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Effect of Fiber Parameters on Mechanical Behavior of Banana-Palmyra Hybrid Fiber Reinforced Epoxy Composites

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Abstract

This article depicts the mechanical properties of banana- palmyra hybrid fiber reinforced epoxy composites as a function of the overall fiber loading (10, 20, 30, and 40 wt.%) and different weight ratios of banana and palmyra (1:1, 1:3, and 3:1). Experimental tests are carried out as per ASTM standards to find the tensile modulus and strength, flexural modulus and strength, inter-laminar shear strength, impact energy and micro-hardness properties. The experimental investigation reveals that the tensile strength, flexural strength, flexural modulus, and interlaminar shear strength show their maximum values at 30 wt.% of fiber loading with banana and palmyra weight ratio as 1:3. On the other hand, tensile modulus, impact energy and micro-hardness increase with increase in fiber loading. Morphological study is also carried out to observe the fractured surface of the hybrid composites using scanning electron microscope.

Keywords: *Fiber loading, hybrid composite, mechanical properties, natural fibers*

1. Introduction

In the last few decades, natural fiber reinforced polymer composites provide us good alternatives to synthetic fiber composites because of synthetic fibers are toxicity to the environment and quite expensive materials. Natural fiber reinforced composites have excellent properties such as light weight, low density, low cost, environmental friendly, biodegradability, renewability, nontoxicity, and nonabrasive processing characteristics [1]. The natural fibers like kenaf, coir, banana, hemp, sisal, jute, vakka, flax, palmyra and pineapple leaf have shown better mechanical properties with a thermoset matrix, thus attracting the attention of researchers and material scientists for the application in civil structures, furniture, consumer goods, food packaging, and automotive components [2-3]. Among various natural fibers, palmyra and banana fibers have the potential to be used as reinforcement in polymer composites which is abundantly available in countries like India, Sri Lanka, and some of the African countries but are not optimally utilized [4]. palmyra is an important agro-fiber which has gained world-wide attention as a potential material for polymer reinforcement due to its natural properties such as high tensile modulus, low density and low elongation at break and its specific stiffness and strength. Banana fiber is a waste product of banana cultivation. Hence, without any additional cost these fibers can be obtained in bulk quantity and used for industrial purposes. Several researches have been taken place in this direction. Satapathy et al. [5] studied the effect of fiber loading on physical and mechanical properties of jute fiber reinforced epoxy composites. It was found that the tensile strength and flexural strength of jute fiber reinforced epoxy composites increases with the fiber loading. These results showed that the jute fiber improves the load bearing capacity and the ability to withstand bending of the composites. The effects of the fiber loading and fiber length on mechanical properties of short banana fiber reinforced epoxy composites were investigated by several researchers [6-7]. It was found that the tensile strength and tensile modulus had their highest values of 67.2 MPa and 653.07 MPa respectively at 15mm fibre length and 30% weight fiber loading. Sapuan et al. [8] carried out the experimental tensile and flexural tests on woven banana fiber reinforced epoxy composites. It was found that the maximum Young's modulus values along longitudinal and transverse directions are 0.976 GPa and 0.863 GPa and stress in longitudinal and transverse directions are 14.14 MPa and 3.398 MPa, respectively. From the results of three-point bending test the maximum modulus and stress in longitudinal direction was recorded to be 2.685 GPa and 26.181 MPa, respectively.

The conventional composites normally possess only one type of reinforcement and termed as monocomposites. Composites having more than one type of reinforcement contained in a single matrix are called hybrid composite. Hybrid composites have unique features that can be used to meet various design requirements in a more economical way than conventional composites [9]. The hybrid composites can be fabricated by the combinations of synthetic–synthetic, synthetic–natural, and natural–natural fiber types. In synthetic–natural fiber reinforced hybrid composites, most of the research works aim to reduce the use of synthetic fibers. Many researchers in the past have developed hybrid composites using synthetic–natural fibers such as banana/glass [10], jute/glass [11], sisal/glass [12], oil palm/glass [13], pineapple/glass [14], kenaf/glass [15] and sugar palm/glass [16] to name the few. Samal et al. [17] evaluated the mechanical properties of banana-glass fiber reinforced polypropylene hybrid composites. The hybrid composite results are compared with banana fiber reinforced polypropylene composites, the results shown that the maximum improvement in the properties was observed at 30 wt% of fiber loading. Idicula et al. [18] evaluated the mechanical properties hybrid composites by adding the short banana/sisal fiber as a reinforcement material. The composites are fabricated at a constant fiber loading of 0.40 volume fraction by varying the relative volume fraction of banana and sisal fiber. This study showed that the banana as the skin material and sisal as the core material gives slightly higher tensile properties as compared to other composites. Ramesh et al. [19] were developed sisal-jute-glass fiber reinforced polyester composites to study the mechanical properties such as tensile, flexural and impact strength. The results showed that the incorporation of sisal-jute fiber with glass fiber reinforced polymer composites can improve the properties. Srinivasan et al. [20] studied the thermal and mechanical properties of a hybrid composite consisting of flax, banana and glass fiber. It was found that the hybrid composite has better mechanical properties compare to the single fiber glass reinforced composite. Flexural and impact properties of banana and pandanus woven fiber reinforced unsaturated polyester composites studied by Mariatti et al [21]. They have concluded that the banana fiber composites exhibit higher flexural and impact properties compared to that of pandanus fiber composites. The effect of glass fiber hybridization with the randomly oriented banana and sisal fiber has been studied by Arthanarieswaran et al. [22]. This study showed that the tensile, flexural and impact properties are affected by the factors such as formation of micro cracks, presence of voids, poor adhesion between fiber and matrix, and fiber pullout. The static and dynamic mechanical properties of banana/glass woven fabric reinforced polyester composites were determined by Pothan et al. [23]. The SEM study revealed that the banana fiber reinforced with polyester composites has better fiber/matrix bonding at 40% fiber loading as compared to 10 and 20% fiber loading. Saw et al. [24] fabricated the jute-coir hybrid composites by using epoxy resin and tested physical and mechanical properties of this composite. It was found that the hybridization of coir fibers composites with jute fibers can improve the density, dimensional stability and extensibility of pure coir composites.

The literature survey on hybrid composites indicated that no work has been reported on epoxy based hybrid composites of banana and palmyra fibers. This research paper attempts to explore the potential utilization of palmyra fibers as composite reinforcement with combination of locally available banana fibers as reinforcement in epoxy matrix. The present work deals with the mechanical characterization of banana-palmyra fiber reinforced epoxy composites at different fiber loadings as well as by varying the weight ratio of banana and palmyra as 1:1, 1:3, and 3:1.

2. Materials and Methods

2.1 Materials Description

In the present work, epoxy resin (LY 556) is used as the matrix material and its common name is Bisphenol-A-Diglycidyl-Ether chemically belongs to 'epoxide' family. The resin and the corresponding hardener (HY 951) were supplied by Ciba Geigy India Ltd. Banana and palmyra fibers are used as reinforcement materials for fabricating the composite specimen. Banana fiber has been obtained from V. K Enterprise, Gujarat and palmyra fiber has been obtained from the local supplier.

2.2 Fabrication of Hybrid Composite

The fabrication of the composite slabs is done by conventional hand lay-up technique followed by light compression molding technique. Keeping the weight ratio of banana and palmyra as 1:1, 1:3, and 3:1, the hybrid composites were fabricated at different fiber weight percentages (0, 10, 20, 30, and 40 wt.%). The epoxy and hardener HY951 are mixed in a ratio of 10:1 by weight as recommended. Banana and palmyra fibers were pre-impregnated with the matrix material. For quick and easy removal of the composite material, a mold release sheet and mold release spray is used on the top and bottom of the wooden mold. Care was taken to avoid formation of air bubbles during preparation. The pressure was applied from the top and then mold was allowed to cure at room temperature for 48 h. After 48 h, the samples were taken out of the mold and cut into required size by diamond cutter for calculating mechanical properties.

2.3 Mechanical Characterization

In the present work, the tensile test is performed by universal testing machine Instron 1195 at a cross head speed of 10 mm/min as per ASTM standard D3039-76. The dimension of the specimen is 153 mm × 12.7 mm × 4 mm and a span length of 70 mm was employed. The tensile modulus and tensile strength of the hybrid composites were determined from the stress strain curves. The three-point bend test is carried out to obtain the flexural properties of all the hybrid composites. The flexural test was carried out on rectangular specimens of composite samples using same universal testing machine Instron 1195 according to the procedure described in ASTM D790. The dimension of the specimen is 100 mm × 12.7 mm × 4 mm and a loading span of 40 mm was employed. The short beam shear tests are performed on the composite samples at room temperature to evaluate the value of interlaminar shear strength (ILSS). The test is conducted as per ASTM standard has the designation D2344-84 using the same universal testing machine Instron 1195. The dimension of the specimen is 45 mm × 10 mm × 4 mm at a crosshead speed of 2 mm/min. The impact test is conducted as per ASTM standard has the designation D 256 by using Charpy impact tester supplied by VEEKAY test lab, India. The dimension of the specimen is 64 × mm 12.7 × mm 4 × mm and the depth of the notch is 2 mm at 45º angle on one side at the center. A Vickers hardness tester is used to measure the micro-hardness of the hybrid composite samples as per ASTM D785 test standards.

3. Result and Discussion

3.1 Tensile Properties of Hybrid Composites

The influence of fiber loading on elastic modulus of the banana- palmyra composites is shown in Fig 1. The elastic modulus increases continuously with increase in fiber loading in all weight ratios. The experimental results shows that the maximum elastic modulus of the hybrid composite is 4.017 GPa, 4.195 GPa, and 3.864 GPa at 40 wt.% of fiber loading with weight ratio of banana and palmyra as 1:1, 1:3, and 3:1 respectively. The percentage increment in elastic modulus of the hybrid composites with weight ratio of banana and palmyra as 1:1, 1:3 and 3:1 is found 27.92, 33.59, and 23.05% respectively at the maximum fiber loading over the pure epoxy. The maximum elastic modulus is obtained for the banana- palmyra fiber composite having weight ratio of 1:3 at 40 wt.% of fiber loading. The tensile properties of hybrid natural fiber composites depend on many parameters such as fiber length, fiber orientation, fiber strength, modulus, and the interfacial bonding between fiber and matrix. The similar trend of results is also observed by previous researchers [25].

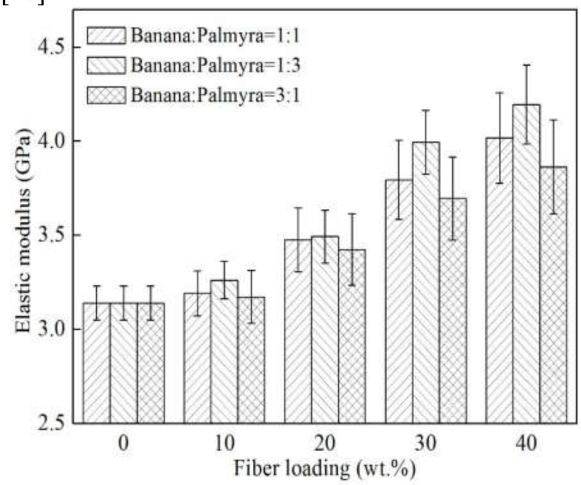

Fig.1: *Effect of fiber loading on elastic modulus of hybrid composite.*

The influence of fiber loading on tensile strength of the banana- palmyra composites is shown in Fig 2. It is observed from the Fig. 2; tensile strength of neat epoxy resin is found to be 32.28 MPa. A gradually increase in tensile strength can be observed with the increase in the fiber loading up to 30 wt.% of banana- palmyra epoxy based hybrid composites. This is due to the proper adhesion between the both types of fiber and the matrix. However, further increase in fiber loading, i.e., 40 wt.%, there is a decrease in the tensile strength. The reason is that the matrix content is highly reduced by the accumulation of excess fibers in the hybrid composites. Moreover, the possibility of fiber entanglements and agglomeration results in the hybrid composite that leads to decrease in stress transfer between the matrix and the fiber. The tensile strength of the hybrid composite with weight ratios of banana and palmyra as 1:1, 1:3, and 3:1 are in the range of 60.38 MPa, 65.84 MPa, and 56.76 MPa respectively at 30 wt% of fiber loading. Hybrid composites with a weight ratio of banana and palmyra 1:3 show higher tensile strength at all fiber loadings. The surface area of the fiber in a unit area of the composite is higher in a palmyra fiber than that of a banana fiber because the diameter of palmyra fiber is less than that of banana fiber. Hence, stress-transfer in the unit area as well as physical interaction is higher in the case of 1:3 weight ratio of banana- palmyra composites [18].

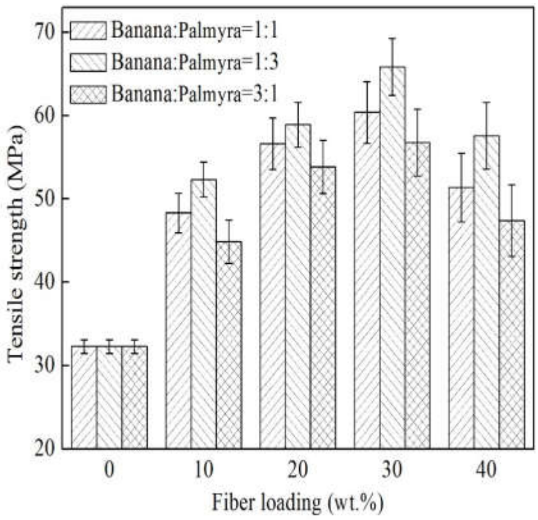

Fig. 2. *Effect of fiber loading on tensile strength of hybrid composite.*

3.2 Flexural Properties of Hybrid Composites

In flexural loading, the hybrid composite samples are subjected to tension, compression and shear stresses [26]. In a flexural test, failure occurs due to bending and shearing. The flexural properties such as flexural strength and modulus of the banana-palmyra fiber reinforced epoxy based hybrid composites are investigated by varying the fiber loading. Figs. 3 and 4 show the effect of fiber loading on flexural strength and modulus of the hybrid composites having weight ratio of banana and palmyra as 1:1, 1:3, and 3:1. It is observed that the flexural properties of all hybrid composites considered in the present study increases with increase in fiber loading up to 30 wt.%. However, further increase in fiber loading the properties decreases.

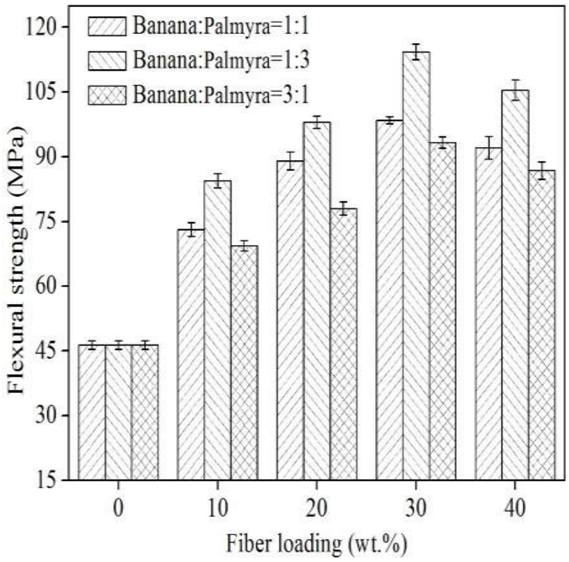

Fig. 3. *Effect of fiber loading on flexural strength of hybrid composite.*

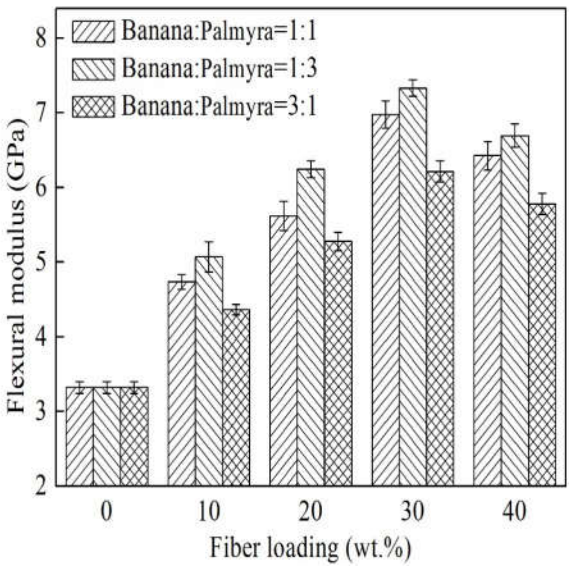

Fig. 4. *Effect of fiber loading on flexural modulus of hybrid composite*

The decrease in flexural properties at higher weight percentages of fiber may be due to weak interfacial bonding, fiber agglomeration, increased fiber-to-fiber interactions and also dispersion problem [27]. According to Mohanty et al. [28], the optimum fiber loading varies with the fiber aspect ratio, nature of fiber and matrix, fiber–matrix adhesion, etc. The flexural strength of the banana and palmyra fiber composite having weight ratio of 1:3 is 16.12% and 22.54% higher than those of banana and palmyra fiber composite having weight ratio of 1:1 and 3:1, respectively at 30 wt.% of fiber loading. The flexural modulus of the neat epoxy resin is found to be 3.32 GPa whereas the flexural modulus of hybrid fiber reinforced composites having weight ratio of banana and palmyra as 1:1, 1:3, and 3:1 is increased to be 110, 120 and 87%, respectively at 30 wt.% of fiber loading. The high strength palmyra fiber layers are able to bear the applied tensile and compressive stresses subjected on the hybrid composites. This results in an increase in the flexural properties of the hybrid composites with weight ratio of banana and palmyra as 1:3. Bledzki and Gassan [29] observed the flexural properties of the composites influenced by various parameters such as degree of crystallinity, the porosity content, and the size of lumen.

3.3 Interlaminar shear strength of hybrid composites

Short beam shear test is carried out on the hybrid composites with different fiber loadings to determine the ILSS. This method is most used in practice for seeking interlaminar shear performance of composites because of its simplicity and inexpensive nature. In this test, the maximum shear stress occurs at the neutral plane where the normal stresses are zero. This results in combination of failure modes, such as, interlaminar shear cracking, fiber rupture and micro buckling [30].

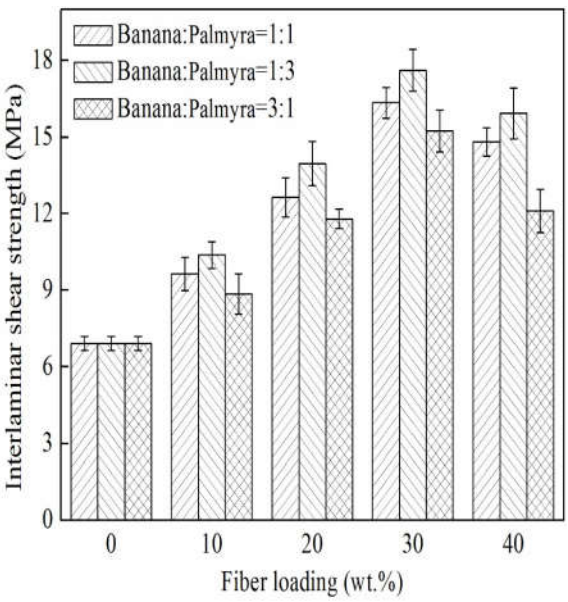

Fig. 5. *Effect of fiber loading on interlaminar shear strength of hybrid composite.*

Fig. 5 shows the effect of fiber loading on ILSS of banana- palmyra hybrid composites. It is noted that the ILSS is increasing with the addition of fiber up to 30 wt.% of fiber loading and is decreasing with further increase in fiber loading up to 40 wt.%. The constituent materials, the fiber loading, the bonding between fiber and matrix, void content and fiber orientation govern the ILSS of the hybrid composites [31]. In the present investigation, the maximum value of inter-laminar shear strength 16.35 MPa, 17.62 MPa, and 15.24 MPa has been recorded for the banana and palmyra fiber composite having weight ratio of 1:1, 1:3, and 3:1, respectively. The reduction of ILSS may be due to the formation of voids in the matrix which is generally located at the interlaminar region of composites.

3.4 Impact Energy of Hybrid Composites

When hybrid composites are used in engineering applications, the toughness of the material should be considered. Impact tests are used for studying the toughness of a material. A material's toughness is a factor of its ability to absorb energy during plastic deformation. Matrix fracture, fiber breakage, fiber–matrix debonding, inter-layer delamination and fiber pull-out are the impotent factors of the impact failure of composites. Fig. 6 shows the effect of fiber loading on the impact energy of the hybrid composites.

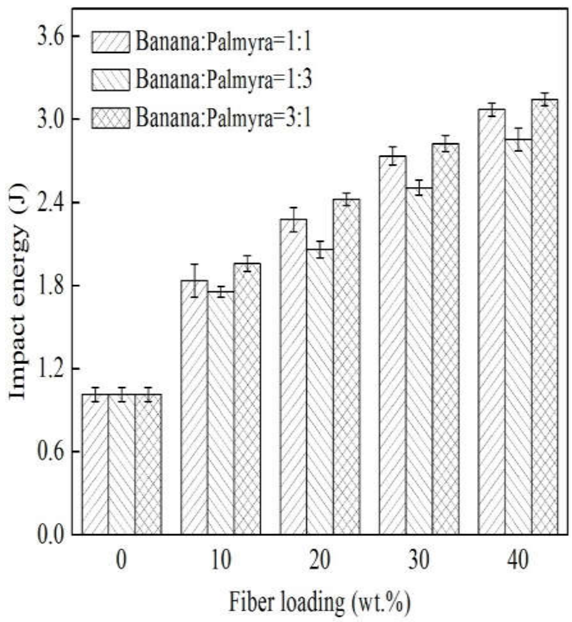

Fig. 6. *Effect of fiber loading on impact energy of hybrid composite.*

The impact energy of the hybrid composites increases with an increase in the fiber loading. When fiber loading is increased, more energy will have to be used up to break the coupling between the interlaced fiber bundles. The highest impact energy absorbed by the banana and palmyra hybrid composites having weight ratio 1:1, 1:3, and 3:1 is found 3.56 J, 3.37 J and 3.77 J, respectively at 40 wt.% fiber loading. The impact strength of the hybrid composite having weight ratio of banana and palmyra 1:1, 1:3, and 3:1 is found 251%, 232%, and 271% higher than that of neat epoxy. By adding cellulose fibers in epoxy resin, surface cracking and brittle behavior are eliminated. It is observed that the impact energy of the banana and palmyra fiber composite having weight ratio of 3:1 is high compared to that of the banana and palmyra fiber composite having weight ratio of 1:1 and 1:3. This is may be due to the fact that natural fibers having a high microfibrillar angle showed a higher composite fracture-toughness than those with small microfibrillar angles [30]. It was reported that the microfibrillar angle of banana fiber is 12° which is more than palmyra fiber microfibrillar angle 8°. Similar trend of increase in impact strength value with the increase in fiber loading is also been reported by few researchers [25].

3.5 Micro-hardness of Hybrid Composites

Fig. 7 shows the effect of fiber loading on the micro-hardness of hybrid composites.

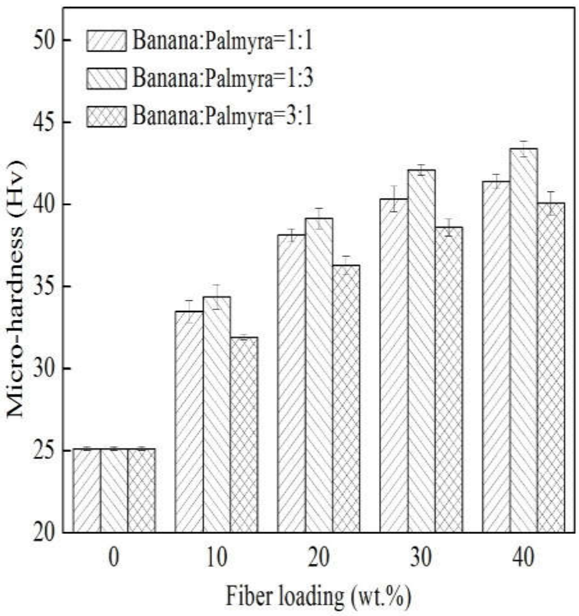

Fig. 7. *Effect of fiber loading on micro-hardness of hybrid composite.*

The test results show that with the increase in fiber loading, the micro-hardness value of the hybrid composites is increases. In general, the fibers that increase the modulus of composites increase the hardness of composites. This is because hardness is a function of relative fiber volume and modulus. The hybrid composite with 0 wt.% fiber loading i.e. neat epoxy has the minimum hardness value of 25.13 Hv whereas hybrid composites reinforced with 40 wt.% of fiber loading with weight ratios of banana and palmyra 1:1, 1:3, and 3:1 exhibits maximum hardness value of 41.42 Hv, 43.39 Hv and 40.08 Hv, respectively. It could be seen that hybrid composite with weight ratio of banana and palmyra 1:3 possessed the highest micro-hardness, compare with those of hybrid composite with weight ratios of banana and palmyra 1:1, 3:1. This is may be due to the brittle nature of the lignocellulosic fiber. A similar trend of increase in hardness value with the increase in fiber loading is also by few researchers [32].

4. Conclusions

Experimental evaluation for the mechanical properties of continuous banana-palmyra hybrid fiber reinforced epoxy composites has revealed the following conclusions.

- Successful fabrication of banana- palmyra hybrid fiber reinforced epoxy based composites is possible at 0, 10, 20, 30, and 40 wt.% of fiber loading by varying the relative weight ratio of two fibers.
- The maximum tensile strength, flexural strength and modulus, and interlaminar shear strength show their maximum values at 30 wt.% of fiber loading with banana and palmyra weight ratio as 1:3. On the other hand, tensile modulus, impact energy and micro-hardness increase continuously with increase in fiber loading.
- As the ratio of palmyra fiber is increased in the hybrid composite, the mechanical properties except impact energy is increased, while the ratio of banana fiber is increased, the impact energy is increased.
- Finally, banana and palmyra fibers as reinforcement in epoxy composites results in a positive hybrid effect for mechanical properties. Therefore, cost-effective and value added hybrid composites having high mechanical properties could be well developed by the judicious selection of banana and palmyra fiber.

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