Experimental observation of Jute/Epoxy composite Plate Subjected to Impact Loading

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Abstract— **World is currently focusing on alternate material sources that are environment friendly and biodegradable in nature. Due to the increasing environmental concerns, biocomposite made from natural fibers and polymeric resin, is one of the recent developments in the industry and constitute the present scope of experimental work. This work presents elaborate explanation on advantages, mechanical and physical behavior of jute fiber – epoxy composites, one of the renewable alternatives. The bicomposite is experimentally investigated in case of low velocity impact loading. The experimental observations in term of damage mechanism, maximum force and maximum energy absorption are studied to understand the effect of fiber orientation. A comparative study with typical synthetic fibers like carbon or glass is also conducted. The characterization tests on jute-epoxy show that the tensile behavior is non linear as found for carbon-epoxy or glass-epoxy plate.**

I. Introduction

Composite materials have experienced rapid development over the last three decades. From satellites to subsea, from automotive to artificial legs, there is likely to be some aspect of composite performance. A structural composite is a material system consisting of two or more phases on macroscopic level, whose mechanical performance and properties are designed to be superior to those of the constituent materials acting independently.

The composite structure is known for its high ratio between its strength and weight. But, this type of structure has several weaknesses, especially in the case of impact loading even if the impact speed and enegy is relatively low. Unfortunately, for an impacted composite structure with a small depth of damage, the structureal strength subjected to lateral compressive load is decreased up to 50-60% from its initial strength.

The literature survey shows a great deal of work conducted on impact behaviour of composites structure made from synthetic fiber like glass or carbon [1-9]. The studies address the influence of stacking sequences on impact damage of composite laminates of high modulus carbon/epoxy and also the effect of low velocity impact with different projectile diameter on carbon-epoxy and glass-epoxy laminates. In all the case studies, complete penetration of the impactor was observed. Also, it was observed that carbon fibres absorb less energy than glass fibre before failure, independent of the impactor diameter. This may explained by the fact that carbon fibre is relatively more brittle than glass fibre.

Literature survey shows that the study on low velocity and energy impact on synthetic composites are numerous [1-7], but on natural composites especially on jute is very rare. Thus this work aims to perform an experimental study of low velocity impact of natural composite made of jute/epoxy.

Jute is a plant (and by analogy the fibre from this plant) which comes from South East Asia. It is one of the cheapest natural fibres. Jute is a ligno-cellulosic fibre, that is partially a textile fibre and partially wood, of approximately 4 meters length. Following, are some properties of jute fibre:

- High specific modulus compared to glass fiber,
- Good insulating and antistatic properties,
- Low thermal conductivity,
- Acoustic insulating properties,
- Poor drapability
- Sensitive to moisture

In this study, specimens of fabric-reinforced composites were made using three different types of fibres: carbon, glass and jute respectively. The matrix used for all the three composites was epoxy. These specimens were tested and the results were compared to understand the behaviour of the natural composite compared to synthetic fibres composites. The main purpose of this study is to characterize the behaviour of the natural fibre composite under low energy impact.

II. EXPERIMENTAL

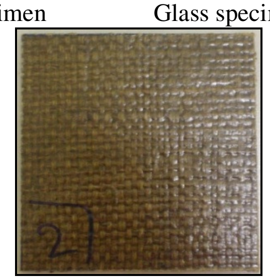
Three flat composite plates from each of the fibers under study, carbon, glass and jute, having dimension of 400 mm x 400 mm with stacking sequence: $[45^\circ]_5$, $[0^\circ]_5$, [0º 0º 45º 0º 0º] were fabricated by hand layup method. Commercial grade epoxy resin system, with hardener to epoxy ratio of 4:1 was used for synthetic fibers while 2:1 was used in the case of jute/epoxy composite plate. Finally regular square test specimens having dimension of 120 mm x120 mm were cut from the big plate, Figure.1 below shows the specimens which are ready to be impacted with the following layups

Specimen 1 [45/45/45/45/45]
Specimen 2 [90/90/90/90/90]
Specimen 3 [90/90/45/90/90]

Two different sets of experiments, tensile and impact test were respectively conducted on to the specimens. To ensure results' repeatability, three samples of 40 mm x 60 mm were cut from each of the composite plate of 120 mm x 120 mm. For clamping purposes in impact and tensile testing machines, aluminium end tabs were bonded to each of the composite specimens. Tensile test was performed to obtain jute/epoxy Young Modulus whereas impact test was performed to find the maximum energy that the plate may absorb before failure.

Carbon specimen

Glass specimen



Jute specimen

Figure 1:Carbon,Glass and Jute Specimens

Figure 2:Impact testing machine

An impact test can be performed using a drop weight or a pendulum impact test machine. In the present study, a drop weight impact machine as shown in Figure 2, was used. The impacting mass also called impactor was equipped with a force sensor and the velocity before impact is obtained by a laser detector.The data obtained allow the calculation of:

- The initial impact energy, using the equation of kinetic energy :

$$E_0 = \frac{m_{impactor}}{2} V(0)^2_{impactor}$$

with:

E_0 : initial impact energy

$m_{impactor}$: impactor mass

$V(0)_{impactor}$: measured impactor's velocity at contact with the structure (corresponding to the time t = 0)

By integrating the equations of fundamental principle of dynamics, the velocity of the impactor during the impact can be obtained from measurements provided by the force sensor.

$$V(t)_{impactor} = V(0)_{impactor} - \frac{1}{m_{impactor}} \int_0^t F(t)dt$$

with:

V(t): impactor's velocity during impact

F(t): measured impact force at *t* time

- The energy absorbed by the structure during impact, knowing the impactor's velocity:

$$E_{abs}(t) = \frac{1}{2} m_{impactor} \left(V(0)^2_{impactor} - V(t)^2_{impactor}\right)$$

with:

$E_{abs}(t)$: energy absorbed by the structure at *t* time

The response of a laminated composite to an impact depends on the impact parameters and the properties of the composite such as: constituent fiber and matrix, stacking sequence, interlaminar shear strength, tensile and flexural properties. Moreover, brittle materials require little energy for crack initiation compared to ductile materials.

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1) *Impactor size:*

In impact testing, geometry and size of impactor is important with respect to the damage induced upon impaction. From the experimental study conducted, it may concluded that energy absorption is greatest with a big impactor (φ20 mm) whereas localized damage is deepest with a small diameter impactor, refer to Figure 3.

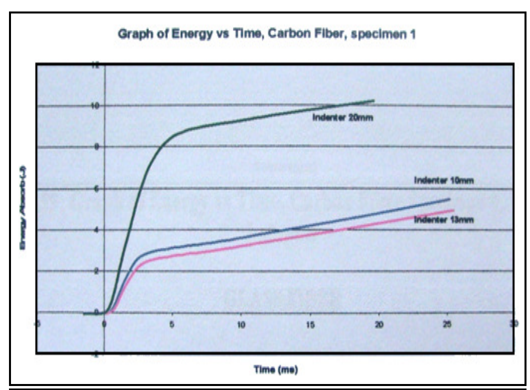


Figure 3, Graph of Energy vs. Time for different impactor sizes.

2) Tensile Test on Composite Specimen

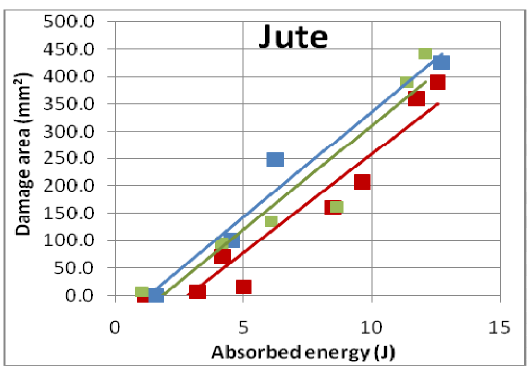
In order to obtain mechanical properties for each type of the fiber reinforced composite material, tensile test was performed using SHIMADZU-AG-X universal testing machine. The elastic characteristics of each composite plate was found which will be later used for finite element analysis. As before, for each fiber type, three specimens of 40 mm x 120 mm, were used.

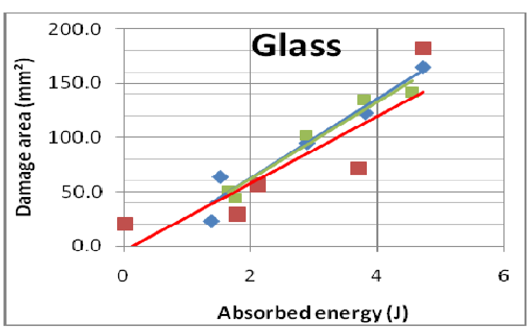
III RESULTS AND DISCUSSION

Failure mechanism

The carbon fiber or the glass fiber, which are susceptible to impact damage because of the brittle characteristics of the reinforced fibers, showed low impact energy absorption, and usually a complete penetration occurs by the impactor. The failure mechanism with the carbon fiber reinforced composite is successive failure of matrix, delamination and fiber breakage.

During impact loading, the area which comes in contact with the impactor is generally called the damaged area and is in fact subjected to the deformation. However, plate bending is most important and pronounced for the corresponding area on the other side of the contact surface. A caliper- was used to measure the damaged area on plates. The studied specimens presented different forms of distorted areas and to measure these areas more precisely four different types of forms were used (square, rectangle, circle and diamond).





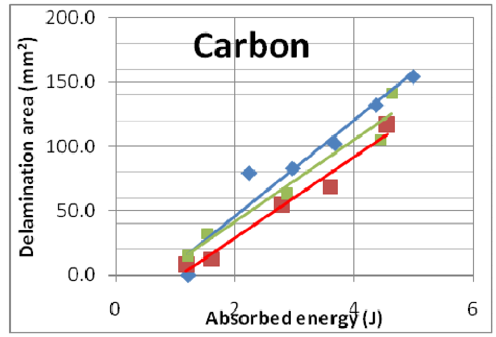


Figure 4: Damage area in function of absorbed energy for each specimen

From Figure 4, it may be observed that, jute specimen has the highest damaged area compared to glass and carbon fibers. This may be explained on account of greater thickness of Jute/epoxy composite plates than the other two types of fiber reinforced plates. However, considering stacking sequence it is observed that specimen no.1 is most brittle followed by no. 3 and no.2. The results of carbon fiber and glass do not respect this order, it may be due to the fact that these plates are too thin that the effect of staking sequence could be observed. The results of the jute seem to be very interesting and significant. We see that the specimen 2 of jute is the one which suffers the least damage instead of specimen 1 of jute. The specimen 3 of jute is located between the two because the layup is a mixture of 0° and 45° layers.

The damaged area does not mean that a material is more fragile than the other but simply that the way the impact energy is absorbed by the composite. For example, in case of specimen no.1, the energy is absorbed by edge delamination and plate bending. Contrary to this, in specimen no2 the energy is absorbed more by the rupture of fibers. In order to better understand the failure mechanism in specimen no.2 of jute/epoxy one can refer to Figure 5 that records strength curves and magnified photos of damaged zone at different impact velocity:

- 1 m/s: the energy is absorbed by compression of the jute fiber. Slight change in strength is observed. At 1.1 m/s: Same as for the tests at 1 m / s)
- 1.4 m/s: Bending is now evident and a characteristic bending failure with fiber breakage at the bottom layer is evident. It can also be seen in the force curve at t = 2 ms, there is a peak.
- 1,5 m/s: It can be seen that the bottom layer is now broken and also bending of the upper layer. It is interesting to note that the Young's modulus of jute is close to that of the resin (E_{jute} = 7.3 GPa and E_{resin} = 3.5 GPa), due to this there is no high shear force between the fiber and resin, and both are working "together"
- 1,6 m/s: The top layer fibres failure can be seen.

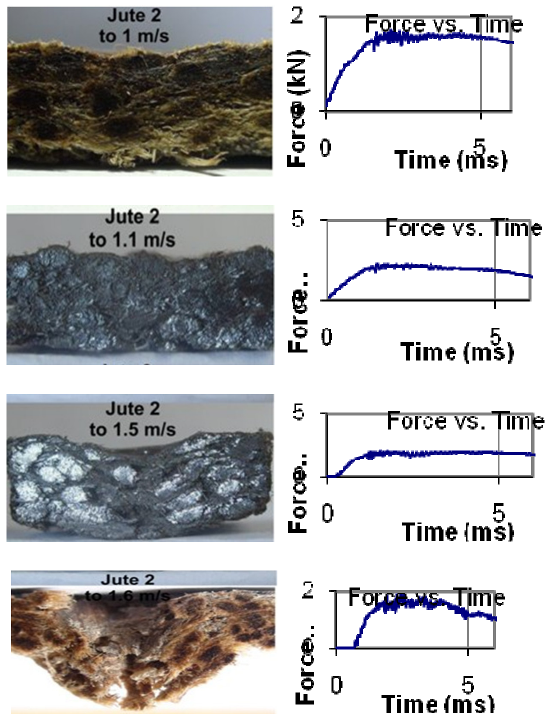


Figure. 5, Investigation of specimen no. 2 of jute/epoxy

In Figure 5 and 6 , from the force diagram and from the pictorial view of the damaged area , it can be concluded that no delamination occurred in the case of jute/epoxy composite specimens as it can be found in glass/epoxy and carbon/epoxy laminate under impact failure.

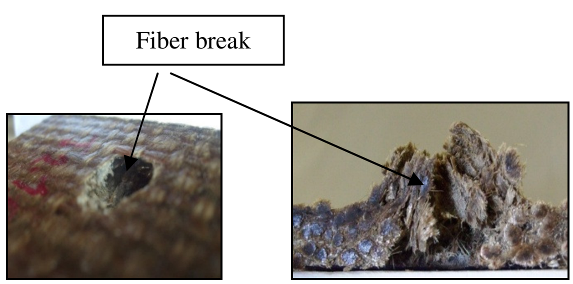


Figure 6: Shear of jute fibre

From the figure 7 and 8, one can observe that the maximum contact force and the maximum energy absorbed is by the 45°/45°/45°/45°/45°stacking sequence specimen.

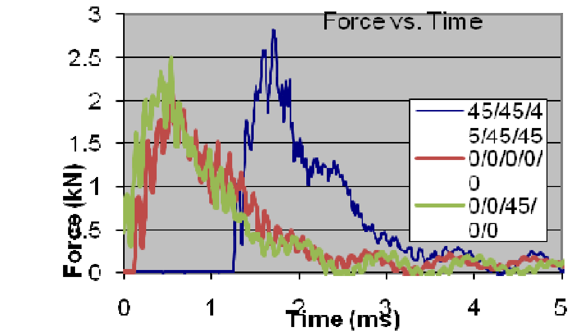


Figure 7 graph of Force VS Time for different stacking sequences of jute specimen

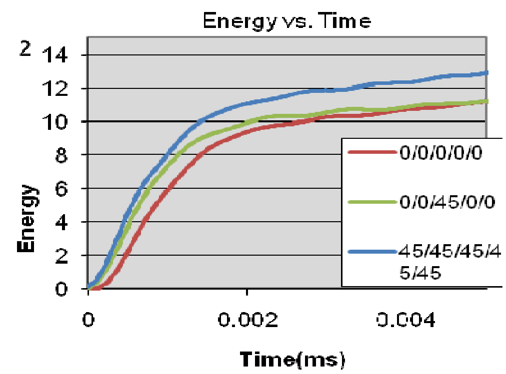
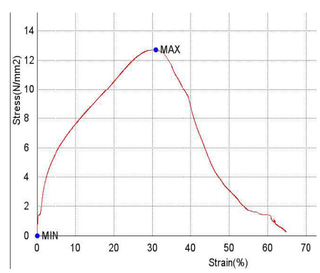
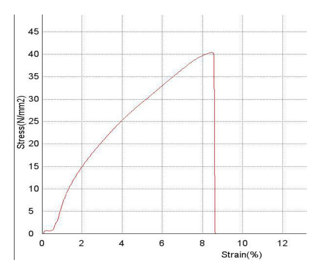


Figure 8 : graph of Energy VS Time for different stacking sequences of jute specimens



Tensile tests - Jute specimen 1



Tensile tests - Jute specimen 2

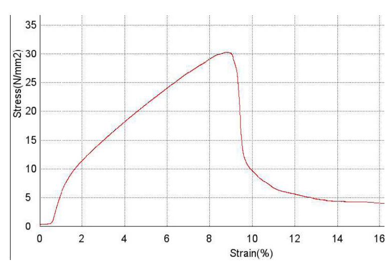


Figure 9: Tensile test for jute specimens

Tensile test were performed for all the types of specimens. Maximum stress, sample elongation and young's modulus, are respectively denoted by ε , σ_{max} and E are recorded. From Figure 9, it can be noted that the stress vs strain curve obtained for Jute/epoxy composite specimens is non linear right from the beginning of the experiment. This behaviour is very important in future simulation studies using finite element approach.

IV CONCLUSIONS

An experimental study on the low velocity impact of jute/epoxy laminates have been carried out. The effect of stacking sequence on the capability of energy absorption was studied and it was found that $[45^0]_5$ is the best configuration that absorbs maximum energy. It is found that the failure of the specimen was by breakage of fibres without delamination which may be attributed to same magnitude of Young's modulus of fibre and matrix. The tensile test of the specimen of Jute/epoxy composite show a non linear behaviour right from the beginning of the experiment which is different from carbon and glass/epoxy laminates.

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