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Analysis of mechanical properties of pineapple leaf/glass fiber-vinyl ester hybrid composite

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ABSTRACT

Pineapple and glass fibers reinforced vinyl ester hybrid composites were prepared in both the dispersed and skin-core types at 40 wt% using hand lay-up technique, and their mechanical properties were studied based on the content of glass fibers (5, 11, 16, and 19 wt%). The effects of the glass fiber addition on mechanical properties were discussed with varying the fiber content by keeping the overall fiber content as constant. The fractographic studies on the fracture surface of tested composite specimens were examined by using scanning electron microscopy. The results were compared with the neat resin samples and pineapple-alone composites. The results show that the mechanical properties of composites increased with an increase in glass fiber addition. Hybrid composite having the pineapple fiber of 21 wt% and the glass fiber 19 wt% show the maximum level of mechanical properties in both types of hybrid composites. The dispersed type hybrid composites show inferior performance than the skin-core type hybrid composites. The theoretical model was used to predict and compare the experimental results and was also found to be in good agreement.

Keywords: Polymer composites, Pineapple leaf fiber, Glass fiber, Mechanical properties, scanning electron microscope

1. INTRODUCTION

Recently, there has been growing attention among material researchers in the development of natural cellulose fibers reinforced polymer composites as skillful materials for the replacement of man-made conventional and synthetic materials such as glass, aramid, and carbon [1-4]. Composites reinforced with natural cellulose fibers can be used as a suitable alternative for ecologically harmful synthetic materials because natural fibers are low cost, and weight, renewable, low production energy requirement, and biodegradable. These composites can be used in many practical applications such as automobile (side panel lining, roof, dashboard, rear wall), structural and construction (composite roof tiles, door panels), and householding components (toys, picture frames, food service trays, storage containers) [5, 6].

Nevertheless, natural cellulose fibers exhibit some drawbacks such as higher moisture absorption [7], low strength properties as compared to synthetic fibers and weak interfacial adhesion with the hydrophobic polymer resin matrix, etc. Therefore, to resolve these drawbacks and to, improve the performance of polymer composites reinforced with natural cellulose fibers, material researchers have suggested the preparation of hybrid fiber reinforced polymer composites [8] and the modification of both fibers and the resin matrix [9, 10]. The meaning of hybridization in fiber-reinforced polymer composites is in the use of various combinations of natural cellulose fiber in polymer matrices (thermosetting and thermoplastics). Hybrid polymer composites can be used to meet the diverse and competing design requirements in a more cost-effective way than conventional composites [11, 12]. Natural fibers can be hybridized with the other natural fibers or synthetic fibers and also with the natural or synthetic particles to prepare the polymer hybrid composites. Using the other fillers (fibers or particles) with natural fibers in the preparation of polymer hybrid composites improves the mechanical as well as thermal properties [13-15].

Among various plant-based natural fibers, the pineapple leaf fibers are one of the abundantly available waste materials of the South region of India. The logical and reasonable utilization of waste pineapple leaf fibers as reinforcing fillers will bring out a better way in the development of composite fields. Moreover, when the natural fibers are hybridized with synthetic fibers at different forms (e.g. dispersed and skin-core

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type) they can exhibit different levels of properties. Fiber-reinforced polymer composites with improved properties can help in the development of materials and engineering industries. Therefore, in the present study, the pineapple fibers are hybridized with the glass fibers to prepare the vinyl ester hybrid composites such as dispersed and skin-core at 40 wt% using hand lay-up technique with the help of the hydraulic compression machine. Mechanical properties (tensile and flexural) of hybrid composites were evaluated with varying both pineapple and glass fiber content by keeping the overall fiber content constant. In the first type, the pineapple fibers and glass fibers are intimately mixed and in the second type, the pineapple fibers are sandwiched (skin-core type) between the glass fiber mats. The fractographic studies on the fracture surface of mechanical tested composite specimens were investigated by using a scanning electron microscope (SEM).

2. MATERIALS AND METHODS

2.1 Materials

Pineapple fibers were extracted manually by hand scrapping method from the fresh leaves of the pineapple plant. After scrapping, the fibers are extracted using a ceramic plate over the pineapple leaf with pressure and fast movement. Then, the extracted fibers are washed with running water and dried under the sunlight. The bundles of the fibers are cleaned by combing. The pineapple fiber with diameter ranges of 0.14 – 0.67 mm was used in this study. No chemical treatments are used to remove both natural and artificial impurities.

The extracted fibers were used as received conditions as reinforcing agents in the polymer resin matrix. For hybridization, E-glass fibers with diameter ranges of 0.55–0.77 mm are used and procured in the non-woven form. The diameter of both the pineapple and glass fibers was measured by using an Optical microscope (METZAR-M, Model-7000 TZM ELITE). Vinyl ester polymer resin (Satyen Polymer Ltd, Bangalore, India) with a density of 1.145 g/cm^3 is utilized as the resin matrix. All chemicals with glass fibers were supplied by the GVR Enterprises, Madurai, Tamilnadu, India.

2.2 Fiber length and content

The length and content of fibers decide the properties of natural fiber-reinforced polymer composites. Better performance of composites can be obtained by the proper contribution of the reinforced fibers with a sufficient range of length and content. The transfer of the applied load from the matrix to the fibers is ensured by the sufficient range of length and content of fibers before the composite fails. From the literature review, it is observed that composites having the fiber aspect ratio of 100-200 and fiber content of 40 wt% give the maximum mechanical properties. Therefore, in the present study, the fiber content and length are considered as 40 wt% and 15 mm (aspect ratio = 107) respectively. For comparative study, pineapple fiber reinforced vinyl ester composites were prepared with 40 wt% of the fibers.

2.3 Preparation of composites

To prepare the dispersed type composites, pineapple and glass fibers are intimately mixed using the mechanical roller and compressed as fiber mat by applying a load of 30 tones in a hydraulic compression machine and also placed in the mould with a size of 150 X 150 X 3 mm. Then, the vinyl ester resin mixture with accelerator, catalyst, and promoter was poured over the mat and the pressure was applied to the complete closure of the mould box. Finally, the mould box was allowed to cure at room temperature for 24 hours.

For the preparation of skin-core type composites, pineapple (core) and glass (skin) fibers are compressed in a hydraulic machine to make a mat. Pineapple mats are kept between the glass fiber mats and placed in the mould. Then, the vinyl ester resin with accelerator, catalyst, and promoter was poured over the compressed fiber mats allowed to cure at room temperature for 24 hours.

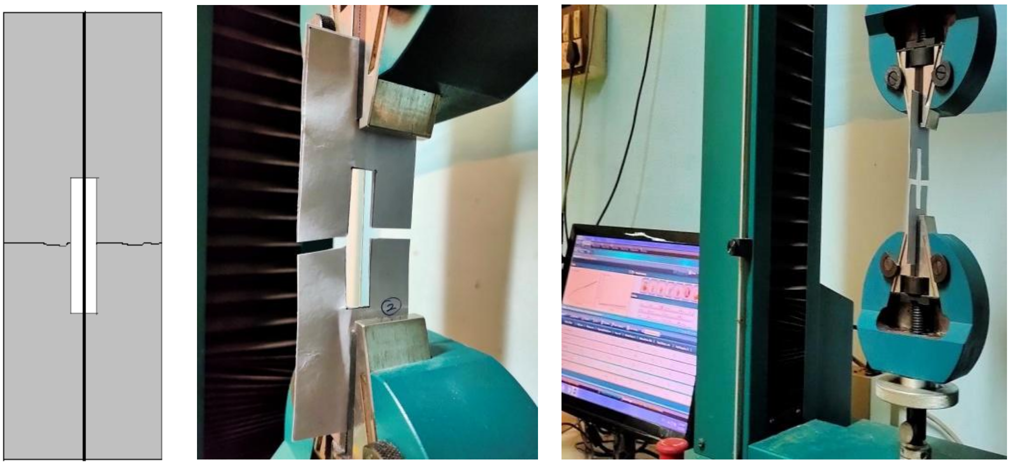
2.4 Testing of composite specimens

According to the ASTM D638-10, composite specimens were tested under tensile load on a computerized universal testing machine with a crosshead speed of 5 mm/min. Flexural tests were conducted on the same universal testing machine according to ASTM D790-10 at a crosshead speed of 5 mm/min. Five samples for each combination were tested, and average results have been reported.

The SEM study was carried out with a HITACHI S-3000N scanning electron microscope on the fractured surfaces of composite specimens after the tests.

2.5 Single fiber test

The single fiber test has been conducted on the randomly selected 20 fibers. The methodology used for the single-fiber test is presented as given below (Figure 1a-1c). The range of values of tensile properties and diameters is given in the Table. The diameter of the fibers has been measured using a computerized optical microscope. The fineness (Tex) of fiber extracted by scrapping on both sides is measured as 4.35.



(a) (b) (c)

Figure 1: (a) Methodology of single fiber test (b), and (c) digital image of tensile fiber test at universal testing machine

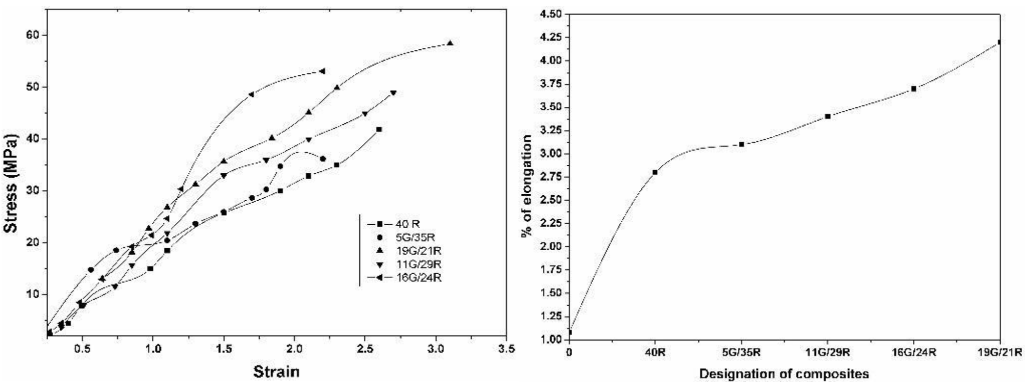
Table 1: The range of typical properties of pineapple fibers

Tensile strength (MPa)	117.5 – 148.7
Tensile modulus (GPa)	5.5 - 19.2
Diameter (mm)	0.14 – 0.67

3. RESULTS AND DISCUSSION

3.1 Stress-strain behavior (dispersed and skin-core types)

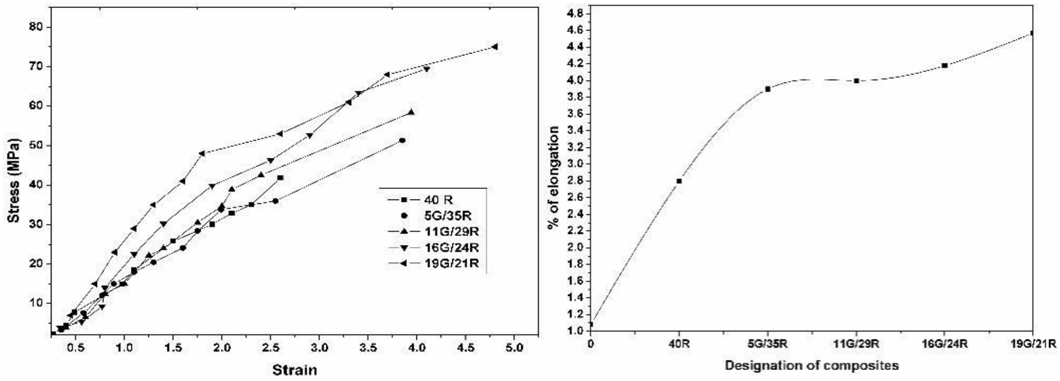
The tensile stress-strain curve of the dispersed type of composites for various fiber weight ratios of pineapple and glass fibers is illustrated in Figure 2a. From Figure 2a, it can be observed that all the curves were almost linear. This is depending upon the percentage of elongation at break of the pineapple and glass fibers in composite systems. The variation of the percentage of elongation of hybrid composites is shown in Figure 2b. It can be clearly seen that the increase of the glass fiber content increases the percentage of elongation of composite systems. It proves that the failure strain of the hybrid composites increases with an increase of glass fiber contents.



(a) (b)

Figure 2: (a) Stress-strain curves and (b) variation of % of elongation of Pineapple/glass fiber hybrid composite (dispersed type)

Figure 3a depicted a tensile stress-strain curve of the skin-core type composites for the various fiber weight ratios of pineapple and glass fibers. All the curves were linear at low strain and then a change in curves was observed at high strain or load. The probable reason is that during the initial load, the glass fibers share the load, therefore, the curves are linear at low strain. Then, a change in curves takes place when the strain of the hybrid composites reaches the Pineapple fiber failure strain. Figure 3b shows the variation of the percentage of elongation of the hybrid skin-core composites. The increase of glass fiber content here also increases the percentage of elongation. The percentages of elongation of skin-core hybrid composites were higher than that of dispersed hybrid composites.

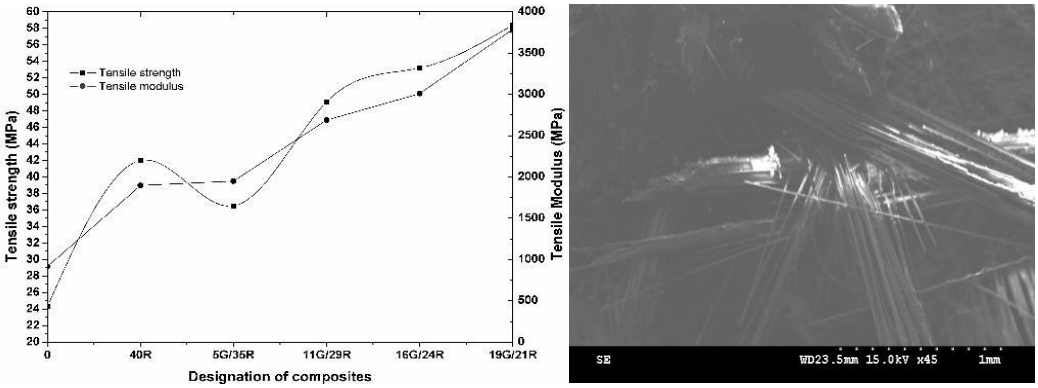


(a) (b)

Figure 3: (a) Stress-strain curves and (b) variation of % of elongation of Pineapple/glass fiber hybrid composite (skin-core type)

3.2 Tensile Properties (dispersed and skin-core types)

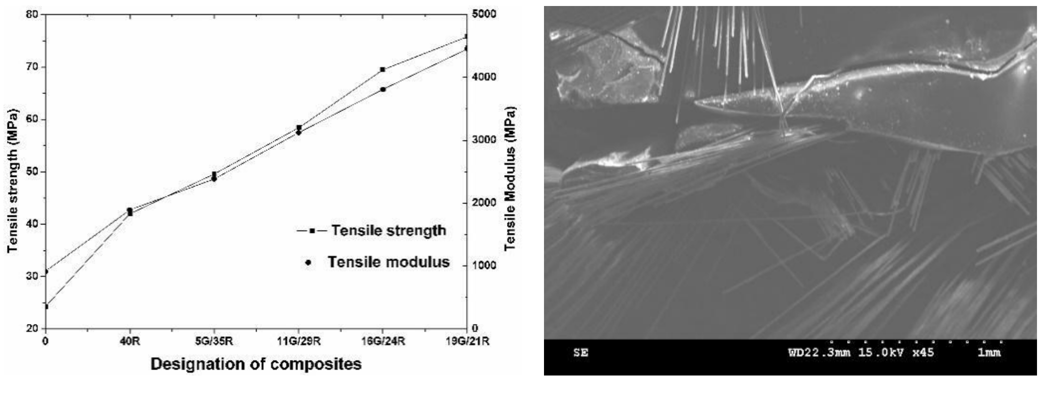
Figure 4a shows the hybrid effect of pineapple/glass fiber composites on the tensile strength. It can be seen that a little drop in tensile strength is observed due to the addition of 5 wt% weight of glass fiber and then tensile strength values increased continuously for further addition of glass fibers. The initial addition of glass fibers with 5 wt% may not be contributing to the improvement in the tensile properties due to the insufficient amount. The 29R/11G composite reaches the tensile strength value of 49.4 MPa, which is 33.8% higher than the neat resin sample. When compared with 35R/5G it gives a 15.6 % of improvement in the tensile strength. Moreover, the 24R/16G composite shows an improvement of 47.14 % when compared with the neat resin sample. The maximum value was identified at 21R/19G composite, which is 58.39 % and 28.08 % higher than the neat resin sample and 40R composite. Figure 4a also shows the variation of tensile modulus of the hybrid composites. Modulus values were continually increased with the addition of glass fibers. The initial addition of glass fibers (35R/5G) gives the tensile modulus of 1952 MPa, which is 17.5% higher than the neat resin sample. The maximum modulus value was obtained at 21R/19G composite, which is 102.6% higher than that of the 40R composite. During tests, it is observed that the glass fibers help pineapple fibers to prevent crack propagation in the hybrid composite system. Therefore, the crack was confined to a small zone and almost horizontal, as shown in Figure 4b. From Figure 4b, it can also be seen that pineapple fiber failure, fiber-matrix debonding, and glass fiber pullout on the fracture surface of 21R/19G composites.



(a) (b)

Figure 4: (a) Variation of tensile strength and modulus, (b) SEM image of the fracture surface of 21R/19G composites (dispersed type) after the tensile test

The hybrid effect of pineapple and glass fiber composites on the tensile properties of hybrid composites (skin-core type) is shown in Figure 5a. The tensile strength of skin-core hybrid composites continuously increases with the glass fiber addition. The incorporation of 5 wt% of glass fibers with 35 wt% of pineapple leaf fibers gives an improvement of 17.8 % when compared with the neat resin sample. 24R/16G composite shows the tensile strength of 71.3MPa and also shows 54.7 % of improvement when compared with the neat resin sample. 21R/19G composite shows the maximum tensile strength value, which is 67.94% and 44.59% higher than that of the neat resin sample and 40R composite. It can be seen that the tensile strength values of skin-core hybrid composites were higher than that of dispersed hybrid composites. The variation of tensile modulus of the hybrid composite for different weight percentages of Pineapple and glass fibers is also shown in Figure 5a. The tensile modulus values also increase continuously with increases of the glass fiber content. Modulus values of skin- core hybrid composites were also higher than dispersed hybrid composites. During the testing of skin-core hybrid composites, first, the inner core of hybrid composite failed when the strain in hybrid composites reaches the pineapple fiber failure strain, which leads to the matrix crack and the de-lamination of glass fiber skin. There is distinct fiber and matrix fracture at the inner pineapple core over a wide zone, which leads to the delamination between the glass fiber skin and the core (Figure 5b). Not much of glass fiber breakage is observed.



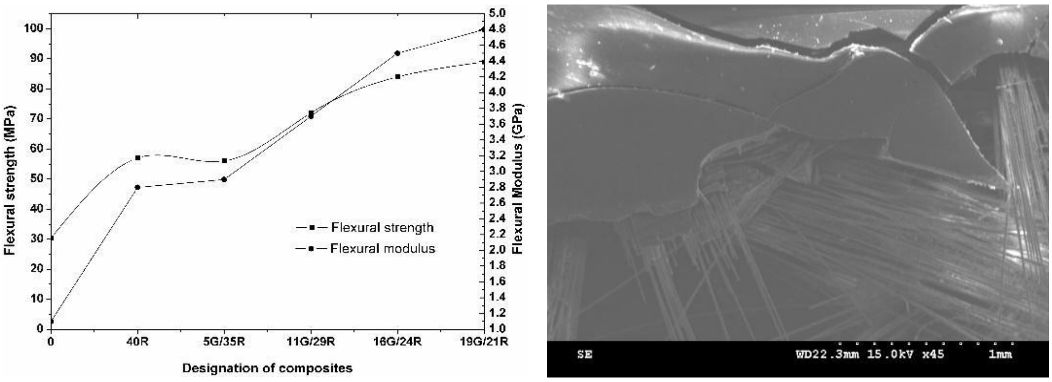
(a) (b)

Figure 5: (a) Variation of tensile strength and modulus, (b) SEM image of fracture surface of 21R/19G composites (skin-core type) after tensile test.

The strength of the pineapple and glass fiber reinforced hybrid vinyl ester composites depend upon the bonding strength of pineapple and glass fibers with matrix. In the case of dispersed hybrid composites, a large contact area exists due to the mixing of pineapple and glass fibers, which leads to low bonding strength between pineapple and glass fibers. However, in the skin-core type, the pineapple fibers are sandwiched between the glass fiber mats, where the contact area between the pineapple and glass fibers is less than that of dispersed hybrid composites. Since the bonding strength between the pineapple and glass fibers, is high, the strength of the skin-core hybrid composites is higher than dispersed hybrid composites. Figure 4b shows the poor bonding capacity of dispersed type composite owing to the dispersion of fibers. Therefore, the mechanical properties of composites were reduced. Figure 5b shows the fractured surface of skin-core type composite, which indicates better interfacial bonding between the glass (high cohesive properties) and pineapple fibers and gives good mechanical properties compared to dispersed type composite.

3.3 Flexural properties (dispersed and skin-core types)

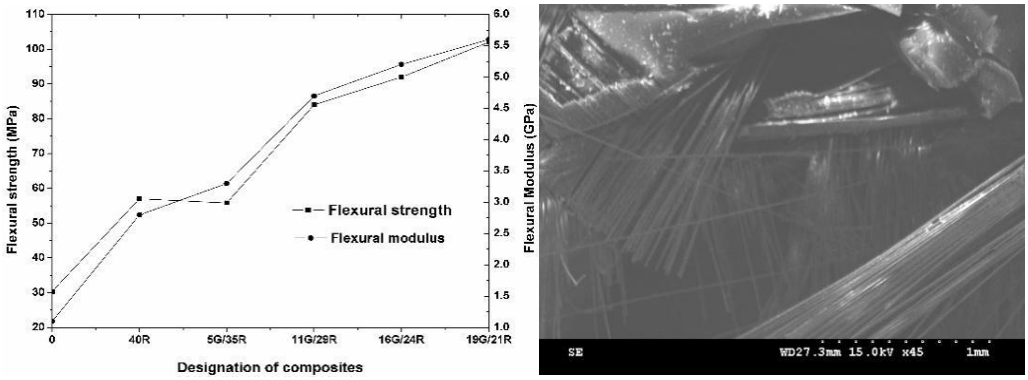
Variation of the flexural modulus of dispersed hybrid composites is illustrated in Figure 6a. From Figure 6a, it can be observed that the flexural modulus of vinyl ester composite increased with pineapple and glass fiber contents. 40R composite shows the flexural modulus of 2.8 GPa, which is 60.71% higher than that of the neat resin sample. The maximum modulus value obtained for the 21R/19G composite, is 77.08% and 41.67% higher than the neat resin sample and 40R composite. The improvement in the 24R/16G composite was 22.8 %when compared with the 40R composite. The improvement in the flexural modulus values was gradually increased due to the addition of the glass fibers. This improvement is proved the contribution of the glass fibers in the enhancement of flexural modulus values. The variation of flexural strength of dispersed hybrid composites is also shown in Figure 6a. From Figure 6a, it can be seen that the flexural strength values have continually increased with the glass fiber addition. The neat resin sample shows the flexural strength of 30.4 MPa and the incorporation of 40 wt% of pineapple fibers results in an increase in flexural strength of 57.3 MPa, which shows the 46.95% of increments. The initial addition of 5 % of glass fibers increases the flexural strength of the composite. The maximum flexural strength value was obtained at 21R/19G composite. Figure 6b shows the SEM image of the fracture surface of the flexural tested 21R/19G composite specimen. The pineapple and glass fiber de-bonding and matrix-crack were observed.



(a) (b)

Figure 6: (a) Variation of flexural strength and modulus, (b) SEM image of the fracture surface of 21R/19G composites (dispersed type) after the flexural test

Variations of flexural strength and modulus of skin-core hybrid composites are shown in Figure 7a. The flexural strength and modulus values continuously increase, with the increase of glass fiber contents. The maximum flexural modulus value was observed at 21R/19G composite. The improvement of 39.4 % was observed when compared with the 40R composite. The flexural strength of the 5G/35R composite was 55.6 MPa, which is 7.9% higher than the 40R composite. However, it is 50.89% higher than that of the neat resin sample. The further addition of 19 wt% glass fiber increases the flexural strength of vinyl ester composites by 70.9%. SEM image (Figure 7b) shows the matrix failure and glass fiber delamination (21R/19G composite specimen). Hybridization of 5 wt% of glass fiber with 35 wt% of pineapple fiber results in an increase of flexural strength by 40.4% for dispersed hybrid composite whereas it is 50.89% for skin-core hybrid composite. It is clear that the fiber arrangements and their distribution have a greater influence on the flexural properties of the composites.



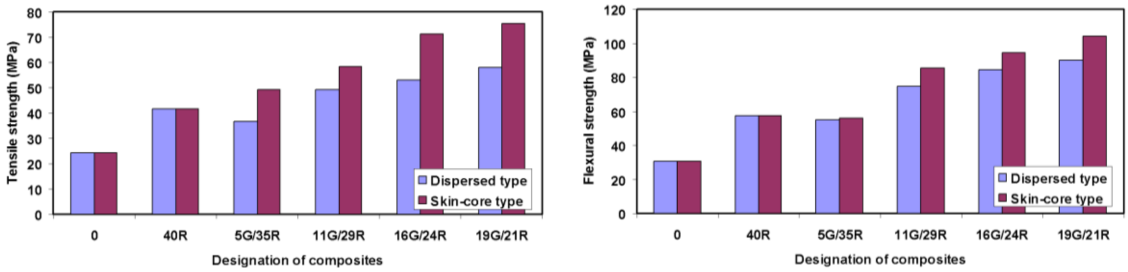
(a) (b)

Figure 7: (a) Variation of flexural strength, (b) SEM image of the fracture surface of 21R/19G composites (skin-core type) after the flexural test.

Figure 6b shows the fractured surface of the dispersed type composite subjected to the flexural test. It was observed that the void formed and discontinuity due to the matrix failure in the composite specimen. The breakage of fibers is clearly shown in Figure 6b. The nature failure is identified as brittle behavior. Figure 7b shows the fractured surface of the skin-core type composite. It was identified that better bonding between the fibers and the matrix with the minimum amount of dislocation of the fibers, enhances the flexural properties of the skin-core type composites than that of the dispersed type composites.

3.4 Comparison of mechanical properties of composites (dispersed and skin-core types)

The comparison of tensile and flexural strength values of dispersed and skin-core type composites is illustrated in Figure 8. It is clearly identified that the skin-core type composites showed the highest value in the case of tensile and flexural strength when compared with the dispersed type composites. It may be due to the strong interfacial adhesion between the fibers and the matrix. The highest values of tensile and flexural strength were obtained at 19G/21R in the skin-core type composite.



(a) (b)

Figure 8: Comparison of (a) tensile strength and (b) flexural strength values of dispersed and skin-core type composites

3.5 Theoretical model

The mechanical properties of the fiber-reinforced polymer composites can be theoretically predicted by using a variety of models and they can compare with the experimental results. The main advantage of this model is the cost-effective and time-consuming formation of the experiments. The different theoretical models are employed to predict the mechanical properties of fiber-reinforced polymer composites: Series and parallel model, Hirsch's model, Halpin-Tsai equation, modified Halpin-Tsai equation, and Bowyer Bader's model. Among various models, Hirsch and modified Bowyer and Badar's (MBB) models are found to be useful in determining the tensile properties of fiber-reinforced polymer composites with long fiber length and hybrid composites. The skin-core type composite shows higher properties as compared to the dispersed type composites. Therefore, the tensile strength of the skin-core type composite was predicted by the Hirsch and MBB models. The Hirsch model is expressed as given below:

$$\sigma_c = x(\sigma_m V_m + \sigma_f V_f) + (1-x)\frac{(\sigma_f V_m)}{(\sigma_m V_f + \sigma_f V_m)}$$

where V_m and V_f are the volume fraction of the matrix and the fiber. The *f, m,* and *c* are the characteristic strength property of fiber, matrix, and composite, respectively. The parameter 'x' varies between 0 and 1 which determines the transfer of applied load between the fiber and the matrix. The value of x depends on the type of the fiber, matrix, and fiber-matrix interaction. For this study, the value of 'x' is taken as 0.97, which gives close values to the experimental results. The tensile strength of the hybrid composites was increased with respect to the weight percentage of the pineapple and glass fibers, as shown in Figure 9. Based on the weight percentage of the fiber, there was an agreement with the theoretical model (Hirsch) in the case of the tensile strength of the hybrid composites. Consequently, the Hirsch model may be applied to predict the tensile strength of the pineapple and glass fiber reinforced vinyl ester hybrid composites.

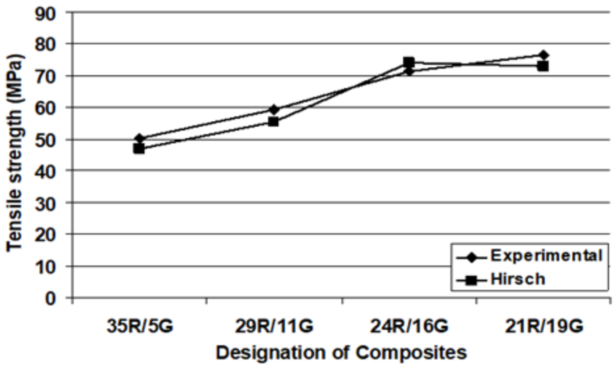


Figure 9: Predicted and experimental results of tensile strength in the Skin-core type composites

In accordance with the modified Bowyer and Badar's model (MBB) [16], the tensile strength of skin-core type composites are predicted using the following equation:

$$T_c = a_v \times T_f \times V_f + T_m \times V_m$$

where $a_v = n_1 \times n_2$ is the overall reinforcing factor. n_1 is the factor of fiber orientation and n_2 is the factor of fiber length. Figure 10 shows a comparison of tensile strength values by the MBB model with the experimental values. The values of n_1 and n_2 in the MBB equations were found to be 1 and 0.49 to obtain a good agreement with experimental strength values. When comparing the predicted strength values with the experimental strength values, it can be identified that there is a small deviation, which may be due to the fewer structural defects that occurred during the preparation of skin-core type composite specimens. It also may be owing to better mechanical interlocking between the fiber and the matrix. When compared to Hirsch's model MBB model has predicted the tensile strength values of skin-core type composites with less deviation.

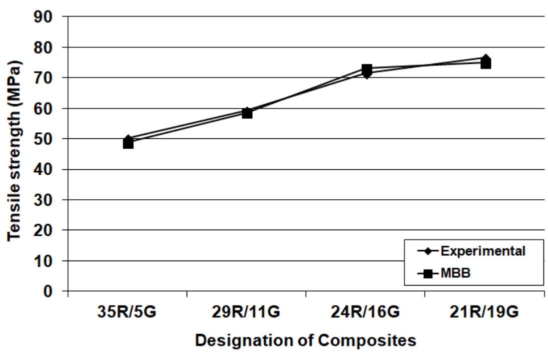


Figure 10: Predicted and experimental results of tensile strength in the Skin-core type composites

4. CONCLUSIONS

Pineapple and glass fibers reinforced vinyl ester hybrid composites were prepared in the forms of the dispersed and skin-core types, and their mechanical properties (tensile and flexural) were studied for varying fiber contents. It is observed that the mechanical properties of both types of hybrid composites increase with the increase of glass fiber contents. The properties of dispersed type hybrid composites were initially dropped with the addition of 5 wt% of glass fibers and then increased on further increasing of glass fiber contents. However, in the case of skin-core type, mechanical properties increased with the increase of the content of glass fibers. The maximum level of mechanical properties was obtained for 21R/19G fiber composites in both types of composites. Dispersed type of hybrid composites shows lower mechanical properties than skin-core-type hybrid composites. The fiber-matrix de-bonding, breakage of fibers, and delamination of fibers were identified on the fractured surface of the composite by the SEM study. The results obtained from theoretical models (Hirsch and MBB) are satisfactory to predict the tensile strength of the composites. The comparison between theoretical and experimental values was found to be in good agreement.

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