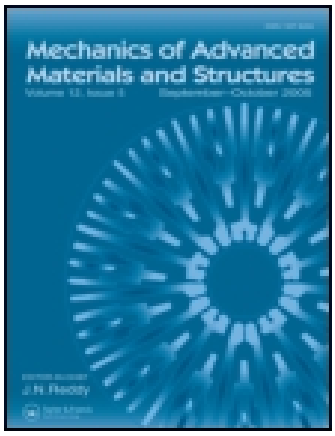

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Tamarind Fruit Fiber and Glass Fiber Reinforced Polyester Composites

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Tamarind Fruit Fiber and Glass Fiber Reinforced Polyester Composites

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Polyester-based hybrid composites were developed by combining the tamarind fruit (Tf) and glass fibers into a polyester matrix. Hardness, impact strength, frictional coefficient, and chemical resistance of hybrid composites with and without alkali treatments were studied. Variation of the aforementioned mechanical properties and chemical resistance was studied with different fiber lengths, such as 1, 2, and 3 cm. A 9 vol% of the tamarind and glass fibers was reinforced into the polyester matrix. The aforementioned mechanical properties were optimally improved at 2-cm fiber length when compared with 1- and 3-cm fiber lengths. Chemical resistance was also significantly improved for all chemicals except toluene. A 3°C rise in decomposition temperature while a 2°C rise in glass transition temperature was observed from TGA and DSC micrograms, respectively.

Keywords: chemical resistance, polyester resin, hybrid composites, mechanical properties, tamarind fruit fiber

1. Introduction

During the past 10 years, a lot of fundamental and applied research has been carried out in polymer matrix composites. Due to the molecular size and their reinforcement, polymer composite offers ample possibility to develop new material with usual properties. First, shrinking a thing means that lesser material is required to build it. Material is like an excess baggage. It costs money, adds weight, and takes up space. These considerations weigh heavily on all engineering decisions and are of utmost importance for certain applications—for example, satellite and space craft systems, which must be as small as possible. Moreover, it is expensive and inefficient to take heavy things into space: the cost of launching the space shuttle in 2004 is about $10,000 per pound of weight. Smaller devices are imperative in the medical field and have enabled unprecedented surgical and imaging techniques. Bulky tools and big cameras simply do not fit inside the delicate pathways of the human body. Smaller systems perform quicker because they have less mass and therefore lesser inertia (the tendency of mass to resist acceleration). This improved speed leads to products that perform tasks faster, just as a fly can flap its wings much faster than a bird. Another example cited is an assembly robot in a factory. It might perform 10 welds in a second, while an enzyme in our body performs as many as millions of chemical operations in the small amount of time. Thermal distortions and vibrations do not perturb smaller devices as much as the larger ones, because the resonant vibration of a system is inversely proportional to its mass. Generally, the smaller the system, the higher its resonance frequency; and the low-frequency vibrational disturbances that affect large systems are less of an issue. Higher motional exactness and dimensional stability are the other important advantages of smaller devices; highly precise measurements or movements are possible on a small scale. Finally, smaller things need less energy in order to function. Power consumptions can make or break a new product design, and miniaturization is one way to minimize the fuel factor. Power density is the amount of power that can be generated per unit volume, which also favors miniaturization. With the growth in environmental awareness and advancement of civilization, man is looking for new materials, which emerge from advanced technology to meet livelihood requirements. Thus, to meet ever-growing and specified performance requirements, professionals started fabricating novel materials from renewable sources or manipulation of the existing old materials. Present conventional materials may not fulfill all of the performance requirements. The aim and objective of this study is to fabricate a light weight, high strength composite that suits for today's transportation systems, which brings fuel economy.

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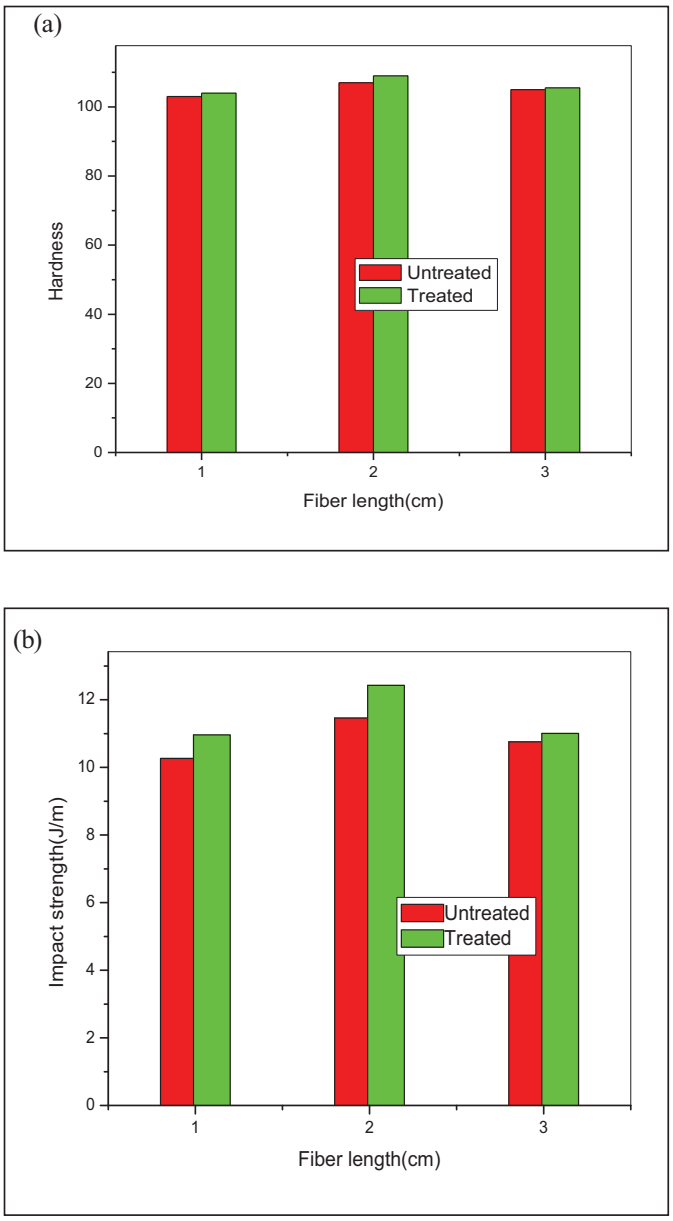

Fig. 1. Treated and untreated polyester-based Tf/glass hybrid composites as a function of different fiber lengths on (a) hardness and (b) impact strength.

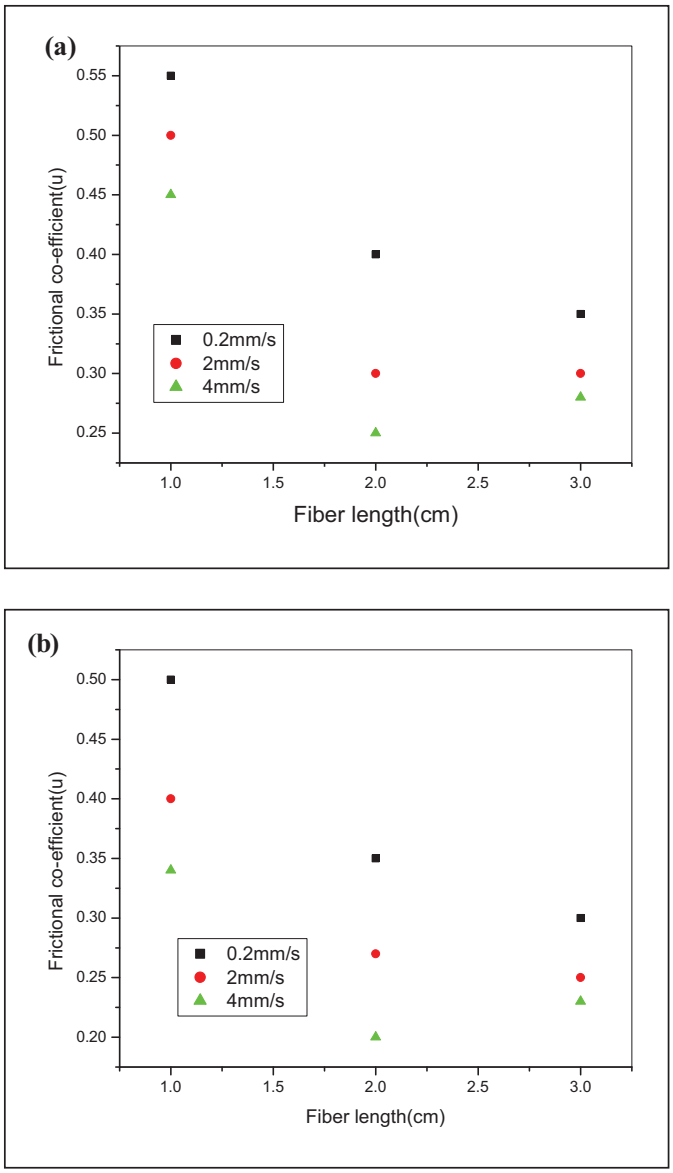

Fig. 2. Frictional coefficient of (a) treated and (b) untreated hybrid (Tf/glass) composites as a function of fiber length after 20 cycles, respectively.

A number of studies have been carried out on sisal fiber [1, 2], bamboo [3–5], jute [6–9], kapok [10], silk fiber [11], *Hildegardia fabric* [12–15], *Sansevieria cylindrical* [16], betel nut [17], oil palm [18], polypropyleneluffa [19], pineapple [20], Ridge Gourd [21], coir, and banana [22–24].

The main aim and scope of the authors is to build a composite system that has a high performance and is a partially green composite and is cost effective. In this study, the authors developed Tf/glass hybrid composites as a function of fiber length. Six different samples were prepared in which three were treated hybrid composites samples and three were untreated hybrid samples as a function of fiber lengths of 1, 2, and 3 cm, respectively. A variation of hardness, impact strength, frictional coefficient, and chemical resistance was studied at different fiber lengths.

2. Materials and Methods

2.1. *Materials*

The type of polyester/accelerator/catalyst resin employed in this investigation was supplied by Ciba-Geigy of India Ltd. Different glass molds were fabricated in order to cast the composite sheets in accordance with ASTM standards. Tf fibers were obtained from the villagers at Enumuladoddi, Anantapur, Andhra Pradesh, India. In addition, the glass fiber was

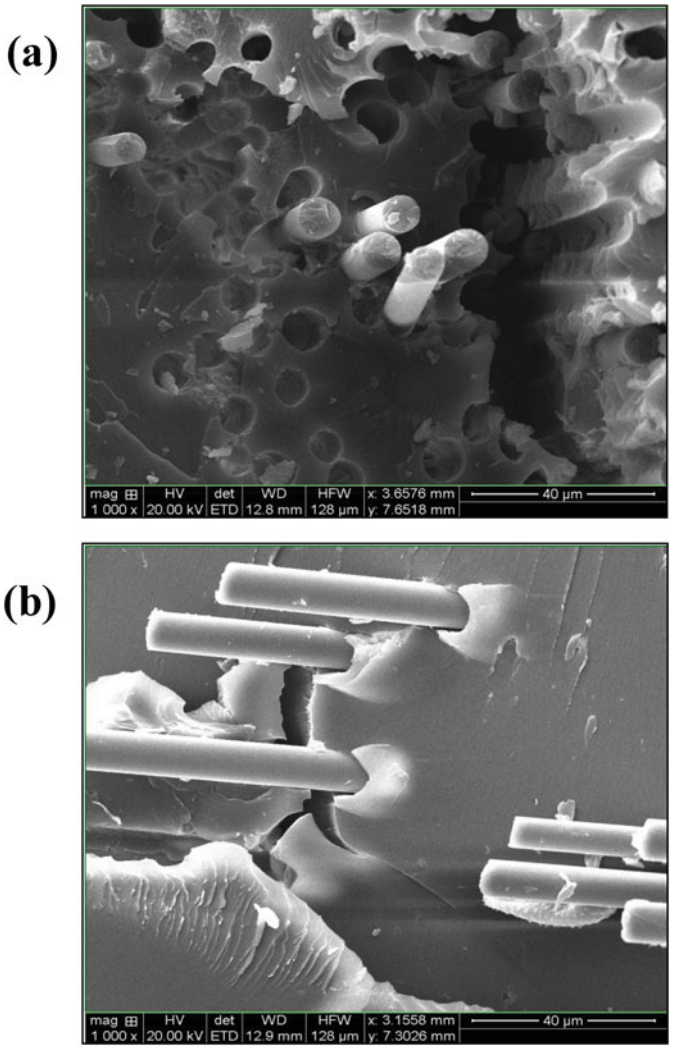

Fig. 3. SEM micrograms for untreated (a) 2 cm fiber length (magn: 1000×); (b) 3 cm fiber length (magn: 1000×) Tf/glass fiber-reinforced polyester composites.

(density: 350 g/m^2) supplied by Saint Gobain Industries Ltd., Bangalore.

2.2. *Composite Manufacturing*

A glass mold with required dimensions was used for making the sample on par with ASTM standards, and it was coated with a mold releasing agent to enable the easy removal of the sample. The resin, catalyst, and accelerator were taken in the ratio of 100:2:2 parts by weight, respectively. Then, a pre-calculated amount of catalyst/accelerator was mixed with the polyester resin and stirred for 10 min before pouring into the mold. The hand lay-up technique was used to impregnate the composite structures. In this technique, the glass fiber and the Tf fibers were wetted by a thin layer of polyester suspension in a mold. A stack of hybrid fibers was carefully arranged in a unidirectional manner after pouring some amount of resin against the mold to avoid the poor impregnation. The remaining mixture was poured over the hybrid fiber. A brush

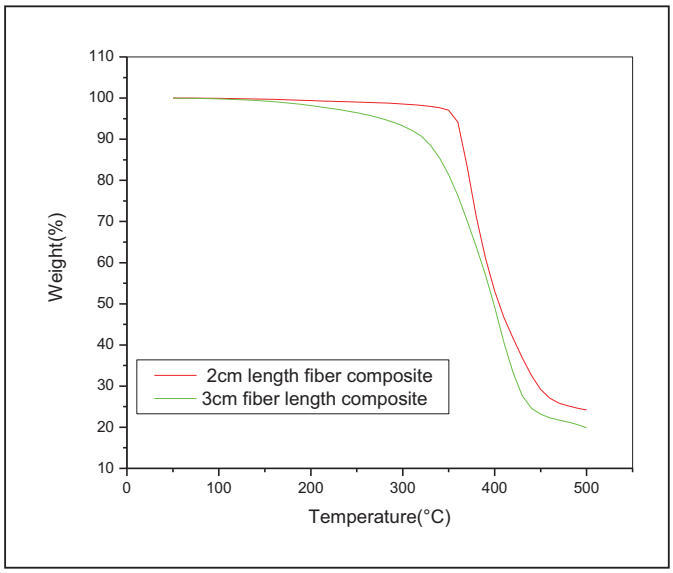

Fig. 4. TGA analyses treated hybrid glass fiber polyester composites function of fiber length.

and roller were used to impregnate fiber. The closed mold was kept under pressure for 24 h at room temperature. To ensure complete curing, the composite samples were post-cured at 80°C for 1 h and test specimens of the required size were cut out from the sheet. Composites with different fiber lengths of 1, 2, and 3 cm, treated and untreated were prepared by keeping the weight ratio of Tf/glass at 1:1.

2.3. *Fiber Treatment*

Tf fiber was taken in a glass tray, to which a 5% NaOH solution was added, and the fibers were soaked in the solution for 1 h.

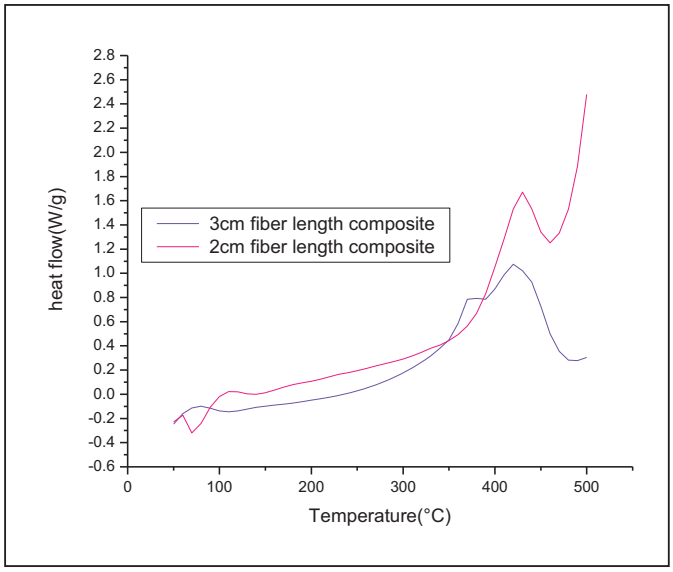

Fig. 5. DSC analyses treated hybrid glass fiber polyester composites function of fiber length.

The fibers were then washed thoroughly with water to remove the excess of NaOH sticking to the fibers. Final washing was done with distilled water and the fibers were then dried in a hot air oven at 70°C for 4 h. The fibers were chopped into short fiber lengths of 1, 2, and 3 cm for molding the composites.

2.4. *Characterization*

The hardness of treated and untreated samples reinforced with Tf/glass polyester-based hybrid composites was measured using a Rockwell hardness testing machine supplied by M/s. PSI Sales (P) Ltd., New Delhi, India. In each case, five samples were tested and the average value tabulated. Test specimens were made on par with the ASTM D 785 ($10 \times 10 \times 6$ mm^3). The diameter of the ball indenter used was 0.25 in. and the maximum load applied was 60 kg as per the standard L-scale of the tester. The testing was carried out at room temperature for all of the samples. All of the readings were taken 10 s after the indenter made firm contact with the specimen. All of the sample surfaces were rubbed with smooth emery paper, which facilitates accurate reading. The impact strength of the composites was measured using an Izod impact tester supplied by M/s. PSI Sales (P) Ltd., New Delhi, India. The samples were made to $63.5 \times 12.7 \times 12.7$ mm^3 dimension using glass molds having the dimension $100 \times 12.7 \times 12.7$ mm^3 and the notch was made according to ASTM D256 specifications. This test was carried at ambient conditions. In each case, five identical specimens were tested and their average load at first deformation was noted and the average value tabulated. Using a friction test, frictional coefficient measurements were performed by sliding a pin on a sample disk at 22°C and 45% relative humidity. Before each test, the surface of the counterpart pin was abraded with No. 1100 abrasive paper and cleaned with alcohol-dipped cotton, followed by drying. This friction test consisted of a rectangular composite pin sliding against the composite sheets. The sliding speed of the friction test was set at 0.2, 2, and 4 mm/s under a constant load of 10 N during 20 cycles. In this study, ASTM G 543-87 was used to prepare the samples (size: $10 \times 10 \times 3$ mm^3) in order to study the chemical resistance of the treated and untreated hybrid composites. The effect of some acids, alkalis, and solvents, that is, glacial acetic acid, nitric acid, hydrochloric acid, ammonium hydroxide, aqueous sodium carbonate, aqueous sodium hydroxide, carbon tetrachloride, benzene, distilled water, and toluene, were used on the matrix and the hybrid composites were studied. In each case, the samples were pre-weighed in a precision electrical balance and dipped in the respective chemical reagents for 24 h. Then they were removed immediately, washed in distilled water, and dried by pressing on both sides with a filter paper at room temperature. Scanning electron microscopy (SEM) was used to studied the fractured surface of the tensile specimen and Jeol SEM (6380LA, Japan) was used for analyzing the SEM study. The specimen was sputter coated with gold to increase surface conductivity. The digitized images were recorded. The thermal characteristics TGA and DSC are measured on hybrid fiber reinforced polyester composites using a SDT Q600 TGA/DSC (TA Instruments) at a rate of 10°C/min under nitrogen flow. Measurements were carried out at 22°C temperature, 40% relative humidity.

Table 1. Effect of chemicals on 1-, 2-, and 3-cm length hybrid fiber composites at % change in weight after dipping for 24 h

	Fiber length		
Chemical	1 cm	2 cm	3 cm
Hydrochloric acid	+1.217	+0.734	+0.873
Acetic acid	+1.282	+1.025	+0.241
Nitric acid	+2.459	+2.310	+1.678
Sodium hydroxide	+1.123	+0.921	+0.568
Sodium carbonate	+0.235	+0.153	+0.245
Ammonium hydroxide	+0.919	+0.834	+0.767
Benzene	+2.380	+3.004	+10.426
Toluene	−2.479	−3.465	+4.810
Carbon tetrachloride	+2.941	+2.063	+2.145
Distilled water	+1.630	+1.419	+1.023

3. Results and Discussion

Tf/glass (1:1) 9 vol% of both fibers were randomly impregnated on polyester with different fiber lengths were evaluated. It was observed that 2-cm fiber length composites had a higher hardness than 1- and 3-cm fiber length composites. It was observed that the treated composites possess higher hardness than untreated as alkali treatment improves the adhesive characteristics of Tf fiber surface by removing hemicellulose and lignin. This surface offers an excellent fiber/matrix interface adhesion and results in the increase in the mechanical properties. The effect of fiber lengths on hardness measurements of Tf/glass polyester hybrid composites is shown in Figure 1a.

The same trend was repeated in which the 2-cm fiber length composites showed superior impact properties than the untreated composites, because alkali treatment improves the adhesive characteristics of the surface of the Tf fiber by removing hemicellulose and lignin. The reason for this is that the surface offers a good fiber/matrix interface adhesion and consequently increased in mechanical properties.

The effect of fiber lengths on impact strength measurements of Tf/glass polyester hybrid composites is shown in Figure 1b. Ashok Kumar et al. [1] envisaged that at 2-cm fiber length performance was improved much better and yet surface offers an excellent fiber/matrix interface adhesion and results in the increase in the mechanical properties than the other fiber lengths of 1 and 3 cm. Noorunnisa Khanam et al. [11] also observed that same trend that at 2-cm fiber length performance was optimized than at 1 and 3 cm. Uma Maheswari et al. [21] observed that size of the filler becomes smaller, thereby greater interactions between filler and the matrix could result in better and more efficient stress transfer. Karthikeyan and Balamurugan [22] studied when fiber pullouts are longer and fiber surface is cleaner, indicating an even worse adhesion between coir fibers and epoxy resin. The surface of coir fiber is covered with a layer of substance, which may include pectin, lignin, and other impurities; the surface is not smooth, spreads with nodes and

irregular strips. After treatment, important modification done is the disruption of hydrogen bonding in network structure, thereby increasing surface roughness. Most of the lignin and pectin are removed resulting in a rough surface. Raghavendra et al. [23] evaluated that the fiber length from 6 mm decreasing tendency in tensile strength has been attributed to two situations: namely, the existence of defects, such as voids, and weak interface bonding between matrix and reinforcement.

Kongkeaw et al. [24] showed that 10 mm in fiber length of a composite has a good adhesion between matrix and fiber. The load acting on the matrix is transferred to the reinforcement via the interface. Thus, reinforcement must be strongly bonded to the matrix if their high strength and stiffness are to be imparted to the composite. It is also noticed that the fiber failed by tearing but no interfacial failure is observed. There are traces of matrix still adhered to the fiber. This in an indication that the adhesion between fiber and matrix was not lost and the failure process was dominated by the matrix material properties. Figure 2a shows the untreated polyester reinforced with Tf/glass hybrid fiber composites, on frictional coefficient as a function of fiber length after 20 cycles, respectively. The friction coefficient decreases with an increase in the sliding speed up to 2 cm fiber length, but coefficient increases with a further increase in fiber length. The lowering of the friction promotes better tribological property, which was significant at 2-cm fiber length. It is observed that the frictional coefficient considerably decreased with increasing the fiber length at higher sliding speeds. Optimal frictional coefficient measurements were found at 2-cm fiber length. Figure 2b indicates that measurements of treated hybrid composites were higher than the untreated ones. Ashok Kumar et al. [1] observed the same trend in which frictional coefficient was inversely proportional to the sliding speed up to the 2-cm length but failed to lived up to the expectations when fiber length was beyond 2 cm. Table 1 shows the weight gain (+) or weight loss (-) values of the treated hybrid composites immersed in acids, alkalis, and solvents. It was clearly evident that weight gain is observed for almost all of the chemical reagents except toluene. It is also observed from the table that treated composites also have weight loss in toluene. The reason is attack of the toluene on the cross-linked polyester hybrid system. After all, 2-cm fiber length composites were significantly participated in chemical resistance. The positive values indicate that the composite materials were swollen with gel formation rather than dissolving in chemical reagents. It was further observed that composites were also resistant to water. This study epitomizes clearly that the Tf/glass hybrid composites are significantly resistant to almost all chemicals except toluene. Therefore, observations suggest that these hybrid composites can be used in aerospace, automobile, and marine applications for making water and chemical storage tanks. Ashok Kumar et al. [1] observed that at a 2-cm length were more substantial values for all chemicals except sodium carbonate and toluene. To investigate the failure mechanism of hybrid fiber composites, the fractured surfaces of specimens were examined. Fractured surfaces of untreated Tf/glass fiber reinforced composites were described for both 2 cm (magn: 1000×) and 3cm (magn: 1000×) magnifications, respectively. SEM photos of fractured surfaces of tensile specimens of untreated 2 cm and 3 cm fibre length Tf/glass fibre reinforced polyester composites were shown in Figure 3(a) and (b) respectively. High content of matrix cracking and fibre pull out was observed in Figure 3(b) which shows the poor bonding between the fibre and the matrix. More fibre is coming out from the matrix in 3 cm fibre length composites. SEM photo of 2 cm fibre length composites shows the fibre pull out during the tensile fracture and more voids shows in the matrix. No matrix cracking observed and no fibre come out from the matrix in 2 cm fibre which shows the good bonding between the fibre and the polymer matrix. Venkata Reddy et al. [10] showed that long uniaxial kapok fiber is equally strong due to the orientation of unidirectional long fiber when compared with the co-hosting glass fiber. Ashok Kumar et al. [1] observed that performance of hybrid attributed due to alkali treatment and 2-cm length of the fiber is more appropriate than the 1- and 3-cm lengths of the fibers. Varada Rajulu et al. [3] thus proved that performances of natural fiber were improved due to the alkali and coupling agent on SEM analysis.

Figure 4 shows the weight loss curves of various composite materials and the polymer with temperature. It is clear that the decomposition temperature of the composite shifted towards the higher temperature due to a decrease in fiber length from 3 to 2 cm. The derivative weight loss curve shows only one peak. The decomposition temperature is 328°C for a 3-cm fiber length, whereas it is 331°C for a 2-cm fiber length. It is clear that the decomposition temperature of the composite shifted towards a higher temperature indicating higher thermal stability of the composite from 3 to 2 cm. The existence of fiber materials in a polymer matrix generally enhances the thermal stability of the composite. Currently, thermal stability increases due to the presence of the fiber phase. The weight-loss temperature curve shows that the residue left beyond 430°C is in line with the fiber content of each sample. These results clearly indicate that enhanced interface and bonding of polyester and hybrid fiber led the increased thermal stability of the composite. A typical thermogram for polyester with two different duo length fiber loadings is shown in Figure 5. The glass transition temperature (Tg) of composite was observed at a temperature of 425°C for 3-cm fiber length; 427°C for 2-cm fiber length. However, with fiber loading the Tg values do not shift. From the above figures it was clearly noted that a 2°C rise in glass transition temperature was observed. An endothermic peak at 430°C is observed for all composites.

4. Conclusions

Natural and synthetic fiber composites of Tf/glass polyester-based hybrid composites were prepared by varying fiber lengths. The variation of hardness, frictional coefficient, impact strength, and chemical resistance of polyester-based Tf/glass hybrid composites has been studied as function of fiber length. It was observed that 2-cm fiber length hybrid composites are having higher hardness and impact strength than 1 and 3 cm. The effect of alkali treatment of hybrid composites on the hardness, impact, frictional coefficient properties, and chemical resistance was also studied. It is found that the treated hybrid composites showed higher aforemen-

tioned mechanical properties than the untreated composites, as the treatment with alkali removes hemicellulose luster due to which the interfacial bonding improves. Frictional coefficient measurements were decreased due to an increase in sliding speed at a constant load force. The authors discovered significant optimal improvements at 2-cm fiber length for treated hybrid composites. It was observed that all composites have resistance to almost all chemicals except toluene. A 3°C rise in decomposition temperature and a 2°C rise in glass transition temperature were observed from TGA and DSC micrograms, respectively.

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