rice husk, sisal, silk and hemp are low cost, abundant and renewable, light in weight, with low density, higher toughness and biodegradable. Natural fibers like jute have the potential to be used as a replacement for traditional reinforcement materials in composites for applications which requires high strength to weight ratio and further weight reduction.[1,2] Sudhir Kumar *et al.*[3] investigated the characterization of chemically modified jute–coir hybrid fiber reinforced epoxy composites. Results showed that the composites reinforced with hybrid jute–coir fibers exhibit superior mechanical, dynamic mechanical and water absorption properties compared to the unhybridized composites for different jute–coir combination. Jochen *et al.*[4] investigated the effect of moisture content on the properties of silanized jute–epoxy composites. The results indicated that enhanced adhesion by application of **y**-glycidoxypropyltrimethoxy-silane as coupling agent leads to distinctly improved mechanical properties such as dynamic modulus was raised by 100%, and to a reduced dependence of the properties on humidity under tensile loading. Debasish *et al.*[5] investigated the effect of grass fiber filler on the mechanical properties of natural rubber. The results indicated that the grass powder fiber offer great tensile strength compared to short coir fiber reinforced composites. Jawaid *et al.*[6] conducted experiment on effect of jute fiber loading on tensile and dynamic mechanical properties of oil palm composites. They have identified that the tensile properties of jute oil palm fiber hybrid composites are increased substantially with increasing the content of jute fibers loading as compared to oil palm epoxy composites. Reinforcing glass fiber into the sisal polypropylene composites enhanced tensile and flexural properties without any effect on tensile and flexural module. In addition to this, adding sisal fiber with glass fiber improves thermal properties and water resistance of the hybrid composites.[7] Ramesh *et al.*[8] investigated on the hybrid composites and the effect of various parameters on the performance of the hybrid composites are subjected to mechanical testing such as tensile, flexural and impact test. The results indicated that the jute composite material shows maximum tensile strength and the jute composite material shows incorporation of sisal–jute fiber with GFRP can improve the properties and used as an alternate material for glass fiber reinforced polymer composites. M. Muthuvel *et al.*[9] investigated that the jute and glass fiber hybrid composite leads to the successful fabrication of glass, jute fiber and chopped fiber reinforced polyester composites with different fiber lengths is possible by simple hand lay-up technique. The mechanical properties of the composites like tensile, flexural and impact strength

---

* *Correspondence to: Department of Industrial Engineering and Management, Faculty of Mechanical Engineering, Khulna University of Engineering and Technology, Khulna 9203, Bangladesh.*
E-mail: rafiqbitr@yahoo.com

M. Rafiquzzaman, M. Islam, H. Rahman, S. Talukdar, N. Hasan
Department of Industrial Engineering and Management, Faculty of Mechanical Engineering, Khulna University of Engineering and Technology, Khulna 9203, Bangladesh

of the composites are also greatly influenced by the stacking sequence. M.A Kabir *et al.*[10] studied that with the increase of fiber loading the values of flexural strength and charpy impact strength of composite material have been decreased. But the values of other mechanical properties remain almost the same. Satish Pujari *et al.*[11] explore the potentiality of jute and banana fiber composites, and emphasize both mechanical and physical properties and their chemical composition. The variation of tensile strength, flexural strength and compressive strength of epoxy based sisal–glass hybrid composites has been studied by H. Doan *et al.*[12] and found that due to the effect of coupling agent (maleic anhydride grafted polypropylene), tensile behavior of short jute fiber reinforced polypropylene composites increased in humid aging conditions, which was attributed to both improved polymer–matrix and interfacial adhesion strength. Hong *et al.*[13] investigated the tensile properties of jute–polypropylene composites in order to detect the reinforcement effects of the untreated and salinized jute fibers. Jawaid *et al.*[14] investigated the flexural performance of tri layer oil palm empty fruit bunches (EFB)/woven jute (Jw) fiber reinforced epoxy hybrid composites. They reported that the incorporation of jute woven fiber in pure EFB composite enhances the tensile property of hybrid composites. Khan *et al.*[15] studied on the mechanical properties of woven jute fabric reinforced poly (L-lactic acid) composites. Mechanical tests were conducted on woven and non-woven jute fabric reinforced PLLA based composites. Woven structure exhibited excellent mechanical behavior like tensile, flexural and impact loadings compared to non-woven composite. Tensile, flexural and impact strengths of WJF/PLLA composite were found higher at warp direction than weft direction. Velmurugan *et al.*[16] studied on the tensile, bending, shear and impact properties of roof light resin; Palmyra/glass fiber hybrid composites are studied. The mechanical properties increased due to hybridization. The properties are increasing continuously due to the addition of glass fiber. The studies are carried out for both skin core and dispersed type hybrid composites. The mechanical properties of fiber skin core construction are higher than the dispersed fiber construction. Boopalan *et al.*[17] made a comparative study on the mechanical properties of jute and sisal fiber reinforced polymer composites and conclude that the mechanical properties of the jute fiber reinforced composites are higher than the sisal fiber reinforced composites. Stocchi *et al.*[18] studied the effect of treatment on the tensile behavior of woven jute fabric/vinyl ester composites at two different times of treatment. It was found that composites with 4 h alkali treated mats under biaxial stress exhibit significant improvement in the stiffness compared to composites with 24 h alkali treated mats under biaxial stress and untreated mats. Tao *et al.*[19] investigated the tensile properties of natural fiber/PLA composites with short jute and ramie as reinforcement. The fiber loading of jute–PLA and ramie–PLA composites were varied from 10 to 50%. It was found that the tensile strength of composites increased up to 30% fiber content and after that it decreased. M. Faezipour *et al.*[20] investigated the mechanical and physical properties of waste silk fibers and wood flour based recycled polycarbonate hybrid composites. They reported that the weight content of poplar wood flour is a key parameter that would substantially influence the mechanical properties of this composites. The tensile and flexural strengths and moduli of the composites were significantly enhanced with the addition of biofibers in both types (fiber and flour), as compared with neat recycle polycarbonate. A. Ashori *et. al.*[21] investigated the hybrid effect of glass and cellulosic fibers on the tensile, flexural and impact properties of bagasse, corn stalk and E-glass fibers based thermoplastics. They reported that the addition of agro-waste materials (bagasse and corn stalk), tensile and flexural properties of the composites was moderately enhanced. However, corn stalk fibers showed superior mechanical properties due to their high aspect ratio and chemical characteristics. Harish *et al.*[22] developed coir composite material, and they evaluated mechanical properties. Scanning electron micrographs obtained from fracture surfaces were used for a qualitative evaluation of the interfacial properties of coir/epoxy and compared with glass fibers. T. Munikenche Gowda *et al.*'s[23] investigation on the mechanical property evaluation of jute–glass fiber reinforced polyester concluded that although the mechanical properties of jute/polyester composites do not possess strengths and module as high as those of other conventional composites, they can process better strengths than wood composites and some plastics. Hence these composites could be considered for future materials use. Because the reinforcing materials eco-friendly, non-toxic, non-health hazardous, low in cost and easily available as compared to conventional fibers like glass, Kevlar, asbestos etc., the composites are a good substitute for wood in indoor applications such as shelves, partitions, wash basins and table tops, and may also be suitable for outdoor uses such as roofing, drainage pipes, automobile components, electrical fittings as well as larger items such as lightweight fishing boats.[24] Hence, with this background, it is concluded that, the composites stand the most wanted technology in the fast growing current trend. Therefore it is worthwhile to explore the possibility of utilizing cheaper material such as natural fiber like jute, bamboo, rice husk etc. as reinforcement. In the present work, jute and glass fiber reinforced hybrid composites were fabricated by hand layout method and their mechanical performances have been investigated by experimentally and numerically.

MATERIALS AND METHODS

Materials

In this study, jute and glass fiber were used as reinforcement, and the epoxy resin (ADR 246 TX) was used as the matrix, shown in Fig. 1. Hardener ADH 160 and Methyl Ethyl Ketone Peroxide (MEPOXE) were used to improve the interfacial adhesion and impart strength to the composites. The glass fiber, hardener and resin were purchased from a chemical company. The woven jute fiber having an average weight 1.3 g/cm^2 and average thickness of 3 mm was collected from Akiz Jute Industries Ltd. Khulna, Bangladesh (Fig. 1). A resin and hardener mixture of 3:1 was used to obtain optimum matrix composition. Material properties, obtained from literature,[23,25] are shown in Table 1.

Fabrication procedure

There are many techniques available in industries for manufacturing of composites such as compression molding, vacuum molding and resin transfer molding. The hand lay-up process of manufacturing is one of the simplest and easiest methods for manufacturing composites. In this study, the composites were manufactured by the hand lay-up process. During the fabrication process, the patterns of the jute fiber and glass fiber were impregnated with unsaturated epoxy resin. First, a releasing agent and resin were applied to the mold surface. Then a layer of the jute fiber/glass fiber was laid down, followed by a

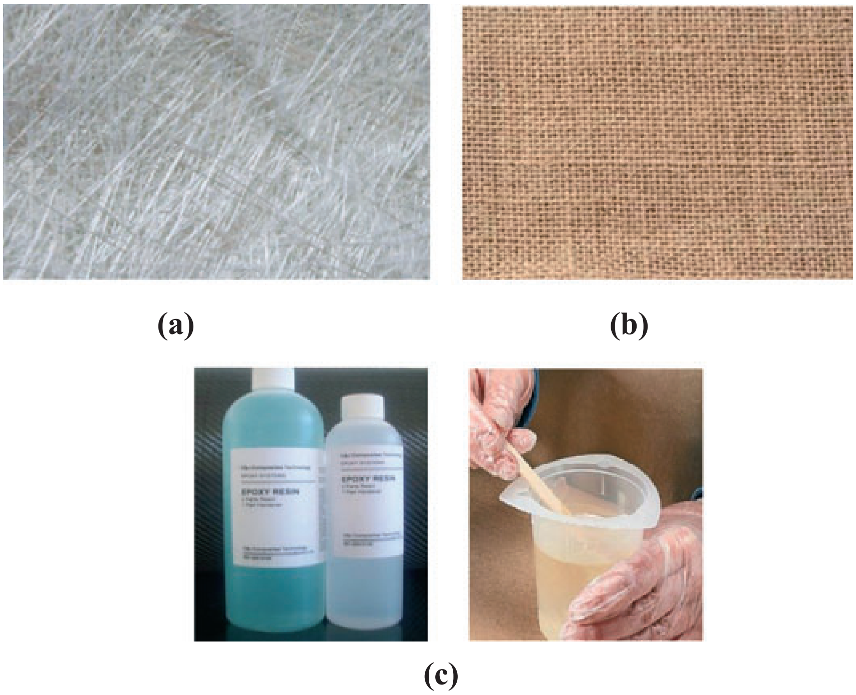


Figure 1. (a) Glass fiber (b) Jute fiber (c) Epoxy resin.

Table 1. Mechanical properties of glass fiber, jute fiber and epoxy resin[23,25]

Properties	Jute fiber	Glass fiber	Epoxy resin
Density (g/cm^3)	1.3	2.54	1.2
Young modulus (GPa)	26.5	75	2.7
Specific Gravity (gm/cc)	1.3	2.5	—
Poisson's ratio	—	0.2	0.4

quantity of liquid resin epoxy poured onto it. Brushes and hand rollers were used to remove any void in the fiber structure and to spread the resin evenly throughout the fibers. The process was repeated until the required number of layers was built up. Finally these specimens are taken to the hydraulic press to force the air gap to remove any excess air present in between the fibers and resin, and then kept for several hours to get the perfect samples. After the composite material gets hardened completely, the composite material is taken out from the hydraulic press, and rough edges are neatly cut and removed as per the required dimensions. The composite laminate samples were cured by exposure to normal atmospheric conditions. The fabricated composites were cut using a grinding machine to obtain the dimensions of the specimen for mechanical testing as per the ASTM D3039 standards. The photographic view and the schematic diagram of the test specimens are shown in Figs 2 and 3 respectively.

Experimental procedure

The tensile test was performed using an electro-mechanical testing machine equipped with the maximum capacity of the load

Figure 2. Photographic view of test specimens (a) Glass fiber reinforced composite (b) Glass–jute fiber reionforced composite (c) Jute fiber reinforced composite.

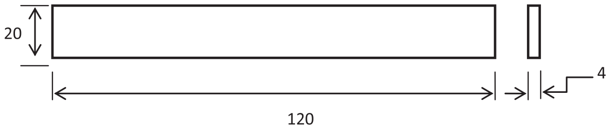


Figure 3. The schematic diagram of test specimens (Unit: mm).

cell at 3 kN. The tensile tests were conducted with a displacement rate 2 mm/min. The specimens were placed in the grip of the tensile testing machine, and the test was performed by applying tension until failure at room temperature. The corresponding load and strain obtained were plotted on the graphs. The strength was calculated from the maximum load at failure of the tensile stress. Flexural testing commonly known as three-point bending testing was also carried out as per ASTMD790. Composite specimens of dimensions 120 × 20 × 4 mm were horizontally placed on two supports, and load was applied at the center. The deflection was measured by the gauge placed under the specimen, at the center. Impact testing was carried out on Tinius Olsen machine as per procedure mentioned in ASTM D256. Composite specimens were placed in vertical position (Izod Test), and hammer was released to make impact on specimen and CRT reader gives the reading of impact strength. All experimental tests were repeated four times to generate the data. Fractured surfaces were comprehensively examined in a scanning electron microscope (SEM) to determine the microscopic fracture mode and to characterize the microscopic mechanism governing fracture.

EXPERIMENTAL RESULTS AND DISCUSSIONS

Tensile test

The different composite specimen samples are tested in the universal testing machine (UTM), and the samples are left to break till the ultimate tensile strength occurs. The tensile stress and displacement curves measured by the tensile test for composite specimens are shown in Fig. 4. The jute–glass fiber reinforced composite samples exhibit a significant difference in strength. Experimental results of tensile of various composites with different weight fractions of reinforcement are presented in Table 2, and the comparison results are presented in Fig. 5. The results show that the overall tensile strength of hybrid composite is higher than single reinforced, when jute fiber content was added 25% of total 40% reinforcement and 33% of total 30% reinforcement. However, when natural fiber content is higher than synthetic fiber content, the over strength is decreased. When added 50% of jute fiber of total reinforcement to support the glass fiber, the tensile strength is decreased 13% compared to the glass fiber composites. On further increasing jute fiber reinforcement, the composite becomes more brittle as jute shows brittle behavior and overall strength decreases. However, when jute fiber content was added in the range 25% to 34%, the best overall strength is obtained.

Flexural test

The flexural stress and displacement curves measured by the tensile test for composite specimens are shown in Fig. 6. The jute–glass fiber reinforced composite samples exhibit a significant difference in strength. Flexural results of various composites with different weight fractions of reinforcement are presented in Table 2 and the comparison results are presented in Fig. 7. Results show that flexural strength of jute composite is lower than that of glass fiber composites because of the less stiffness of jute fibers in comparison to glass. The addition of jute fiber with glass fiber, the composite gives better flexural strength compared with single reinforced composites. However, when jute fiber content was added in the range 25% to 34%, the best overall strength is obtained.

Impact strength

For analyzing the impact capability of the different specimens an impact test is carried out by Charpy impact test. The energy loss is found out on the reading obtained from the Charpy impact machine. Experimental results of impact testing of various composites with different weight fractions of reinforcement are presented in Table 2 and the comparison results are presented in Fig. 8. The results indicated that the maximum impact strength is obtained for hybrid composites followed by glass fiber composites. However, jute composites exhibit low performance compared to other composites. On increasing the amount of jute content, which is more brittle than glass fiber, the overall brittleness of material increases and impact strength decreases.

Scanning electron microscopy (SEM) analysis

Fractured surfaces were comprehensively examined in a SEM to determine the microscopic fracture mode and to characterize the microscopic mechanism governing fracture. The SEM image of the samples underwent test is presented in Fig. 9. The fracture

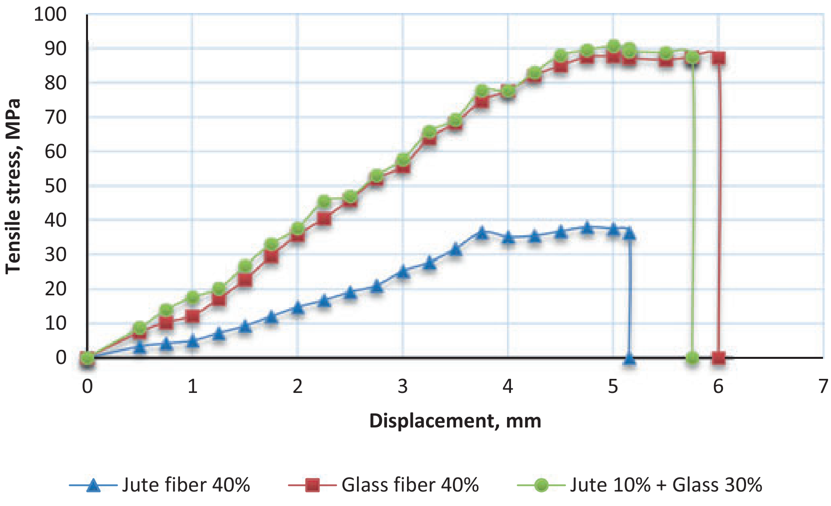


Figure 4. Tensile stress versus displacement relationship between various composites.

Table 2. Experimental results of tensile, flexural and impact test for various composites

No. of experiment	Total reinforcement weight %	Fiber weight %		Tensile strength (M Pa)	Flexural strength (M Pa)	Impact strength (J/m^2)
		Jute	Glass			
01	40	40	0	39.67	65.87	178.56
02		0	40	87.53	89.67	235.13
03		20	20	74.65	82.76	206.89
04		10	30	89.56	107.89	265.87
05		30	10	64.89	76.78	189.65
01	30	30	0	35.77	62..87	168.56
02		0	30	80.34	85.65	213.33
03		15	15	70.67	79.76	197.89
04		10	20	81.76	95.69	239.87
05		20	10	57.89	71.78	169.75

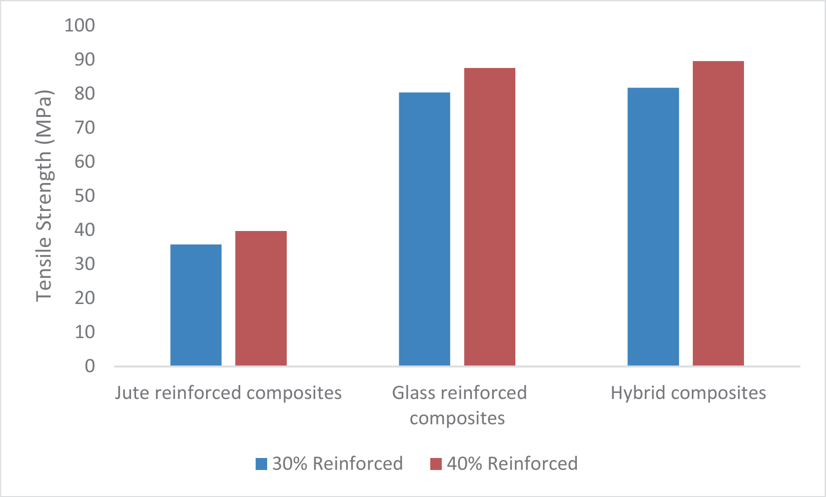


Figure 5. Comparison of tensile strength.

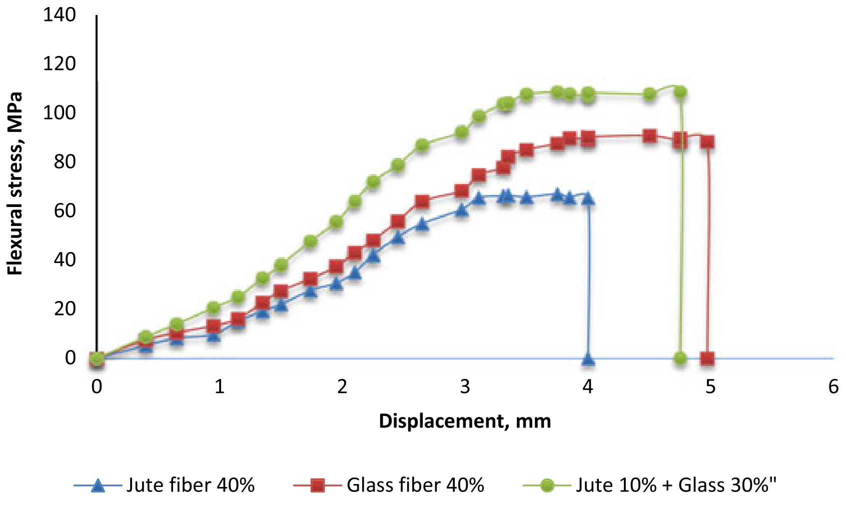


Figure 6. Flexural stress versus displacement relationship between various composites.

takes place in the specimen by the application of the load. The figures indicate the fiber fracture and pullout from the specimen and also the dislocation of fibers. The fiber pullout occur because of the lack of interfacial adhesion between the glass/jute fiber and epoxy matrix. The agglomeration is the collective stacking or collection of fibers together in the matrix which reduces the

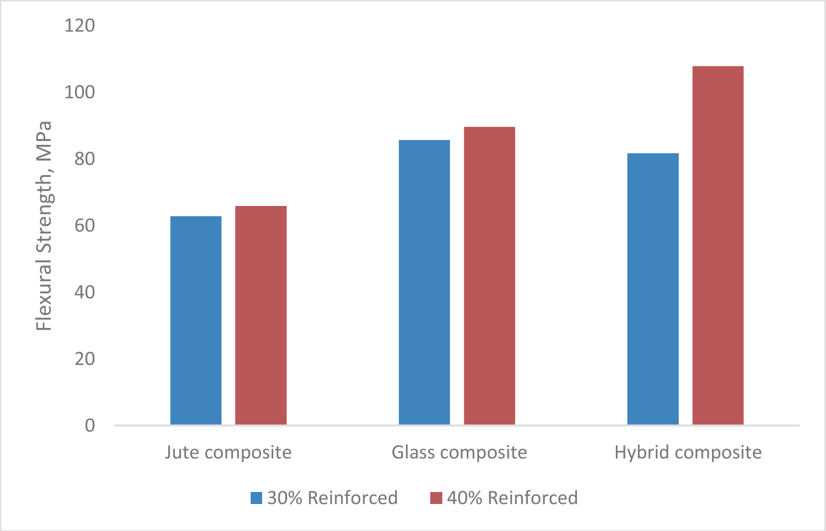


Figure 7. Comparison of flexural strength.

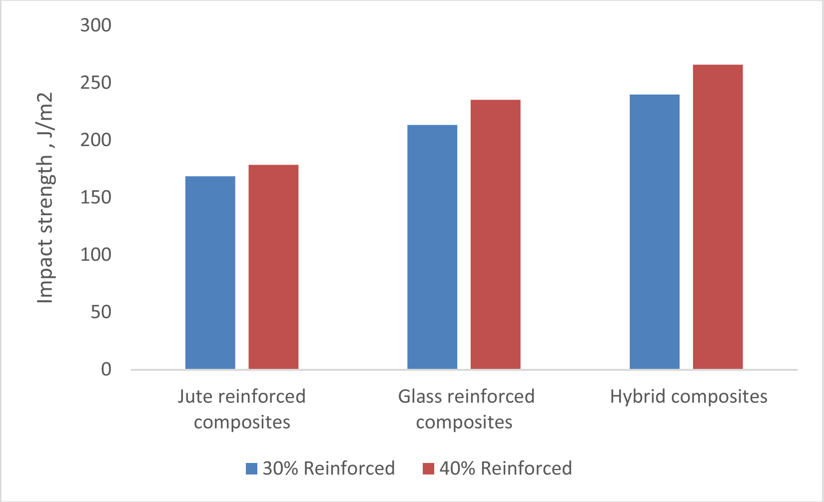


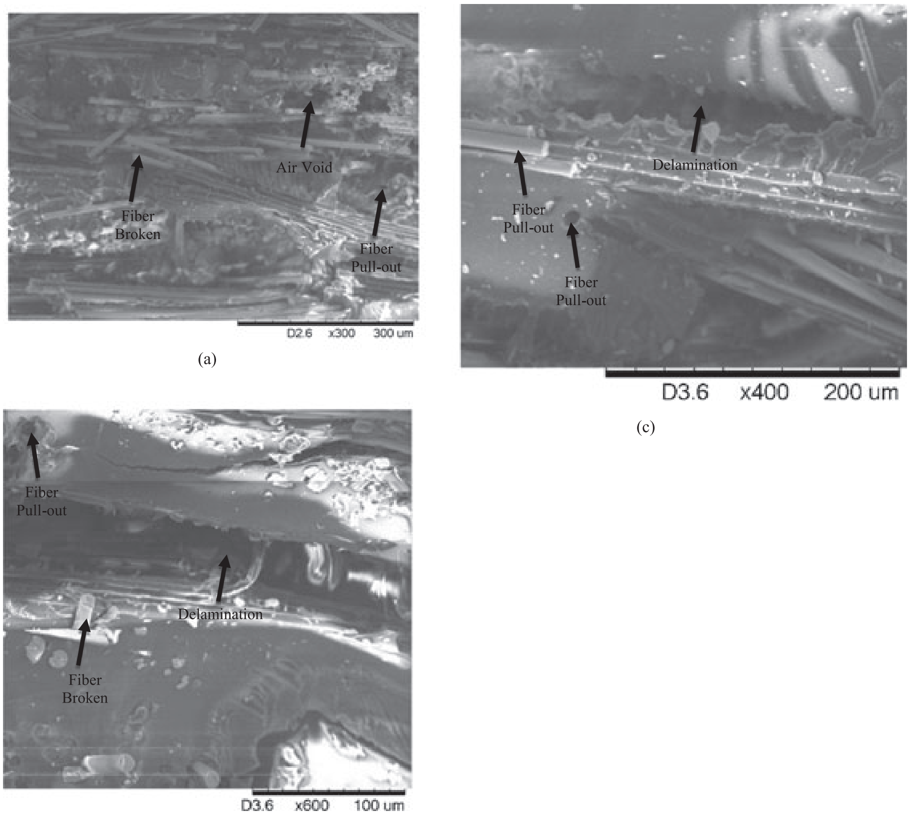
Figure 8. Comparison of impact strength.

strength by non-uniform stress transfer. The fiber–matrix adhesion, dispersion and orientation of fibers, fiber agglomeration, and presence of air voids these are the influential factors for reduction of strength of the fiber reinforced composite. The main fracture mechanisms were longitudinal splits, matrix cracking, and delamination.

NUMERICAL ANALYSIS

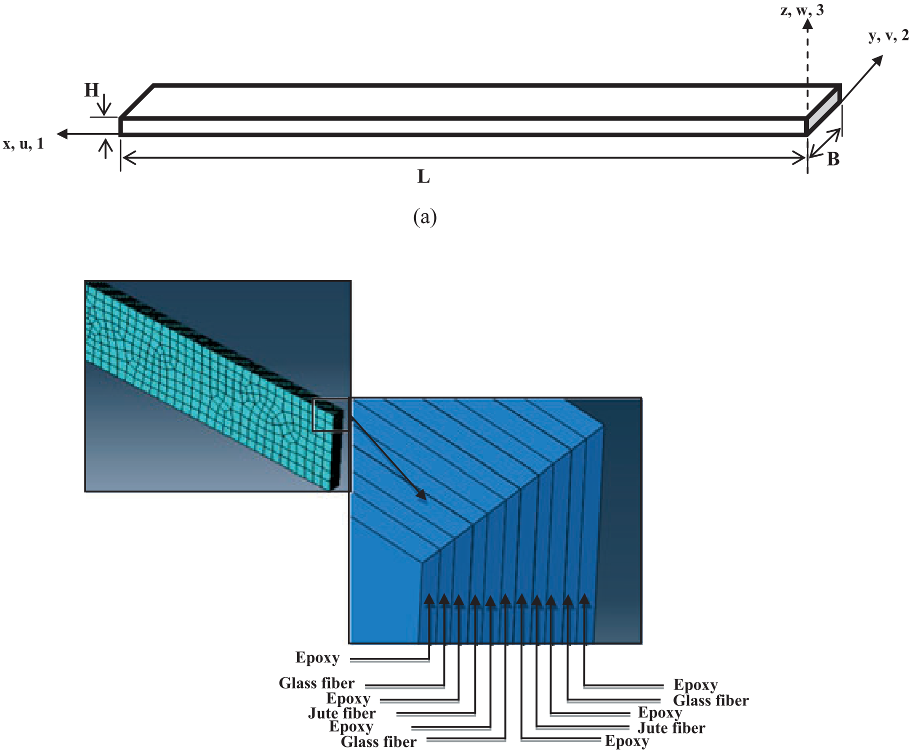
Numerical analysis

In numerical analysis, a three-dimensional laminate composite was conducted using the finite element method (FEM) to describe the overall behavior of the composite. A schematic illustration and finite element mesh of the model is shown in Fig. 10. Geometry of numerical model is L = 200 mm, H = 4 mm and B = 25 mm. Creating the plate was the initial task in modeling the composite plate using the FEM. Parts of the module were used to build the different parts of the model. In this study, the models were created and divided into a number of different layers of composite plates to represent the different material properties for each layer of the laminate. Later, all the layers were assembled to form the entire model. It is essential to note that in this study, the composite plate had been assigned as an isotropic type of material in the input in the FEM which has the same elastic properties in all directions. Each layer in the model was meshed separately with a local element coordinate system representing the orientation of the layer. A 20 node quadratic brick element was used in this model. In this model the glass and jute fiber was embedded in the epoxy resin in a three-dimensional packing arrangement. The glass fiber and jute fiber volume fraction was modeled as a real microstructure in an epoxy resin matrix of 30% and 10% respectively. For the simulation, the bottom edge of the test coupon was constrained and a force was applied to the top edge. The line on the bottom of the shell was constrained in the y-direction. To simulate, a total force of 1000 N had to be prescribed. The boundary condition is as follows:



(a) (b) (c)

Figure 9. Fiber pull out, fiber failure and delamination in the fracture surface after (a) tensile failure (b) flexural failure (c) impact failure.



(a)

(b)

Figure 10. (a) Geometry (b) layer combination and mesh of the FEM model.

$$
\begin{aligned}
u_x &= 0,\ \tau_{xz} = \tau_{xy} = 0 \text{ on } x = 0\\
u_y &= 0,\ \tau_{yz} = \tau_{xy} = 0 \text{ on } y = 0\\
u_z &= 0,\ \tau_{zy} = \tau_{zx} = 0 \text{ on } z = 0
\end{aligned}
$$

$$u_x = \varepsilon_{ave}L, \int_{z=0}^{z=L} \cdot \int_{y=0}^{y=H} \tau_{xz}dydz = 0, \quad \iint \tau_{xy} = 0 \text{ on } x = L$$

$$u_y = U_y,\ \tau_{yz} = \tau_{xy} = 0, \int_{z=0}^{z=L} \cdot \int_{x=0}^{x=H} \tau_{xz}dxdz = 0, \iint \tau_{yz} = 0 \text{ on } y = H$$

$$u_z = U_z,\ \tau_{zy} = \tau_{zx} = 0, \int_{x=0}^{x=L} \cdot \int_{y=0}^{y=H} \tau_{xz}dxdy = 0, \iint \tau_{zx} = 0 \text{ on } z = H$$

where ε_{ave} is macroscopic strain, U_y and U_z are constants which are determined such that the share component of traction is free. In this study it is assumed to be a linear static elastic analysis.

NUMERICAL RESULTS AND DISCUSSIONS

The stress versus displacement curve measured by experiment and the FEM for jute–glass fiber reinforced composite is shown in Fig. 11. For the FEM analysis, the displacement was recorded as the input value and the load was recorded along the tension direction. The FEM results showed very similar stress–strain char-

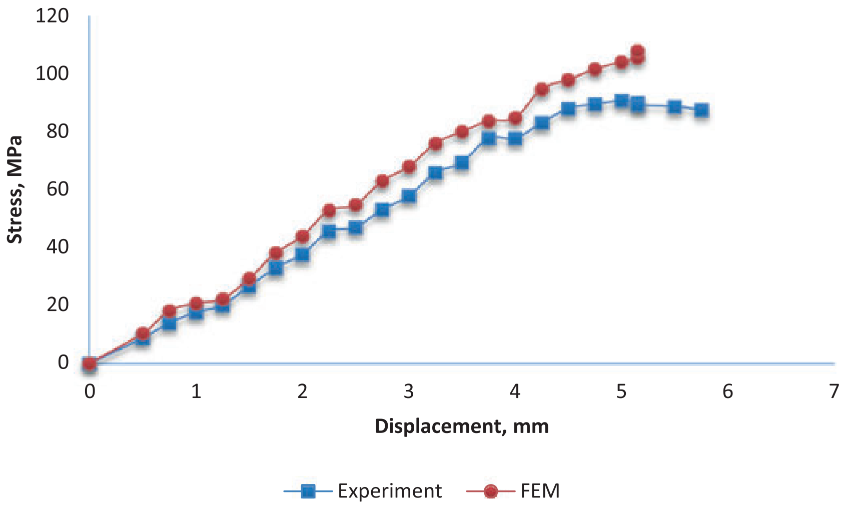


Figure 11. Stress versus displacement relationship for jute–glass fiber reinforced composite.

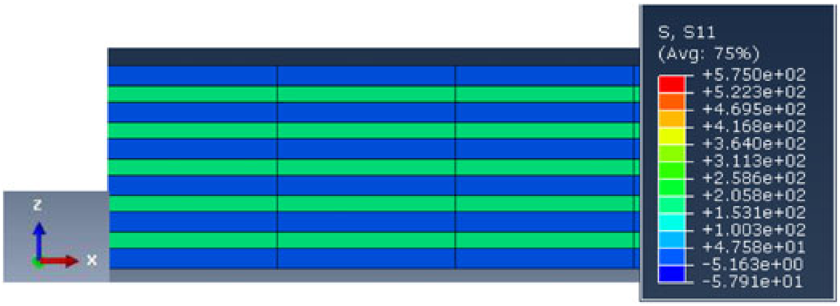


Figure 12. Stress distribution of σ_{11} along x direction at x = L/2 and y = B/2.

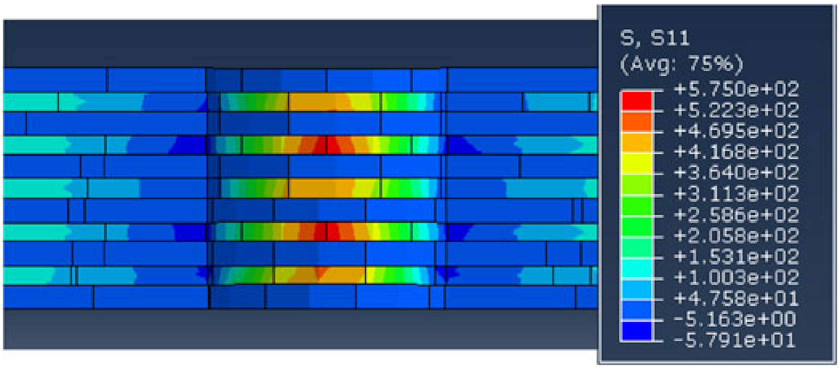


Figure 13. Stress distribution of σ_{11} along z direction at x = L/2 and y = B/2.

Table 3. Price of fiber in context of Bangladesh

Type of fiber	Price/kg ($)
Jute fibers	$ 1.125
Glass fibers	$16.25

Table 4. Cost analysis of composites (30% jut fiber + 70% glass fibers)

Fibers	Weight (g)	Price ($)
Jute	330 g	$0.37
Glass	670 g	$10.9
	Total cost of 30% jute and 70% glass fibers	$11.25
	Total cost for 100% glass fibers	$16.25
	Cost Reduce (with respect to glass fibers)	$5.00
	Percentage of cost reduction	30.71%

acteristics of experimental results. However, FEM results showed about 16% higher stress compared to the experimental results. For the FEM analysis, the glass fiber was considered as homogeneous materials. The inhomogeneous effect of the real microstructure of jute and glass fiber may be the cause of the lower stress compared to the FEM results.

The stress distributions of σ_{11} under axial tension load of 1000 N of the laminate composite is shown in Figs 12 and 13. This figure shows the high stress developed in the glass layer and jute layer compared to the epoxy layer. This simulation results support the experimental results where delamination and fiber breakage were noted in the fracture surface observation.

COST ANALYSIS

Results of this study show that optimum range for natural jute fiber is around 30% of the total reinforcement. The cost analysis of making our investigated hybrid composite is shown in Tables 3 and 4. In local market the price of glass fiber and jute fiber is given in Table 3. The cost analysis results show that the total cost reduced 31%, when taken advantage of both natural and synthetic fibers and produce hybrid composite.

CONCLUSIONS

In this study, fabrication and mechanical performances of glass–jute fiber polymer composites were studied. Results showed that by incorporating the optimum amount of natural fibers, the overall strength of glass fiber reinforced hybrid composite can be increased and cost saving of more than 30% can be achieved. The fracture mechanisms because of static loading consist of delamination, debonding and fiber pull-out which is agreeably closer to the numerical results. By incorporation of natural and synthetic fibers into the polymer, the mechanical properties almost enhanced to greater extent. It can thus be inferred that jute fiber can be a very potential candidate in making of composites, especially for partial replacement of high-cost glass fibers for low load bearing applications. As such, commercial exploitation of jute composites for non-structural applications promises excellent potential. With increasing emphasis on fuel efficiency, jute composites would enjoy wider applications in automobiles and railway coaches.

Acknowledgements

The authors are very much grateful to the Ministry of Science and Technology (MOST), Bangladesh and Khulna University of Engineering and Technology (KUET), Bangladesh, for providing necessary fund and their lab facility for successful completion of this research.

REFERENCES

[1] K. K. Chawla, *Composite Materials: Science and Engineering*, 2nd ed.,, Springer, New York, **1998**, ppp. 13–87.
[2] S. A. S. Goulart, T. A. Oliveira, A. Teixeira, P. C. Mileo and D. R. Mulinari, *Proc. Eng.*, *10*, 2034 (**2011**).
[3] S. K. Saw, G. Sarkhel and A. Choudhury, *J. Appl. Polym. Sci.*, *125*, 3038 (**2012**).
[4] J. Gassan and A. K. Bledzki, *Polym. Compos.*, *18*, 179 (**1997**).
[5] D. De, D. De and B. Adhikari, *Polym. Adv. Techl.*, *15*, 708 (**2004**).
[6] M. Jawaid, H. P. S. Abdul Khalil, A. Hassan, R. Dungani and A. Hadiyane, *Composites: Part B.*, *45*, 619 (**2013**).
[7] K. Jarukumjorn and N. Suppakarn, *Composites: Part B.*, *40*, –623 (**2009**).
[8] M. Ramesh, K. Palanikumar and R. K. Hemachandra, *Composites: Part B.*, *48*, 1 (**2012**).
[9] M. Muthuvel, G. Ranganath, K. Janarthananand and K. Srinivasan, *Int. J. Eng. Res. & Tech.*, *2*, 335 (**2013**).
[10] M. Alamgir Kabir, M. Huque, M. Rabiul Islam, k. Andrzej and C. Bledzki, *Bio Resources.*, *5*, 1618 (**2010**).
[11] P. Satish, A. Ramakrishna and M. Suresh Kumar, *Int. J. Cur. Eng. and Tech.*, *2*, 121 (**2014**).
[12] T. T. L. Doan, S. L. Gao and E. Mäder, *Comp. Sci. Tech.*, *66*, 952 (**2006**).
[13] C. K. Hong, I. Hwang, N. Kim, D. H. Park, B. S. Hwang and C. Nah, *J. Ind. Eng. Chem.*, *14*, 71 (**2008**).
[14] M. Jawaid, H. P. S. Abdul Khalil and A. Abu Bakar, *Mat. Sci. Eng. A.*, *528*, 5190 (**2011**).
[15] M. Saiful Islam, A. Kovalcik, M. Hasan and V. Kumar Thakur, *Int. J. Polym. Sci.*, 2 (**2015**)Article ID 813568.
[16] R. Velmurugan and V. Manikandan, *Composites Part: A.*, *38*, 2216 (**2007**).
[17] M. Boopalan, M. Niranjana and M. J. Umapathy, *Composites: Part B.*, *51*, 54 (**2013**).
[18] A. Stocchi, B. Lauke, A. Vázquez and C. Berna, *Composites: Part A.*, *38*, 1337 (**2007**).
[19] Y. Tao, L. Yan and R. Jie, *Transac. Nonfer. Met. Soci. China.*, *19*, 651 (**2009**).
[20] M. Faezipour, R. Shamsi, A. Ashori, A. Abdulkhani and A. Kargarfard, *Polym. Comp.*, (**2014**). DOI: http://dx.doi.org/10.1002/pc.23339.
[21] A. Ashori1, A. Nourbakhsh and A. Kazemi Tabrizi, *Polym-Plast. Tech. and Eng.*, *53*, 1 (**2014**).
[22] S. Harish, D. Peter Michael, A. Bensely, D. Mohan Lal and A. Rajadurai, *Mat. Charact.*, *l60*, 44 (**2009**).
[23] T. Munikenche Gowda, A. C. B. Naidu and R. Chhaya, *Composites: Part A.*, *30*, 277 (**1999**).
[24] A. K. Mohanty and M. Misra, *Polym. Plast. Tech. Eng.*, *34*, 729 (**1995**).
[25] M. Rafiquzzaman, S. Abdullah1 and A. M. T. Arifin, *Fib. and Polym.*, *16*, 640 (**2015**).