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# A Study on the Mechanical Behaviors of Jute-Polyester Composites

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**Abstract**

In the present exposition, coupon specimens extracted from jute-polyester laminates fabricated by the hand layup method combined with compression molding are subjected to tensile, compression and flexural tests in a UTM. Next a novel hybrid jute-steel composite is studied under similar conditions. It is shown that the gap in tensile strengths in warp and weft directions found in plain jute laminates is perceptibly reduced in their hybrid jute counterparts. Also, hybrid jute laminates have substantive residual tensile strengths on reaching peak strengths as compared to plain jute-polyester composites which fail abruptly, i.e. in a brittle manner, on reaching peak strength. Additionally, hybrid jute composites displayed higher tensile modulus and flexural stiffness, and consistent compressive strength as compared to plain jute-polyester composite laminates. It is shown that improvement in moisture resistance is an additional advantage of hybrid jute laminates.


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*Keywords:* Jute-PolyesterComposite; Hybrid Laminate;Tensile Strength/Modulus;Compressive Strength, Flexural Stiffness; Mositure Absorption.

## 1. Introduction

Fiber-reinforced composites which can often be tailored for a specific structural need are rapidly replacing conventional materials such as metals in a number of industry sectors including aerospace, automotive, rail, petrochemical, civil construction, marine vessels, and sports goods. In demanding applications such as an aircraft body, high performance or advanced fiber-reinforced composites with exceptionally high elastic modulus and failure strengths are preferred. Man-made fibers such as glass and carbon fibers have been dominant as reinforcements in polymer matrix composite materials. However, within the past few decades, utilization of natural plant-based fibers in the form of jute, hemp, coir, flax, etc. in a polymeric matrix has attracted the attention of the scientific community. Due to growing environmental concern over using synthetic fibers in composites, researchers have felt the need for exploring renewable resources in the form of natural plant fibers as reinforcement in composites.

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As an additional benefit, such a consideration would ensure good economic returns for cultivation of the above-mentioned natural fibers. When compared with man-made fibers, natural fibers are generally of lower cost and density, and are biodegradable with acceptable specific mechanical properties. Also, unlike glass fibers, these are generally not hazardous to health. Hence, it makes a lot of sense to study and characterize natural fiber-reinforced composites for common applications in which these are still relatively rare.

Bledzki and Gassan [1] have reviewed the most readily-used natural fibers in polymer composites up until 1999 in their review paper. Faruk et al. [2] in their paper reviewed more recently-used natural fibers as reinforcement in polymer composites (from 2000 to 2010). Summerscales et al. [3] in Part 1 of their review paper discussed in detail growth, harvesting, fiber separation and then characterization of bast fibers. Bast fibers included were jute, hemp, nettle, kenaf and flax. In Part 2 [4] of their review the same authors focused on micromechanics-based prediction of the properties of natural bast fiber reinforced composites, manufacturing techniques, and characterization using microscopy, mechanical, chemical and thermal techniques. The review concluded with a brief overview of potential applications and environmental considerations which might expedite or constrain the adoption of these composites. Ku et al. [5] reported a detailed review of the tensile properties of natural fiber reinforced polymer composites. In this review, various aspects such as effect of fiber volume fraction and surface treatment of fibers on tensile strength of composites were discussed.

It may be pointed out that relatively few studies are available on mechanical characterization of jute fiber based composite laminates [6-12]. Shah and Lakad [6] presented the mechanical properties of unidirectional jute-polyester and jute-epoxy composites as well their hybrid versions by adding glass fibers. Acha, Marcivich and Reboredo [7] carried out physical and mechanical characterization of jute fabric; the authors further investigated the effects of jute fiber treatments on the performance of resulting composites. Gowda, Naidu and Chhaya [8] evaluated various basic mechanical properties of jute-polyester composites such as tensile strength, compressive strength, flexural strength, impact strength, in-plane shear strength, inter-laminar shear strength and hardness. In their studies, the authors demonstrated the potential of this renewable source of natural fiber for use in a number of consumable goods. Ahmed and Vijayarangan [9] investigated mechanical behavior of isothalic polyester based untreated woven jute-fabric composites under tensile, compressive, in-plane shear, inter-laminar shear and impact loading conditions.

One of the main concerns in the use of natural fiber reinforced composite materials is their susceptibility to moisture absorption and the effect of the latter on their physical, mechanical and thermal properties. A few authors have studied the moisture diffusion phenomenon in natural fiber based composites and the effect of moisture uptake on their properties [13 -16].

In the current work, a systematic comparative study has been carried on the mechanical behaviors of jute-polyester composite laminates of varying ply counts, and the efficacy of hybridization with steel mesh is shown.

## 2. Materials and Methods

Commercially available bidirectional untreated woven jute mat with a thread count of 17 × 15 (i.e. 17 and 15 yarns in warp and weft directions respectively per inch) was used as a reinforcement for the fabrication of jute-polyester composites in the current study. The area density of the commercially-available jute mat used was approximately 220 $g/m^2$ (gsm). The density of the jute fibers was likely to be in the range of 1.3-1.4 g/cc [3]. The thickness of jute mat was found to be around 0.5 mm. In Fig. 1 is shown a piece of jute mat used in the manufacturing of composite laminates. The matrix material was prepared from commercially available general purpose polyester (GPP) resin to which were added cobalt naphthenate accelerator and MEKP catalyst in a weight ratio of 1:0.015:0.015 respectively.

Jute-polyester (JP) composite laminates were manufactured for different volume fractions of jute fiber by the hand-layup technique. Jute fabrics were pre-impregnated with the matrix material. The impregnated layers were placed one over the other and pressed for two hours in a compression molding machine. Uniform thickness was achieved by using spacers of desired thickness between the mold plates. After two hours, the laminate was removed from the mold and cured at room temperature for forty-eight hours. One such JP composite laminate is shown in Fig. 2.

Laminates with different counts of jute plies were fabricated. These laminates were designated as nJ, where n (= 4, 5, 6, 7) is the number of jute plies in a given laminate. In addition, hybrid laminates with steel mesh plies interspersed between jute plies in a symmetrical configuration with respect to a laminate mid plane were made. The hybrid laminates were named as nJmS, where in addition to n (= 4) jute plies, m (= 1, 2, 3) is the number of steel plies incorporated in a laminate. Laminates of different configurations resulted in different volume fractions of jute. The volume fraction of jute fiber, $V_f$, can be calculated for a given laminate using the following relation:

$$V_f = \frac{\rho_m W_f}{\rho_m W_f + \rho_f W_m + \frac{\rho_m \rho_f}{\rho_s} W_s} \quad (1)$$

where, $W_f$= weight of jute fibers; $W_m$= weight of matrix i.e. resin; $W_s$= weight of steel plies; $\rho_f$= density of jute fibers; $\rho_m$= density of matrix; and, $\rho_s$= density of steel. If a laminate contains jute mat plies only, $W_s$=0 should be substituted in the right hand side of Eq. (1).

The volume fraction of steel, $V_s$, in a hybrid jute-steel laminate can be obtained from the following relation:

$$V_s = \frac{\rho_m \rho_f W_s}{\rho_m \rho_s W_f + \rho_f \rho_s W_m + \rho_m \rho_f W_s} \quad (2)$$

It is noted that the sum of volume fractions of jute, steel and polyester in a given laminate is unity (i.e. $V_f + V_s + V_p$ = 1). The volume fraction of polyester, $V_p$, can therefore be obtained as (1- $V_f$ -$V_s$).

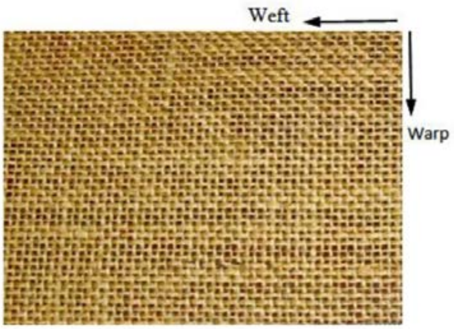


Fig. 1. A piece of woven jute mat

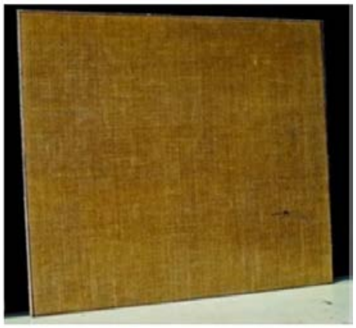

Fig. 2. A fabricated jute-polyester composite laminate

## 2.1. Specimen Preparation

Test specimens of required dimensions were cut from laminates as per the relevant ASTM standards. Three specimens each in warp and weft directions were cut from the same laminate for tensile, compression and flexural tests. Specimens were carefully cut from the laminates using a diamond saw with sufficient allowance for finishing. Final dimensions were arrived at by finishing the specimens with medium grade emery paper.

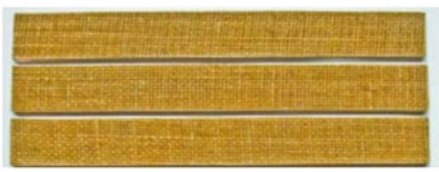

Fig. 3. Coupon specimens for tensile testing

Fig. 4. Servo-hydraulic UTM used for characterization tests

### *2.2. Tensile Testing*

Tensile specimens of jute and hybrid jute composites were prepared as per the ASTM-D3039 standard. A few such samples are shown in Fig. 3. Thickness of specimens varied depending on the number of jute plies and volume fraction of jute fiber in a given laminate. Tests on specimens of jute-polyester as well as hybrid jute-steel composites were carried out using a computer-controlled servo-hydraulic Universal Testing Machine (UTM) of make BiSS, Bangalore, India, with a load cell of capacity 100 kN (Fig. 4). All tests were carried out at a crosshead speed of 1 mm/min for determining the tensile strength and stiffness of a given composite laminate.

### *2.3. Compression Testing*

UTM-based compression tests were carried out as per the ASTM-D6641 standard at a cross-head speed of 1 mm/min. According to the stated standard, a compression test specimen measured 130 mm in length and 13 mm in width, and was held in a UTM between grips with a small gage length of 12 mm to avoid buckling of the specimen during the application of compressive load in a test. Load-displacement data was collected until failure occurred in a given specimen.

## 3. Results on Mechanical Behaviors of Laminates

Average tensile strengths of tested coupon samples of different laminate configurations mentioned earlier are presented in the form of a bar chart in Fig. 5. It can be readily seen in this figure that the tensile strength of a laminate is higher in the warp direction as compared to the weft direction. Also, there is a noticeable increase in the strength of a plain jute-polyester laminate in the warp or weft direction as the number of jute plies increased. It is quite likely that this gain in strength (50 MPa for 4J to about 70 MPa for 7J in the warp direction) was mainly due to an increase in the volume fraction ( $V_f$ ) of jute fibers as the laminate thickness (3-3.5 mm) did not change appreciably while the number of jute plies was increased from 4 to 7. Fig. 5 also indicates that the presence of steel plies in a hybrid jute-polyester laminate does not lead to an enhancement of tensile strength when one or more of jute plies in the original plain jute-polyester laminate are replaced with steel plies in the hybrid laminate. The main reason for this behavior is the fact that even in a hybrid laminate, the peak load reached in a tensile test is limited by the strength of jute fibers in a woven jute mat. A benefit of hybridization, however, is the fact that the difference in strengths in warp and weft directions is perceptibly lower for a hybrid laminate as compared to a laminate reinforced with only jute mats.

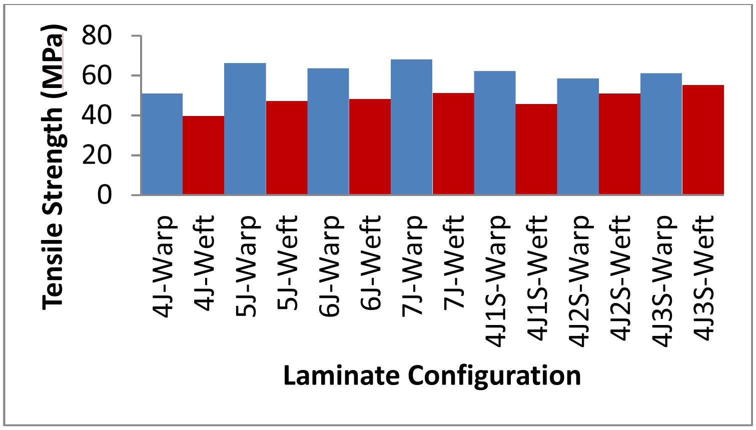


Fig. 5. Tensile strengths showing higher consistency of hybrid jute-steel composite laminates

Data on standard deviation (SD) of tensile strength for multiple coupon samples extracted from a given laminate is presented in the bar chart displayed in Fig. 6. The maximum SD as a percentage of mean tensile strength (of samples tested for a given laminate configuration) is found to be around 6% only which points out to the spatial consistency of mechanical properties in a laminate.

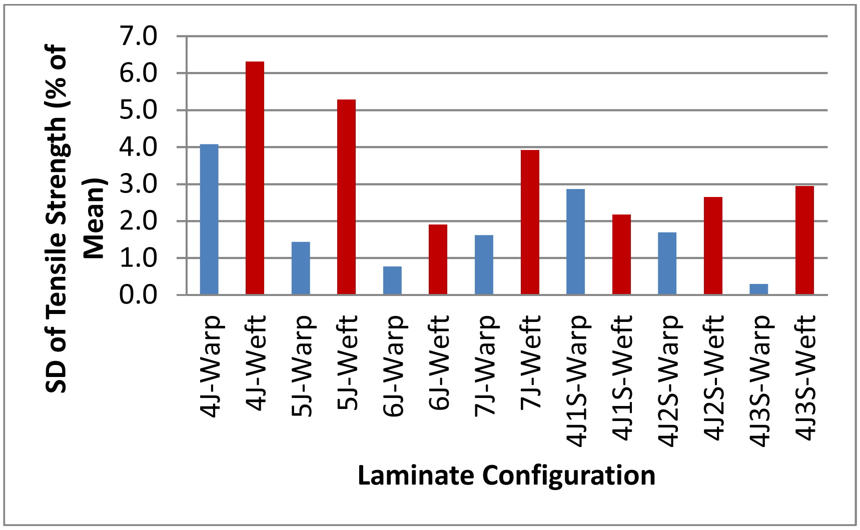


Fig. 6. Variability of tensile strengths of samples of a given laminate configuration

Bars on tensile strengths and % values of SD given in Figs. 5 and 6 were an outcome of tensile stress versus tensile strain curves obtained in tests carried out in a calibrated UTM shown in Fig. 4. A set of typical test-based curves for the laminate types considered in the current study for warp direction is given in Fig. 7. It is clearly seen in the latter figure that each hybrid jute-steel-polyester laminate possesses a secondary strength after the initial drop in peak stress and fails at a substantively higher strain as compared to laminates with jute plies only. Thus, hybrid laminates would generally have higher energy-absorption capability as compared to purely jute ply-based laminates, and are unlikely to fail catastrophically.

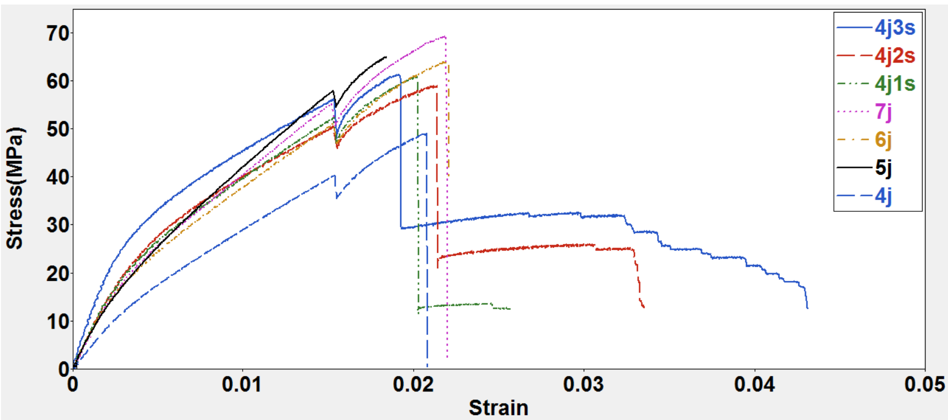


Fig. 7. Stress-strain curves for jute and hybrid jute composites obtained under quasi-static tensile loading

The tensile moduli of the tested jute laminates are presented in Fig. 8. The groups of blue and mustard bars tend to indicate that tensile modulus increases with respect to (a) jute fiber volume fraction for laminates reinforced with only jute mats, and (b) combined volume fraction of jute and steel in the hybrid laminates. Unlike in the case of tensile strength which did not increase on addition of steel reinforcement, tensile modulus registered a consistently higher value for hybrid laminates as compared to corresponding only jute ply-based laminates.

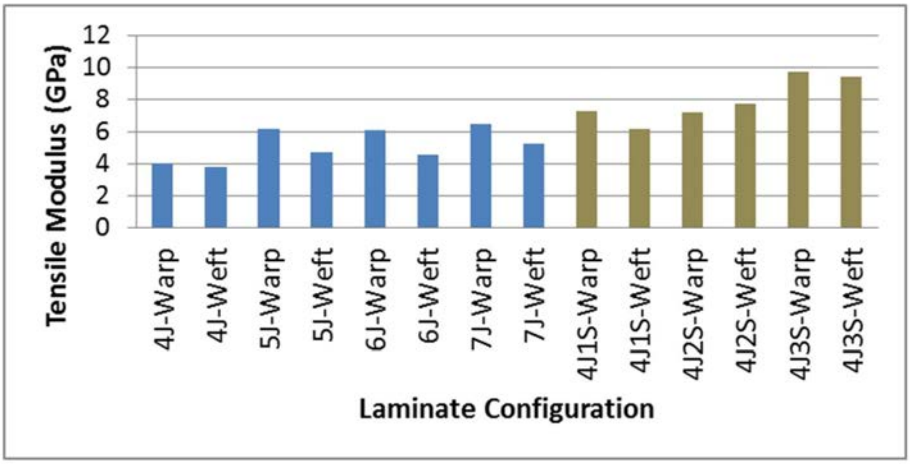


Fig. 8. Tensile moduli of plain and hybrid jute laminates

A picture of a compression testing specimen held between the hydraulic grips of the UTM used earlier for tensile testing is shown in Fig. 9. Additionally, a photo of a jute-polyester specimen subjected to a three-point bending test in the same UTM is given in Fig. 10.

Fig. 9. A compression specimen within grips

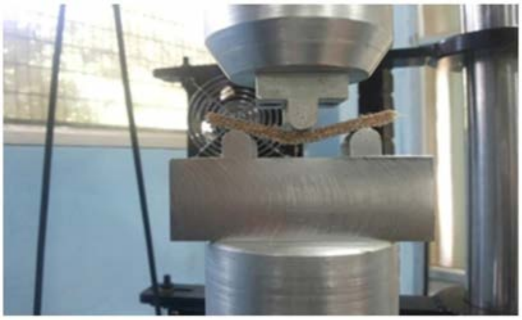

Fig. 10. A specimen being subjected to flexural testing

Test-based laminate compressive strengths are presented in a bar chart in Fig. 11. It is observed in this figure that compressive strength decreases with increasing fiber volume fraction (i.e. decreasing polyester volume fraction) in purely jute ply-based laminates. On the other hand, the compressive strength of a hybrid laminate is nearly same for different configurations of the laminate and is around 60 MPa.

Load-displacement curves obtained from typical flexural tests, one of which is shown in Fig. 10, are given in Fig. 12. It is noted from this figure that: for the same total number of plies, there is an increase in slope of the force-displacement curve for a jute-steel laminate as compared to its corresponding jute-only version. This outcome would imply that flexural modulus would potentially increase when one or more of the jute plies in a laminate is replaced with a steel ply. Additionally, it needs to be pointed out that while a plain jute composite specimen fails quickly (in a brittle manner) on reaching the peak load, the flexural load persists at a steady level subsequent to reaching the peak load in a hybrid laminate. Thus the present category of hybrid jute composite laminates is potentially a safer option compared to plain jute laminates for structural components subjected to bending loads.

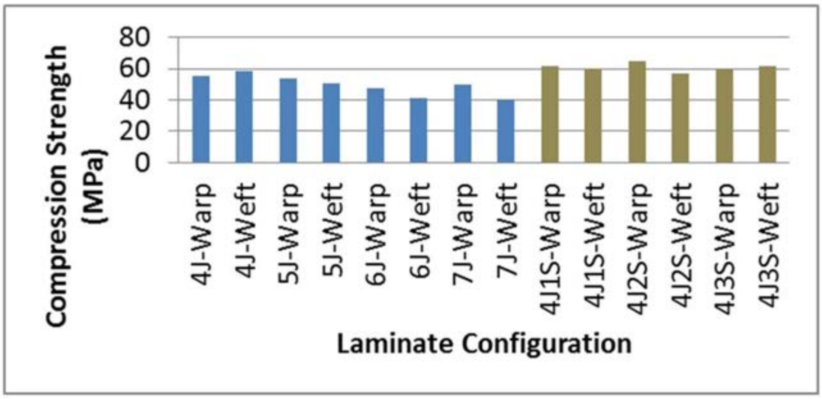


Fig. 11. Compression strengths of plain and hybrid jute laminates

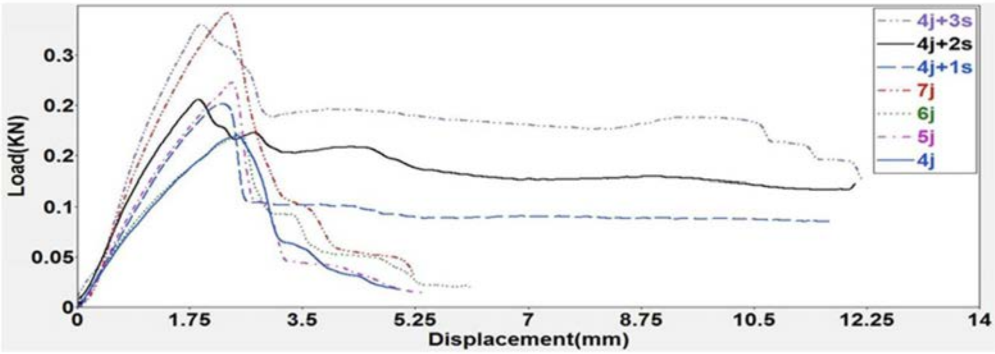


Fig. 12. Load-displacement curves obtained in flexural testing of plain and hybrid jute laminates

## 4. Effect of Moisture Absorption

Applications of natural fiber based composites such as the current jute-polyester composite can be seriously limited due to the propensity of such composites towards moisture absorption which can lead to a deterioration in mechanical properties such as tensile modulus. A limited study has been conducted here to assess the rate of moisture absorption in plain jute-polyester and hybrid jute-steel-polyester laminates.

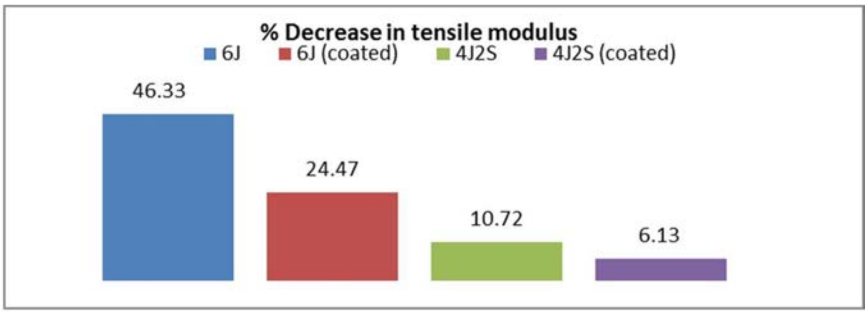


Fig. 13. Reduction in tensile modulus due to water absorption by composite specimens

Pairs of 6J and 4J2S coupons of same dimensions as the tensile test specimens previously considered were used in the present moisture absorption study. In one each of the two types of specimens mentioned, the four cut faces containing laminate thickness as one dimension were coated with polyester resin. In the tensile test results presented in Fig. 13, these specimens are referred to as 6J (coated) and 4J2S (coated). It was found that uncoated 6J and 4J2S specimens absorbed around 7% and 4% of moisture respectively after being immersed in water for 36 hours. On the other hand, after the same time interval of 36 hours, coated specimens of types 6J and 4J2S absorbed only 1.5% of moisture. It observed from Fig. 13 that percent reduction in tensile modulus due to moisture absorption is significantly lower in hybrid laminates as compared to plain jute laminates.

## 5. Conclusion

In the current study, selected mechanical properties of jute-polyester composites have been compared with those of hybrid jute-steel-polyester composites. It has been found that the hybridization is generally beneficial in terms of increasing tensile and flexural moduli, reducing chances of brittle failure, and arresting fall in tensile modulus due to moisture absorption.

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