Fibers and Polymers 2020, Vol.21, No.7, 1508-1514
DOI 10.1007/s12221-020-9853-4

ISSN 1229-9197 (print version)
ISSN 1875-0052 (electronic version)

Effect of Natural Fiber Loading on Mechanical Properties and Thermal Characteristics of Hybrid Polyester Composites for Industrial and Construction Fields

S. Sathees Kumar*

Department of Mechanical Engineering, CMR Institute of Technology, Hyderabad 501 401, Telangana, India
(Received August 7, 2019; Revised November 1, 2019; Accepted November 7, 2019)

Abstract: In the present work tensile, flexural, impact and hardness properties of sorghum bicolor, sisal fiber and jute reinforced with polyester composites are described for the first time. The hybrid composite plates are fabricated for different fiber weights by hand lay-up method. To investigate the mechanical attributes tensile, flexural, impact and hardness tests were performed as per ASTM standard. The mechanical test results revealed a regular trend of an increase in tensile, flexural, impact and hardness properties to adding natural fibers. Good adhesion between the natural fibers and the polyester matrix is also responsible for the effective resistance capability. Further, thermal stability and thermal decomposition of the composite material observed by thermogravimetric analysis (TGA) and differential thermal analysis (DTA). The work concludes that sisal, jute, and sorghum bicolor fiber have high potential as reinforcement for composite production. This type of composite material can be useful for automobiles, industrial applications and construction fields.

Keywords: Composite, Jute, Polyester, Sisal, Sorghum, TGA

Introduction

For the most part, numerous sorts of filaments which are bounteously accessible, for example, jute [1], sisal [2], coir, kenaf, oil palm [3], bamboo, ramie and flax straw and so forth. The investigation of mechanical properties, particularly interfacial exhibitions of the composites dependent on normal filaments because of the inadequate interaction holding among the hydrophilic common strands and the hydrophobic polymer frameworks. In light of this examination, an improved strategy that could all the more precisely assess the interfacial attributes among normal fiber and polymeric lattices were intended [4]. In cases where the aim is to obtain lightweight products, natural fibers can be used as reinforcement with success. These fibers can also be used as thermal and acoustic insulators. There are many studies in the literature looking for new applications with natural fibers for the manufacture of materials in which the resistance is not the most important requirement [5]. Compared to glass fibers, the production of natural fibers causes less environmental impacts. This is because the cultivation of natural fibers depends primarily on solar energy and needs a small amount of energy from fossil fuels in the production and extraction processes [6].

Sisal is a commonly occurring plant with an annual worldwide fiber production reported to attain 4.5 million tons [7]. The cellulose content of sisal varies between 49.6 wt% and 61 wt%, depending on the age of the plant [8]. Sisal fiber length is found to be between 1 and 1.5 m, with average diameters of 200 μm and the most important advantages of sisal fibers are their low cost, lightweight, and one of the highest tensile strengths of all-natural fibers (511-635 MPa) [9]. The main utilization of sisal fibers is found as a rope source for marine and agricultural applications [10]. The use of sisal as novel source material will allow us to obtain new nanoparticle dimensions, widen the range of potential applications and increase the supply of cellulosic materials usable for nanocomposite materials [11]. The tensile strength of the composites showed a positive hybrid effect when the relative volume fraction of the two fibers (banana and sisal) was varied, and maximum tensile strength was found to be in the hybrid composite having a ratio of banana and sisal 4 : 1. The impact strength of the composites was increased with increasing volume fraction of sisal [12]. Tensile strength and modulus of short, randomly oriented banana and sisal fiber reinforced epoxy resin hybrid composites were predicted using the Rule of Hybrid Mixtures (RoHMs) equation. RoHM equation predicted tensile properties of hybrid composites are little higher than experimental values [13]. The incorporation of sisal fiber with GFRP exhibited superior properties than the jute fiber reinforced GFRP composites in tensile properties and jute fiber reinforced GFRP composites performed better in flexural properties [14]. The tensile and flexural strength for jute-epoxy composites are higher than jute-polyester composites and the impact energy of jute polyester is better than jute-epoxy composites [15]. In this work, Sorghum, sisal, and jute were used because, Sorghum is a perennial crop that grows from 10 to 15 feet tall in temperate and tropical climates. Because its stem has high sugar content, the plant is being cultivated for fodder, syrup, molasses, sugars, and small-scale ethanol production [16]. Sweet sorghum fiber and pulp can be used for the manufacture of fine-quality writing and printing paper as well as corrugated and solid

*Corresponding author: shrutishyami@gmail.com

particle boards due to its flexibility and tensile strength [17]. The availability and low cost of sweet sorghum stalk make it a potential source of fiber for various industrial applications. Data on the extraction conditions and fiber characteristics can be used for further studies especially for its application in the fabrication of improved biodegradable polymer composites [18].

Jute, a natural fiber in polymer composites would be suitable for the primary structural applications, such as indoor elements in housing, temporary outdoor applications like low-cost housing for defense and rehabilitation and transportation. The insulating characteristics of jute may find applications in automotive door/ceiling panels and panel separating the engine and passenger compartments [19]. In previous works some authors are investigated, the Sisal-jute-GFRP hybrid composites are environment-friendly and user-friendly materials and have very good elastic properties [20]. The purpose of this work is to investigate the probable utilization of sisal, sorghum, and jute fiber areas reinforcement in polyester matrix composites. Also, the effect of the above fibers content on the mechanical behavior, thermal stability and thermal degradation of the composites were investigated.

Experimental

Materials

Materials In this present investigation Sisal, sorghum and Jute fibers are used for fabricating the hybrid composite specimen. The sisal, sorghum, and jute fibers are obtained from Ebenezer fiber products, Coimbatore, Tamilnadu, India. Cobalt Naphthenate as accelerator and Methyl ethyl ketone peroxide (MEKP) as a catalyst is acquired from M/s. Supreme scientific Ltd., Madurai, India. The polymer used in this work development was unsaturated terephthalic polyester resin in the pre-accelerated form, produced by Royal Polímeros under the commercial name of Denverpoly 754. The Cobalt Naphthenate added as 2 % with the resin and the catalyst approximately 2 to 3 m*l*.

Sisal Fiber

The extraction method of sisal fibers. The sisal leaves are cut from sisal plant and tied into bundles by using bags. Then bags contain the sisal leaves are retted in tanks for 3-4 days. The retted leaves are washed in running water and the top portion of the leaves are removed manually to get the fiber separately and cleaned and dried in the sun. Each fiber is taking apart according to fiber sizes and grouped accordingly.

Jute Fiber

Jute takes nearly 3 months, to grow to a height of 12-15 ft, during the season, then cut and bundled and kept immersed in water for retting process, where the inner stem and outer, get separated and the outer plant gets individualized, to form a Fiber. Then the plant gets separated and washed to remove dust from the plant.

Sorghum Bicolor

The extraction method of sorghum bicolor is given follow, the sorghum plant is cut from the cultivated field and tied into the bundles by using bags. Then the bag contains sorghum bicolor plants that are put on the road for removing the sorghum grains. After removing the sorghum grains the remaining plant is left on the road for 2-3 days. The top portion of the plant is removed by manually to get the fiber separately and cleaned and dried in the sun.

Mould Preparation

The mould used in this work was made of well-seasoned plywood of 250×250×3 mm dimensions. Fabrication of the composite material was done in this mould by the hand lay-up process. The top and bottom surfaces of the mould and walls were coated with wax, remover and allowed to dry. The mould is placed in at atmosphere condition for preparing to make a composite material.

Preparation of Hybrid Composite Specimen

To fabricate the hybrid polyester composite, de-wax is applied as a primary coating of mould and the releasing agent is spread over the bottom and wall of the wooden mould. The polyester resin and catalyst are mixed in a weight percentage of 10:5 to form a matrix and coated on the bottom of the mould. The composite specimen consists of a total of 5 layers in which polyester resin layers have coated the bottom, middle and top of the specimen. The second and fourth layers are formed by sisal, jute, and sorghum bicolor fibers. The sisal, jute, and sorghum bicolor fibers are cut into 30 mm, 30 mm and 10 mm length respectively and distributed uniformly at the second and fourth layers of the mould. The matrix is poured over the natural fibers evenly then pressed and pushed down with the iron roller to avoid and eliminate the air bubbles. After fabrication, the composite specimen kept for several hours in sunlight for removing the moisture content. As per the dimensions of mechanical tests, excess resin and fiber edges of specimen are properly removed. Fabricated designation of the specimen and weight % of fiber composition for hybrid composites as shown in Table 1.

Table 1. Specimen designation and weight % of fiber composition for hybrid composites

Designation of specimen	Weight % of natural fiber composition		
	Sisal	Jute	Sorghum bicolor
A	50	45	5
B	40	50	10
C	50	35	15
D	40	40	20
E	50	25	25
F	40	30	30

Figure 1. Fabricated hybrid composites specimen.

Sisal and jute fibers have more tensile and flexural strength [16], this is the main reason for considering both fibers with maximum weight % in fiber composition compared to sorghum bicolor. Fabricated hybrid composite specimen as shown in Figure 1.

Mechanical Testing

The tensile test is conducted on a Tinius Olsen 10 kN Universal testing machine (UTM) with a gauge length of 75 mm and the cross-head speed of the machine is set at 5 mm/min. The specimen size for the tensile test is 115 mm×20 mm×3 mm according to ASTM D638. Flexural tests also conducted by the same tensile testing machine. The size of the specimen for the flexural test is 110×15×3 mm according to ASTM D790. The impact test is conducted on a Tinius Olsen tester. This test involves the sudden and dynamic application of load on the specimen. The impact test is conducted on a Tinius Olsen testing machine according to ASTM D256 standard. The Izod test specimen as per dimensions are 65 mm×15 mm×3 mm. The hardness test is conducted on a Shore D hardness test machine (Model SRT-102) manufactured by S. C. Dey and Co., Kolkata, India. The ASTM D2240 standard specimen is carried out in the shore (Durometer) hardness tester (Make, Hiroshima, Japan) 1.40 mm diameter, 30º Cone indenter extension up to 2.54 mm with an applied force of 44.45 N. Each hardness test specimen is prepared for the size of 35 mm×15 mm×3 mm [21].

Tensile Test

The tensile test generally performed on flat specimens as shown in Figure 2. In the tensile test, an uni-axial load was applied through both the end. The tensile test specimen of hybrid composites is fixed in the experimental setup and loading arrangement of the specimen for the tensile test. The testing process consists of the insertion of the test sample in the machine and operating tensile force to it till it fractures. The tensile force is documented as a perform of the expansion in gauge length. The experiments are conducted four times in each composition and the average values are taken for results.

Figure 2. Specimen for tensile test.

Figure 3. Flexural test specimen.

Flexural Test

In this experiment, the 3-point bending method is used to find out the flexure of the specimen with a support span length of 70 mm. The cross-head speed of the machine was set at 2 mm/min. The measurements were taken at five magnitudes of the constant load for six specimens [22]. Flexural test specimen as shown in Figure 3.

Impact Test

Notched- bar impact test of material provides information on failure mode under high-velocity loading conditions leading to sudden fracture where a sharp stress raiser (notch) is present. This test can be used as a quick and easy quality control check to determine if a material meets specific impact properties or to compare materials for general toughness. This test involves the sudden and dynamic application of the load on the specimen. This test measures the amount of energy absorbed by the specimen for the break-in J/m^2 [23]. impact test specimen as shown in Figure 4.

Hardness Test

The hardness of a particular sample refers to its stiffness or resistance of being broken to have its shape changed permanently when the load is applied to it. The indentation value reflects the resistance to local deformation, which is a complex property and related to modulus, strength, elasticity,

Figure 4. Specimen for impact test.

plasticity and dimensional stability. It also gives an idea about the degree of cross linking [26].

Scanning Electron Microscope

The morphology of the PA6 composites is observed using a Scanning Electron Microscopy (SEM) on a JEOL equipment model JSM-5300LV with 10 kV of voltage acceleration.

Thermogravimetric Analysis (TGA)

Thermogravimetric analysis is performed by EXSTAR TG/DTA 6300, Hitachi, Japan.

TG instrument with the temperature accuracy ±5 °C to examine the thermal degradation behavior of the maximum tensile strength achieved specimen (D). Approximately, 10mg of powdered samples are placed in an alumina crucible with a diameter of 7 mm and are heated under the dynamic linear rate of 10 °C/min., with a 50 cm^3/min nitrogen flow from 50 °C to 600 °C.

Results and Discussion

Tensile Strength

It can be observed from Figure 5 and Figure 6. that tensile strength and tensile modulus of the polyester composite increases with natural fiber loading in all cases. The hybrid composites A, B, C, and D show gradual enhancement of tensile strength. The hybrid composites showed a positive effect up to the weight% of sisal (40 %) and jute (40 %) shared equally (D). From the Figure 5. and Figure 6 when the fiber contents of sisal and jute fibers were increased, the tensile strength and tensile modulus of the composites are increased. From the results, maximum weight % of the sisal, jute fiber and minimum weight % of sorghum contents hold the ductile property of hybrid composites.

However, the E and F composites reveal a slight decrease in tensile strength. The reason for the negative effect occurs of the specimens E and F, the weight % of jute and sorghum shared equally. Whenever decreasing the jute fiber and increasing sorghum contents the ductile property of the composite slightly decreased.

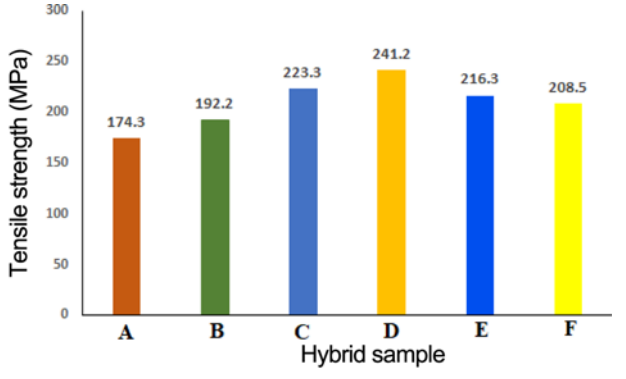

Figure 5. Tensile strength comparison of different composite materials.

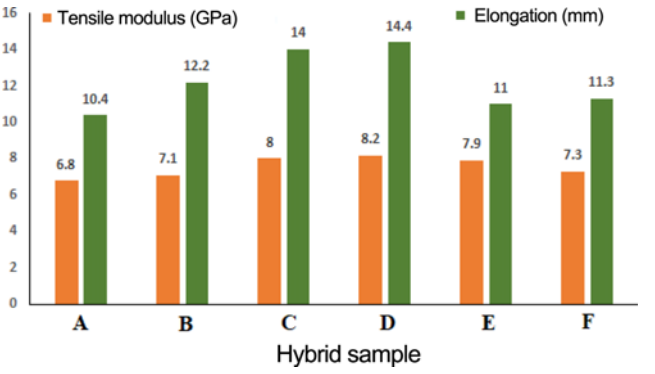

Figure 6. Tensile modulus and elongation of different composite materials.

Results revealed that adding 40 weight % of sisal, jute and 20 weight % of sorghum provides the highest value of tensile strength (241.2 MPa) when compared with other composites and it is evident that the addition of sisal and jute effected in good ductile properties.

Figure 6 indicates the elongation of hybrid composites, the elongation property of composites also increased up to the level of 14.4 mm (D). The ductile property of composites increased gradually from A, B, C and D specimen. Suddenly it has reduced on E and F specimen. Increasing the sorghum fiber contents may be reduced the ductile property and increased the brittleness of the specimens.

Flexural Strength

From Figure 7, the flexural strength of the composites increases with the increase in the sisal and jute fiber loading until 40 weight% (D). The maximum flexural strength 86.8 MPa is obtained at 40 weight % of both fiber loading. The flexural strength of E and F composites are increased compared with A, B and C composites. But D composite is reached maximum flexural strength compared to all

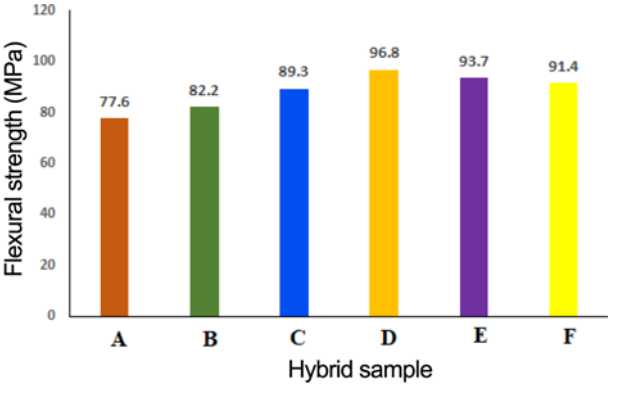

Figure 7. Flexural strength comparison of different composite materials.

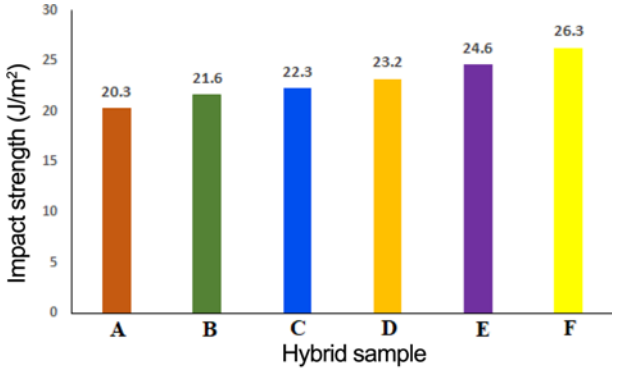

Figure 8. Impact strength comparison of different composite materials.

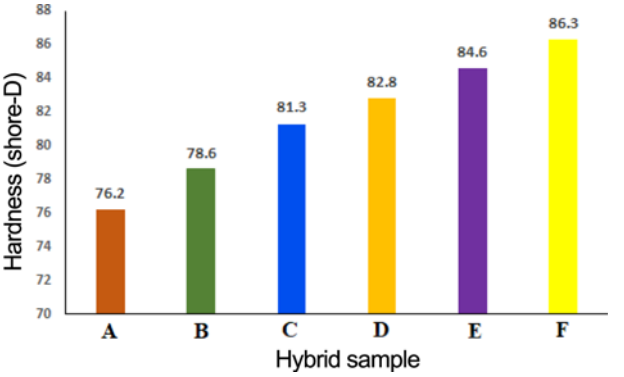

Figure 9. Hardness comparison of different composite materials.

composite specimen. The jute fiber inclusions enhance the load bearing capacity and ability to withstand bending of the composites [23].

From the results proved, inclusions of jute added to sisal fiber the flexural capacity of the composite has been increased. But the flexural value starts decreases because of the random orientation of the sisal jute and sorghum fibers. The non-uniform distribution of natural fiber results may be in the variation of flexural strength value.

Impact Strength

Figure 8 indicates the impact strength of composites increases from A, B, C, D, E, and F gradually. The jute and sorghum fibers both are weight of 30 % and sisal 40 % reached the maximum impact strength about 26.3 J/m^2 in specimen F. Hybrid specimens of A, B,C,D, and E are minimum impact strength 20.3, 21.6, 22.3, 23.2 and 24.6 J/m^2 respectively compared to F specimen.

Good adhesion between the fiber and matrix is also responsible for the good resistance to crack propagation during impact tests. The increased fiber content will increase the contact area between the fiber and matrix if there is good impregnation of fibers in the resin. At higher fiber loading the impact transfer should be more efficient [24].

Hardness

Figure 9, the hardness of hybrid composites increases from A, B, C, D, E, and F progressively. The jute and sorghum fibers both are the weight of 30 % and sisal 40 % reached the maximum hardness of about 86.3 in specimens Compared to F specimens A, B, C, D, and E are minimum hardness 76.2, 78.6, 81.3, 82.8 and 84.6 respectively. Usually, the presence of a more flexible matrix causes the resultant composites to exhibit lower hardness [25]. The reason for increasing the hardness is the better dispersion of fibers into the polyester matrix stronger interfacial adhesion to the fiber matrix.

SEM Observation of Fracture Surface of the Natural Fiber Composites

The internal characteristics of the natural fiber composite material utilized for the examination is analyzed as a result of SEM. The image of the tensile break composite material of natural fiber is exhibited in Figure 10(a) and 10(f). The Figure 10(a) reveals the interrelationship between the sisal fiber and polyester resins. tensile break image of 10(a) proportion proves a few deformation and long cracks development. Because of inappropriate scattering of the sisal, jute sorghum and polyester resin might be made the miniaturized scale splits in the internal area of the composites. This might be made negative impacts in the proportion of natural fiber and polyester composites. Figure 10(b) Natural fiber shows the strong interactions between the fibers/matrix and arranged in the two layer longitudinal directional alignment of the fiber which indicates high ductile load-carrying capacity and less delamination. The SEM picture Figure 10(b) unmistakably uncovers the correct dispersion of polyester resin and sisal fiber composites. Figure 10(c) the poor interfacial bonding is observed, due to the uneven distribution of natural fibers and improper mixing results in polyester detached from the particles along with the voids, plastic deformation and microcracks on the composites.

In Figure 10(d) The internal surface of natural fiber reinforced polyester was characterized by slight deformation and cracks formation, which corresponds to its quite good mechanical properties. The addition of 50 % of sisal revealed negative effect on tensile properties of polyester composites; this fact was found back to inhomogeneity, deformation and crack formation in the matrix as shown in Figure 10(e). The improper interlinking of Sisal with jute and sorghum fibers has created deformation on polyester composites. It is clearly visible that the fractured surface possesses deformation and the broken particles. It has also taken place in a brittle way and agrees with the lowest elongation as shown in Figure 10(f). The particles were

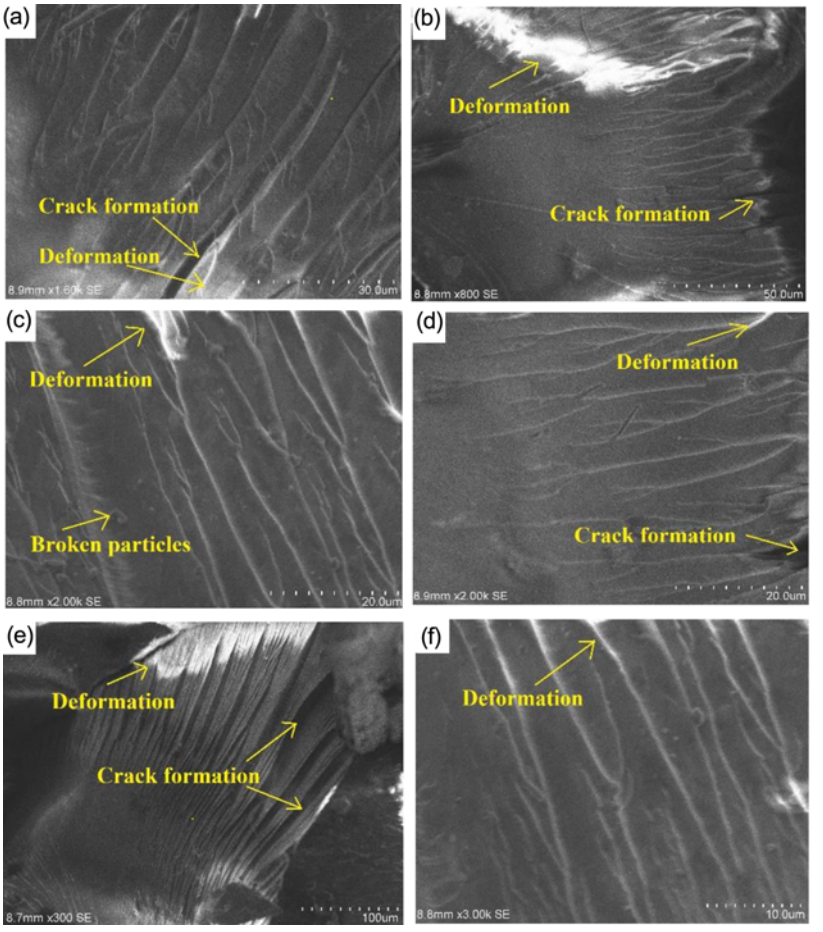

Figure 10. SEM images of the tensile fractured surfaces of hybrid polyester composite specimens; (a) A, (b) B, (c) C (d) D, (e) E, and (f) F.

poorly bonded to the polymer matrix and split easily during the tensile test process. Overall conclusion of SEM images are proper scattering of natural fiber and resin it might give great positive outcomes.

TGA of Hybrid Composite Specimen - D

This test is carried for the maximum tensile strength achieved the composite specimen D (Sisal 40 %, jute 40 %, and 20 % sorghum). The thermal degradation was determined by the TGA and Differential Thermal Analysis (DTA) thermogram as shown in Figure 11. As expected, the two stages of degradation are evident in both the profiles which correspond to temperature regions of different constituents like moisture evaporation (upto 100 °C) and degradation of the hybrid composite material (100-450 °C). The de-polymerization of composites usually occurs between 400 and 450 °C. The initial peak of fibers reinforced polyester composites was found at 93 °C which represents the loss of moisture and other volatiles at the first degradation. It is observed between room temperature and 100 °C.

The next peak which is obtained around 465 °C which

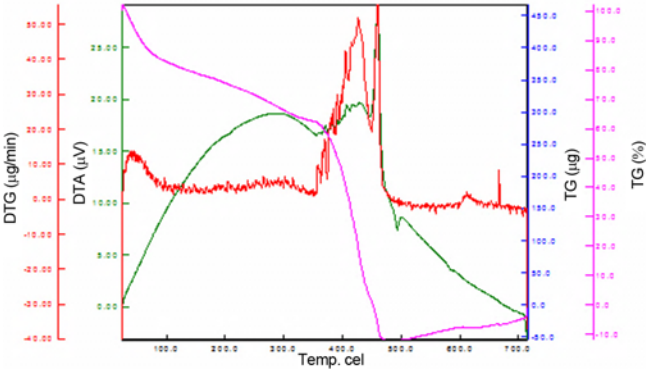

Figure 11. TGA of hybrid composite specimen - D.

denotes DTA degradation of natural fibers and the prominent peak appears at the temperature corresponding to the maximum degradation rate. Moreover, natural fiber reinforced with polyester composites increases the degradation temperature (400 °C to 480 °C) due to retaining and improving the structural order to minimizing the amorphous

content. A greater crystalline structure essentially requires a higher degradation temperature which is evident in optimal natural fibers with polyester composites. The derivative thermogravimetric (DTG) curve shows the decomposition temperature of polyester composite material value which is above 430 ^{o}C.

Conclusion

The sisal, jute, and sorghum bicolor natural fibers are reinforced polyester composites on different weight percentages by hand layup method. The mechanical and thermal properties of composites are identified and conclusions are drawn.

1. The results indicated for D specimen the maximum tensile strength, tensile modulus and elongation of hybrid composites show at 241.2 MPa, 8.2 GPa, and 14.4 mm respectively. By increasing the sisal and jute fiber wt% and decreasing sorghum contents the ductile property of the composites is increased.
2. The flexural strength is increased gradually and reached a maximum at 96.8 MPa in D specimen. The uniform dispersion of natural fiber results might be increasing the flexural strength value.
3. The impact strength is achieved maximum at 26.3 J/m^2 in F specimen. Good adhesion between the natural fiber and polyester matrix is responsible for the better impact strength.
4. The maximum hardness attained at 86.3 in F specimen. The hardness of a composite depends on the distribution of the fibers into the polyester matrix.
5. The uniform distribution and incorporation of the natural fiber particles in the microstructure of the polyester resin is the major factor responsible for the enhancement of the mechanical properties. SEM observation confirms the stronger interfacial bonding characteristics of polyester composites.
6. Thermal stability and decomposition are observed for the maximum tensile strength attained specimen (D) by TGA and DTA.
7. This type of composite material can be useful for packaging, light weight automotive parts (interiors for cars), shipping industry for mooring small craft, and construction fields.

References

1. I. K. Varma, S. R. Anantha Krishnan, and S. Krishnamoorthy, *Composites*, **20**, 383 (1989).
2. K. Joseph, S. Thomas, and C. Pavithran, *Compos. Sci. Technol.*, **53**, 99 (1995).
3. M. Jacob, S. Thomas, and K. T. Varughese, *Compos. Sci. Technol.,* **64**, 955 (2004).
4. Y. Li, Y. W. Mai, and Y. Lin, *Compos. Sci. Technol.*, **60**, 2037 (2000).
5. N. Defoirdt, S. Biswas, L. Vriese, L. Q. N. Tran, J. V. Acker, and Q. Ahsan, *Compos. Part A-Appl. Sci. Manuf.,*, **41**, 5885 (2010).
6. S. V. Joshi, L. T. Drzalb, A. K. Mohanty, and S. Arora, *Compos. Part A-Appl. Sci. Manuf.,* **35**, 371 (2004).
7. N. Chand, R. K. Tiwary, and P. K. Rohatgi, *J. Mater. Sci.*, **23**, 381 (1988).
8. N. Chand and S. A. R. Hashmi, *Met. Mater. Process*, **5**, 51 (1993).
9. Y. Li, Y. W. Mai, and L. Ye, *Compos. Sci. Technol.*, **60**, 2037 (2000).
10. P. S. Mukherjee and K. G. Satyanarayana, *J. Mater. Sci.*, **19**, 3925 (1984).
11. N. L. G. de Rodriguez, W. Thielemans, and A. Dufresne, *Cellulose*, **13**, 261 (2006).
12. M. Idicula, N. R. Neelakantan, Z. Oommen, K. Joseph, and S. Thomas, *J. Appl. Polym. Sci.,* **96**, 1699 (2005).
13. N. Venkateshwaran, A. Elayaperumal, and G. K. Sathiya, *Compos. Part B: Eng.*, **43**, 793 (2012).
14. M. Ramesh, K. Palanikumar, and K. H. Reddy, *Procedia Eng.,* **51**, 745 (2013).
15. A. Gopinath, M. S. Kumar, and A. Elayaperumal, *Procedia Eng.*, **97**, 2052 (2014).
16. W. L. Rooney, J. Blumenthal, B. Bean, and J. E. Mullet, *Biofuel. Bioprod. Bior.,* **1**, 147 (2007).
17. S. Kumar and P. Marimuthu, *J. Indian Pulp and Paper Technical Association*, **24**, 47 (2012).
18. Z. J. Vasquez, C. R. S. Patalud, P. M. O. Tarnate, S. G. Ramirez, E. C. Escobar, and C. C. Vaso, *Philipp. EJ. Appl. Res. Dev.*, **6**, 1 (2016).
19. O. A. Khondker, U. S. Ishiaku, A. Nakai, and H. Hamada, *J. Polym. Environ.*, **13**, 115 (2005).
20. K. Sabeel Ahmed, S. Vijayarangan, and A. C. B. Naidu, *Mater. Des.*, **28**, 2287 (2007).
21. S. Sathees Kumar and G. Kanagaraj, *Int. J. Polym. Anal. Char.,* **21**, 378 (2016).
22. S. Sathees Kumar and G. Kanagaraj, *J. Inorg. Organomet. Polym. Mater.*, **26**, 788 (2016).
23. S. Mantry, A. Satapathy, A. K. Jha, S. K. Singh, and A. Patnaik, *J. Reinf. Plast. Compos.,* **29**, 2869 (2010).
24. D. Akesson, M. Skrifvars, J. Seppala, and M. Turunen, *J. Appl. Polym. Sci.*, **119**, 3004 (2011).
25. V. S. Sreenivasan, D. Ravindran, V. Manikandan, and R. Narayanasamy, *Mater. Des.,* **31**, 111 (2012).
26. S. S. Kumar and G. Kanagaraj, *J. Polym. Eng.,* **37**, 547 (2017).