FABRICAION AND MECHANICAL PROPERTIES OF 3D JUTE FABRICS REINFORCED COMPOSITES

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Abstract

The effects of fabric structures on the mechanical properties of jute fabrics reinforced composites were reported in the current study. The jute fabrics are two-dimensional (2D) plain and three-dimensional (3D) orthogonal structures. A room temperature cured epoxy resin and polylactic acid (PLA) was used as matrix matters. Four composites (2D jute fabric/epoxy, 2D jute fabric/PLA, 3D jute fabric/epoxy and 3D jute fabric/PLA) were developed by molding assistant manufacturing techniques on a hot press machine. A material test system (MTS 810) was used to characterize the tensile properties of the composites. Furthermore, an IZOD impacting instrument was used to examine the impacting energy absorption of the composites. The experimental results revealed that both the 2D and the 3D jute fabrics enhanced the tensile strength and tensile modulus of pure epoxy and or PLA specimens. The 2D and 3D jute fabric composites, also, are good in impact strength compared to pure epoxy and or PLA resin.

1 Introduction

A rapid growth has occurred in the consumption of fiber reinforced polymer composites, great versatility, and processing advantages at favorable costs by permutation and combination of various fibers and polymers for last three decades. Fiber reinforced composites possessing unique properties for versatile applications as alternatives to conventional materials like woods, metals and ceramics have been prepared. Early work on composites focused almost entirely on polymer base materials. Traditionally, high- performance fibers such as glass, carbon and kevlar fibers have been used to improve both the strength and stiffness of petroleum-based polymeric matrices.

However, the use of high-performance reinforcement and petroleum-based polymeric matrices is disturbing the control of residues at the end of the lifetime of their composites. These composites have been caused the environmental problems due to hardly treatment after used, especially in recyclable, renewable and degradable.

In recent years, there has been a great growth in research, development and application of natural fiber composites. A composite containing at least one constituent (e.g. matrix or reinforcement) that is derived readily from renewable resources may be considered a bio-composite. The manufacture, use, and removal of traditional composite structures usually made of glass, carbon, and aramid fibers are considered critically because of growing environmental awareness. Cellulose fibers from kenaf, hemp, ramie, flax, sisal, coir, and jute are also being used as reinforcing materials. Since 1980s, the interest in composite made from cellulose fiber has been growing. The indisputable advantages of cellulose fibers, such as low abrasion, multi functionality, low density, low cost, availability, and no waste disposal problems encourage applications on composite. The available technical studies suggest that natural fiber materials certainly have the potential to compete with glass fibers in composite materials [1].

Natural fiber composite is the great demand in the whole world for environmental and ecological concern. Among all the natural fiber reinforcing materials, jute appears to be a promising material because it is relatively inexpensive and commercially available in tropical countries [2-4]. It has relatively low density and higher strength and modulus than plastic and is a good substitute for conventional fibers in many situations. Among commodities, thermosetting epoxy possesses outstanding properties like good surface hardness, scratch resistance, and excellent electrical properties. As a material of construction, jute epoxy composite can play a vital role all over the world. In order to compete with the synthetic fiber reinforced composite, the mechanical properties of jute epoxy composite should be improved. Some workers prepared jute epoxy composite with the improved mechanical properties by treating the epoxy resin over jute fiber. To enhance the use of jute fibers, a broader systematic investigation is necessary to search for chemical modifiers and physical treatments. Several processes such as chemical treatments [5-9] and UV treatments [10] have been developed to modify fiber surfaces. Saha, P., et al. found that the tensile strength of jute fibers increased by treating the jute fibers with an alkali solution under elevated temperatures and high pressure steaming conditions [5]. The alkalizations of flax fibers, also, enhance the fiber/matrix bonding with an epoxy resin [6]. Yoldas Seki indicated that the adhesion between jute fabric and thermoset resin can be improved by treating the jute fibers with alkali and oligomeric siloxane [7]. The alkalization, acetylation, cyanoethylation and silane coupling agent had been used to modify the fiber surface and its internal structure by Min Zhi Rong et al. [8]. They reported that adhesion at the interface between sisal bundles and matrix and that between ultimate cells play a key role in determining the mechanical behavior of the laminates. In 2010, Yanjun Xie et al. [9] reviewed the recent progress in using silane coupling agents for natural fiber reinforced polymer composites and concluded the requirement of a chemical bonding between the organofunctionalities of silanes and the matrices. For UV treatment, Jochen Gassan et al. improved the mechanical properties of jute-epoxy composites using UV-oxidation of fibers under a balance between increased polarity of fiber surface and decrease of fiber strength [10]. The mentioned articles concerned to treating natural fiber to enhance the interface strength between fiber and matrix. The used reinforcements are mostly short fibers or mats that have a low reinforce efficient. Therefore, the mechanical properties of short natural fiber or mat reinforced matrix are limited comparing to conventional long fiber reinforced materials. Some researchers [11-18] tried to improve the properties of natural fiber composites by inducing natural fabric to reinforce polymer matrix. The modulus, Poisson's ratio and strength of untreated woven jute fabric-reinforced polyester composites were studied by T. Munikenche Gowda et al [11]. They concluded that although the mechanical properties of jute/polyester composites do not possess strengths and moduli as high as those of conventional composites, they do have better strengths than wood composites and some plastics. Since the reinforcing material is an eco-friendly, non-toxic, non-health hazardous, low in cost and easily available as compared to conventional fibers like glass, Kevlar, etc., the composites are a good substitute for wood in indoor applications. In addition, the jute composites are good for environmental friendly materials while reinforced with biodegradable matrix [12, 13]. Some articles indicated that jute fabric can improve the mechanical properties of thermoplastic[14-16] or thermoset[17, 18] matrix composites. Alsina O. et al [14] found that the values of the thermal conductivity, thermal diffusivity and specific heat of the jute/polyester composites are usually higher than those of the resin matrix. Stocchi A. et al. reported that a significant improvement in stiffness of woven jute fabric/vinylester laminates could be achieved by treated with alkali and a high tensile strength could be obtained by treating the fabric with alkali under stress for proper hours [15]. The jute–glass fabric reinforced polyester hybrid composites have been evaluated by Ahmed K. et al. They reported that the rule of hybrid mixture can be conveniently used for predicting the elastic properties of bidirectional [0/90] jute and glass fabric reinforced hybrid composites. They also found that the jute composites have higher notch sensitivity than jute–glass hybrid composites. For jute fabric reinforced thermoset composites, the fracture toughness is strongly dependent upon the whether the composite is being tested in the weft or warp directions; there are strong anisotropic effects. A superior balance of stiffness, strength and toughness can be achieved and expected if the yarn, textile design and hybrid pattern are improved [17]. The hybrid pattern significantly affects the tensile and flexural properties [18]. Therefore, the jute fabric can improve the mechanical properties of epoxy resin by proper treatment of fiber and weaving pattern design. However, none of the open literatures have studied the use of three-dimensional jute fabric to reinforce the polymer matrix composite. So, the effect of fabric types (2D plain and 3D orthogonal) on tensile and impact properties of jute fabric reinforced epoxy and PLA composites were studied.

2 Experimental Procedures

2.1 Materials

Commercial products of 2-D plain jute fabric (13 picks/inch, 15 ends/inch and five count/yarn) were used to reinforce epoxy and PLA resin to get a referred material. A jute yarns with count of 3 were used as warp and weft yarns for 3-D fabrics weaving. The epoxy resin system (AW 56A and AW56C, Yi-Bo Chemical Co. Ltd., Taiwan) and PLA chips (NCP0004, Wei Mon Industry Co. Ltd., Taiwan) were used as matrix materials. Sodium hydroxide was used to purify the jute fibers.

2.2 Fabrics weaving

Two types (2D and 3D) of jute fabrics have been used in the current experiment. Schematics of the fabrics are shown in figure 1. As shown in figure 1(b), the 3D preform has three sets of yarn which vertical to each other, it called orthogonal. Due to the orthogonal structure of the preform, a Dobby loom had been modified to weave the preform. The fabric densities of 3D fabric are 22 ends per inch in x-direction, seven ends per inch in y-direction and 14 ends per inch in z-direction. The dimensions of 3D fabric are A4 in size, and the thickness of 3D fabric is 3.2 mm.

2.3 Sample preparation

There are two steps (pretreating and impregnating) in sample preparation. In the first step, the 2D and 3D jute fabrics were immersed in 10% alkali solution for one hour for purification, wash in water, and dried under 60^{o}C for 24 hours. After finished the pretreating step, the fabrics were, then, impregnated with the mentioned epoxy resin to make composite panels. Five 2D jute fabrics were impregnated the epoxy resin by hand lay-up method. The impregnated 2D fabrics were vacuumed for two hours to release void and cured at hot-press machine under 90^{o}C for four hours. The post cure temperature was 110^{o}C for two hours under a press of 50 psi at the hot-press machine.

For the manufacturing of 3D jute/epoxy composites, a resin dipping tank used to impregnate with the resin. The 3D jute fabrics put in the tank for one hour and then vacuumed for two hours. The curing process was carried out in an oven under 90^{o}C for four hours. The impregnated 3D fabrics were set in a mold, covered with a steel panel to flat the composite under 110°C for two hours. However, the hand lay-up technique cannot be used to make thermoplastic composites. A resin film molding method used to make 2D/PLA and 3D/PLA composites. Thirty grams of PLA chips were molded to film with one mm in thick in a hot press machine under 190 °C for three minutes. Eight PLA films and five 2D plain jute fabrics were stacked and heated under 190 °C for 20 minute in the hot press. For the manufacturing of 3D/PLA composite, one 3D orthogonal jute fabric and 12 PLA films were used to make the composite. All the composites are A4 size. The composite thickness was controlled at 3.5 mm by a mold. The weigh contents were about 32% and 30% for 2D and 3D composites, respectively. The void content was 3% for the 2D composite and 4.2% for the 3D composite.

2.4 Measurements

In this study, a material testing machine (MTS 810 series) was used to perform the tensile tests at laboratory ASTM D3039. Tensile specimens cut from the prepared composite samples were 175 mm long, 20 mm wide and 3.5 mm thick and were clamped over an area of 20 by 40 mm^2 at each end. The gauge length of the tensile specimen was 65 mm. The grid pressure was hydraulically controlled. The testing cross-head speeds were 5 mm/min for the tensile test. The axial displacement was measured by the machine according to the movement of the crosshead.

Impact tests were performed on an Izod impact testing machine (CY-6458, Chun Yen Testing Machine Co., Taiwan) in accordance with ASTM D256 at impact energy of 13.4 Joule. The dimensions of the Izod impact specimen are 63.5 X 12.7 X 3.5 mm^3, and were provided with a 2.54 ±0.05mm deep notch. The notching specimens were opened by using a single-tooth cutter and were all with a notch tip radius of 0.25mm. All the mechanical properties reported to represent the average value of five readings at least.

3 Results and Discussion

3.1 Weaving and treatment

Prior to the weaving of 3-D fabrics, the jute yarns were been sized with starch to prevent jute yarn breaking during weaving process. In addition, the devices (tensioners, heddle eyes, and reed) were been coated Teflon to reduce the friction between yarns and the devices of weaving loom. After finishing the weaving process, the produced fabrics had been desized in a hot-water bath prior to the resin impregnating process.

3.2 Tensile test

A typical tensile stress-strain relation of jute/PLA composites is shown in figure 2. The peak stress of 2D/PLA composite is higher than that of 3D/PLA composite. Moreover, the failure strain of 3D/PLA composite is larger than that of 2D/PLA composite. The difference was caused by the fiber architecture of jute fabrics. The 3D orthogonal fabric is less dense. It is ease to elongate the fiber under tension. So, the tensile modulus of 3D/PLA composite is lower than that of 2D/PLA composite (figure 3). As shown in figure 3, both the 2D plain and the 3D orthogonal jute fabrics possess the reinforced effect to PLA resin. The tensile modulus of 2D/PLA composite is 94.3% higher than that of pure PLA specimen. For 3D/PLA composite, it is 58.3 % higher than that of pure PLA in tensile modulus. Figures 4 and 5 show the peak stress and breaking strain for the composites, respectively. The average peak stress of pure PLA, 2D/PLA and 3D/PLA composites is 23.26 MPa, 44.83 MPa and 37.74 MPa. The 2D/PLA composite is about 94% higher than that of pure PLA. For tensile testing, the 2D/PLA and 3D/PLA composites have the equivalent resistance in deformation. In addition, the tensile energy at break for the composites could be found in figure 6. The energy is calculated from the curve of load-displacement. Not only, the 2D/PLA composites but the 3D/PLA composites have good energy absorption compared to pure PLA specimens.

Figure 7 shows the typical stress-strain relations for jute/epoxy composites under tension. The 2D jute/epoxy composites have well in tensile strength but have been weak in deformation, which compared to 3D jute/epoxy composites. Table 1 summarizes the modulus, breaking stress and strain of jute/epoxy composites under tensile test. It indicates that adding jute fabric to epoxy that increasing the tensile modulus. The moduli of 2D jute/epoxy and 3D jute/epoxy composites are 26.6% and 15.2% higher than that of pure epoxy specimens, respectively. As indicated in table1, the 3D jute/epoxy composites have low break stress, in other words the 3D fabrics don't improve the composites in tensile strength. However, the 3D jute fabrics enhanced the resistance to tensile elongation. The breaking strain (4.86%) of pure epoxy specimens is higher than that (1.33%) of 3D jute/epoxy composite.

3.2 Impact

The results of impact testing for the PLA based, and epoxy based jute composite are show in figure 8 and figure 9, respectively. Both 2D and 3D jute fabrics improved the impact energy absorption. For PLA based composites, the impact energy for 2D or 3D jute/PLA composite is 12% higher than that of pure PLA specimen. It also has 35% improved for epoxy based composites. Finally, the 2D and 3D jute composites have the similar ability to resist the impact loading.

4 Conclusions

The jute fiber can be used to weave three-dimensional fabrics by pre-treating with start solution. The tensile modulus and strength can be improved by adding jute fabrics. The reinforced effect of 2D jute fabrics in tension test is much better than that of 3D jute fabrics. The impact resistance for PLA and epoxy can be enhanced by adding jute fabrics into the resin.

Natural fiber seems to be the potential in the application of loading structure by treating the fibers to form fabric structures. How to enhance the natural fiber's properties by weaving skill seems to be a good research topic.

References

[1] La Mantia, F.P. and M. Morreale, *Green composites: A brief review.* Composites Part A: Applied Science and Manufacturing, **42**(6): p. 579-588, (2011).

[2] Davoodi, M.M., et al., *Mechanical properties of hybrid kenaf/glass reinforced epoxy composite for passenger car bumper beam.* Materials & Design, **31**(10): p. 4927-4932, (2010).

[3] Sapuan, S.M. and M.A. Maleque, *Design and fabrication of natural woven fabric reinforced epoxy composite for household telephone stand.* Materials & Design, **26**(1): p. 65-71, (2005).

[4] Alves, C., et al., *Ecodesign of automotive components making use of natural jute fiber composites.* Journal of Cleaner Production, **18**(4): p. 313-327, (2010).

[5] Saha, P., et al., *Enhancement of tensile strength of lignocellulosic jute fibers by alkali-steam treatment.* Bioresource Technology, **104**: p. 6-14, (2010).

[6] Vandeweyenberg, I., et al., *Improving the properties of UD flax fibre reinforced composites by applying an alkaline fibre treatment.* Composites Part A: Applied Science and Manufacturing, **37**(9): p. 1368-1376, (2006).

[7] Seki, Y., *Innovative multifunctional siloxane treatment of jute fiber surface and its effect on the mechanical properties of jute/thermoset composites.* Materials Science and Engineering: A, **508**(1-2): p. 247-252, (2009).

[8] Rong, M.Z., et al., *The effect of fiber treatment on the mechanical properties of unidirectional sisal-reinforced epoxy composites.* Composites Science and Technology, **61**: p. 11, (2001).
[9] Xie, Y., et al., *Silane coupling agents used for natural fiber/polymer composites: A review.* Composites Part A: Applied Science and Manufacturing,**41**(7): p.806-819, (2010).
[10] Gassan, J., V. S., and G. b, *Effects of corona discharge and UV treatment on the properties of jute-fibre epoxy composites.* Composites Science and Technology,**60**: p. 7, (2000).
[11] Gowdaa, T.M., A.C.B. Naidua, and R. Chhayab, *Some mechanical properties of untreated jute fabric-reinforced polyester composites.* Composites:Part A,.**30**:p. 8, (1999).
[12] Mohanty, A.K., M.A. Khan, and G. Hinrichsen, *Influence of chemical surface modification on the properties of biodegradable jute fabrics polyester amide composites.* Composites: Part A, **31**: p. 8, (2000).
[13] Mohanty, A.K., M.A. Khan, and G. Hinrichsen, *Surface modification of jute and its influence on performance of biodegradable jute-fabric Biopol composites.* Composites Science and Technology, **60**: p. 10, (2000).
[14] Alsina, O., et al., *Thermal properties of hybrid lignocellulosic fabric-reinforced polyester matrix composites.* Polymer Testing, **24**(1): p. 81-85, (2005).
[15] Stocchi, A., et al., *A novel fiber treatment applied to woven jute fabric/vinylester laminates.* Composites Part A: Applied Science and Manufacturing, **38**(5): p. 1337-1343, (2007).
[16] Ahmed, K., S. Vijayarangan, and A. Naidu, *Elastic properties, notched strength and fracture criterion in untreated woven jute–glass fabric reinforced polyester hybrid composites.* Materials & Design, **28**(8): p. 2287-2294, (2007).
[17] Liu, Q. and M. Hughes, *The fracture behaviour and toughness of woven flax fibre reinforced epoxy composites.* Composites Part A: Applied Science and Manufacturing, **39**(10): p. 1644-1652, (2008).
[18] Jawaid, M., H.P.S. Abdul Khalil, and A. Abu Bakar, *Woven hybrid composites: Tensile and flexural properties of oil palm-woven jute fibres based epoxy composites.* Materials Science and Engineering: A, **528**(15): p. 5190-5195, (2011).

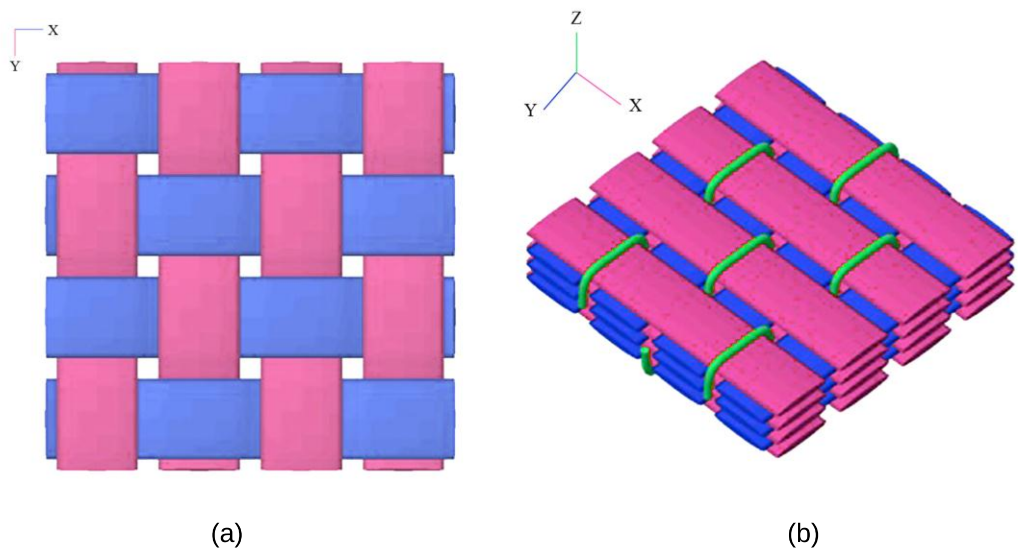

Figure 1 Schematics of 2D plain fabric (a) and 3D orthogonal fabric (b).

Materials	Modulus(MPa)	Break Stress (MPa)	Strain at Break (%)
Epoxy	2449.43	64.37	4.86
2D/Epoxy	3099.91	62.56	2.64
3D/Epoxy	2822.73	34.06	1.33

Table 1 Tensile characteristic of jute/epoxy composites.

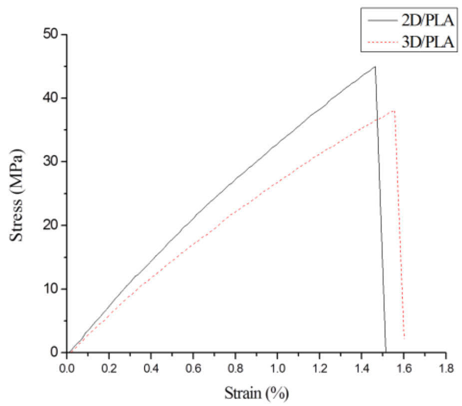

Figure 2 Typical tensile stress-strain curves of jute/PLA composites.

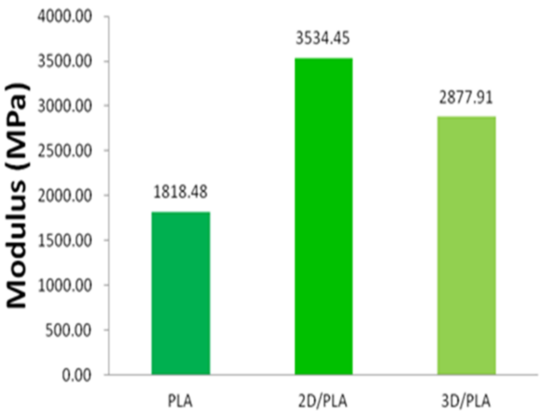

Figure 3 Effects of fabric types on the tensile modulus of jute/PLA composites.

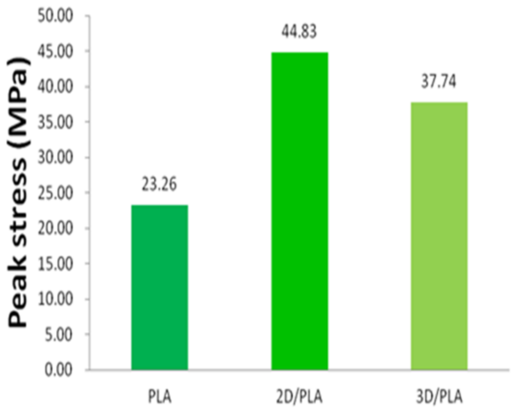

Figure 4 Effects of fabric types on the tensile strength of jute/PLA composites.

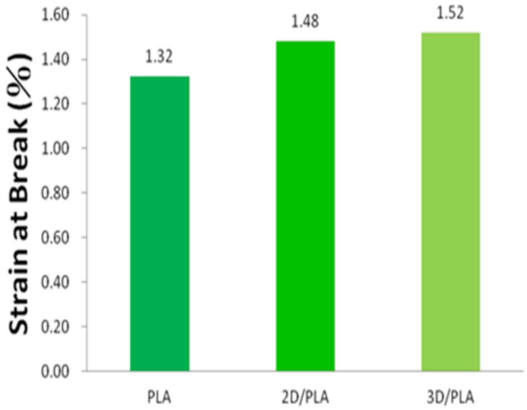

Figure 5 Effects of fabric types on the tensile strain of jute/PLA composites.

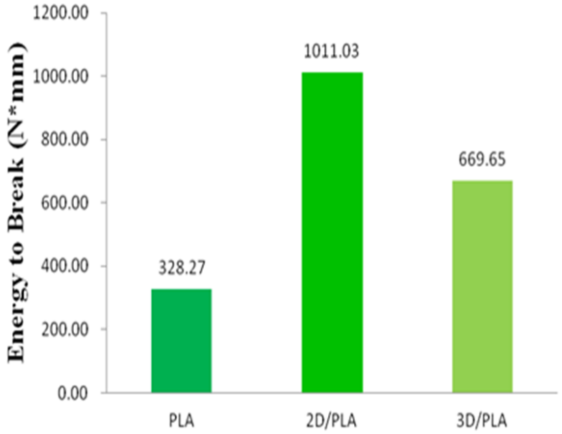

Figure 6 Effects of fabric types on the tensile energy to break of jute/PLA composites.

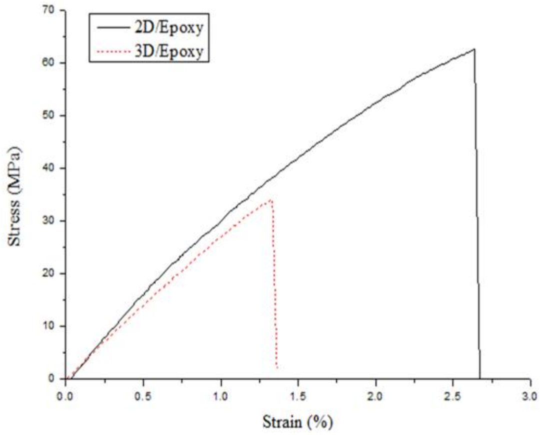

Figure7 Typical tensile stress-strain curves of jute/epoxy composites.

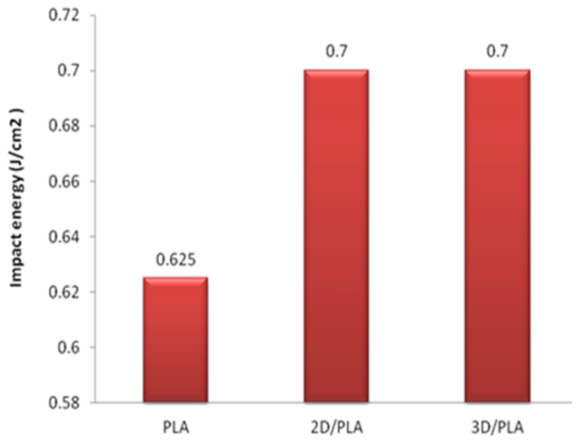

Figure 8 Effects of fabric types on the impact energy of jute/PLA composites.

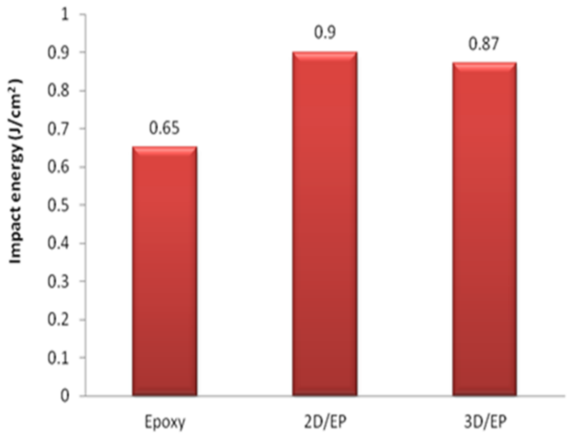

Figure 9 Effects of fabric types on the impact energy of jute/epoxy composites.