Investigation of Mechanical Properties of Sisal Fiber and Sugar Palm Fiber Reinforced Hybrid Composites

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Abstract

Natural fibers have received a lot of coverage as reinforcements in polymer matrix composites. Out of all the reinforcing fibers, hybrid composites made of natural fibers have been attracting the attention of researchers as high-potential reinforcement materials for composite materials. These fibers are easily available as agriculture-based products. Natural fibers are low cost, bio-degradable, sustainable, and lightweight materials for composite applications. In this experimental work, sisal fiber and sugar palm fibers were used as reinforcement in different ratios to fabricate hybrid composites by the compression moulding technique while maintaining a total fiber loading of 30wt%. Tensile tests using a UTM INSTRON machine, flexural tests using a UTM DTRX machine, impact tests using an IZOD IMPACT D256 machine were conducted, and water absorption was also determined. The obtained results show that the composite made of a sisal fiber 20% and sugar palm fiber 10% combination exhibits better tensile properties with a stress value of 6.67N/mm^2, and an Izod impact value of 42.461J/m. While the composite with a sisal fiber 10% and sugar palm fiber 20% showed a better flexural stress value of 67.29N/mm^2, the water absorption test was carried out for four days with a 96-hour analysis. This research addresses that specimen-2 with sisal 20% and sugar palm fiber 10% absorbs less water compared to other composites.

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1. Introduction

In recent days, composite materials (made up of fiber and matrix) are used for sport goods because of their high stiffness and strength-to-weight ratios, long fatigue life, resistance to electrochemical corrosion, and other superior properties of composites. Especially, the Fiber-reinforced composite laminates are commonly used in helmet shells and other high-performance goods due to their high specific stiffness and strength, etc. Mostly, to use the composite materials in these applications, various types of tests like Tensile and Compressive tests, free and forced vibration tests, deformation, and damage tests, etc., are done on the composites. It is essential to know the impact characteristics of these sports goods, which may be subjected to impact loads in complex environmental conditions. If the load on the sports goods increases, large translation deflections and internal stresses can occur, which may lead to failure of the structure. Hence, to avoid the typical problems caused by impact, it is important to conduct the impact load test. Due to the cost-effective machining of metal alloys, natural fiber-reinforced composites are in high demand. Fibers that are natural and readily available, less costly, reusable, biodegradable, and environmentally friendly can reduce the cost of fibres. In comparison to composites reinforced with carbon fibres, the hybrid fibre-reinforced composite is designed to improve thermal and mechanical properties.

The focus on natural fibres is increased as their cost is less when compared to synthetic fibres which are petroleum-based products. Natural fibre composites are manufactured using natural or synthetic resin with reinforcement as natural fibres. The high specific properties, low density, light weight, and renewable source are its highlighting advantages. Sisal and sugar palm fibres, due to their ease of availability and increasing demand for environmentally friendly materials, have marked their importance in composite engineering. To understand the various research components of the present work and to identify the scope of this work, an elaborative literature survey has been carried out.

Zewdie Alemayehu et al., [1] reviewed that different orientations of the fibre have enhanced the mechanical properties of the sisal fibre composite material. Sisal fibre was extracted using a knife from the sisal plant leaves. To remove cellulosic matter and improve the surface roughness of the fibre, it was treated with NaOH for 24 hours. The composite was made with fibre orientations of 0, 45 & 90. From the test results, it was found that the sisal fibre composite is a good lightweight replacement for conventional materials in vehicle body applications. Muralidharan et al. [2] investigated the effect of CG and KG fibre hybridization on seawater diffusivity, service life, and tensile strengths of their composite systems via hydrothermal ageing. The hybrid composites were aged in seawater for 50, 150, and 300 days at temperatures ranging from 20 to 40 degrees Celsius.

Common failure modes for the bast fiber-reinforced composite include fiber pull-out, fiber fracture, and matrix cracking, while delamination was reported as the major failure mode for the hybrid composite. Common failure modes for the bast fiber-reinforced composite include fiber pull-out, fiber fracture, and matrix cracking, while delamination was reported as the major failure mode for the hybrid composite. Common failure modes for the bast fiber-reinforced composite include fiber pull-out, fiber fracture, and matrix cracking, while delamination was reported as the major failure mode for the hybrid composite.

Getu et al., [3], reviewed the performance of sisal- and bamboo-reinforced polyester hybrid composite (BSFRHC). The compressive strength of the hybrid composite reinforced with bamboo/sisal fibre showed that the 0°-fibre orientation composite exhibits higher compressive strength than the 90° fibre orientation composite and the bidirectional (0°/90°) fibre orientation composite. A unidirectional 90° fibre orientation was found to have higher tensile and flexural strength. It was found that the bamboo- and sisal-fibre-reinforced hybrid composite in a unidirectional 0° orientation has the potential to be used for automotive interior part applications. Kumar et al., [4] represents a brief overview of the properties of natural fibres and natural fibre-reinforced composites, which is an emerging area in polymer science, and demonstrates how natural fibres are a good alternative to synthetic fibres in transportation such as automobiles, railways, aerospace, packaging, and construction industries for ceiling, paneling, partition boards, etc. Kumar et al., [5] systematically examined the influence of Himalayan bast fiber (Nettle and Bauhinia vahlii) on the physical, mechanical, and sliding wear rate of hybrid reinforced epoxy composites.

Dananjay et al., [6] studied Kevlar-29, basalt fibre, and carbon fibre, which find tremendous use in the automotive, defense, and aerospace industries. These applications require precision machining with very close tolerances. Oladele et al., [7] represents the influence of chemically treated sugar palm kernel shell fibre (PKSF) and particulate cassava peel (PCP) as hybrid reinforcements on some selected mechanical properties. The use of these agro-based materials in both treated and untreated conditions is imperative since they yielded high and improved mechanical and wear properties.Though much has been done with sugar palm kernel shell fibre, not much has been done with particulate cassava peel for the development of composite materials.The analysis of its elemental composition, therefore, encourages the use of the material as another good source of agro-waste that has the potential for engineering applications. The reinforcement content with the optimum value was 6 wt.% from chemically treated PKSF/PCP hybrid reinforced composites.

Patrick Ehilmoisili et al., [8], investigated the hybridization of microwave-treated plantain fibres with MWCNT in an epoxy composite, using the hand lay-up and compression moulding techniques.Hardness and impact strength showed an improvement up to 20% and 27%, respectively, as the carbon nanotube content increases from 0.5% to 1% wt., whereas there was a decrease in strength for tensile and flexural properties as the MWCNT content increases from 1 to 2 wt.%.Thermal conductivity has shown a significant improvement up to 43% as the MWCNT content increases, and SEM analysis suggests uniform surface roughness was achieved after the microwave treatment of the fibre and good mechanical interlocking of the hybrid fibres with the polymer matrix.

Selvan et al., [9] Three samples (kenaf - kenaf), (sisal - sisal), and (kenaf - sisal) combinations were fabricated by the compression moulding process. It is found that the kenaf – sisal combination has better mechanical behaviour compared to other composites; it exhibits a tensile strength of 156 MPa and a flexural strength of 282 MPa. The thermal stability and wear behaviour of tri-fillers reinforced hybrid composites are investigated by Sathesihkumar et al., [10] Vertical injection moulding techniques are used to create Silica (S), Coconut shell (C), and Graphite (G) filler reinforced homogeneous and functional graded epoxy composites. The impact of filler content, design parameters, and their interaction on the wear and friction behaviour of SCG composites has been studied. This study provides an important reference and basis for further study of the mechanical behavior of natural fibre composites.

2. Materials and Methods

Over the past few years, the focus of researchers has been on eco-friendly, biodegradable, and low-density composites obtained from plant fibres. The fibres obtained from plants are abundant, and only a small quantity of fibre is used in fertilizer, cattle-feed, household applications, etc., with the bulk of the fibres being burnt in the field, which also affects the environment. Instead of wasting these natural fibres, they can be used with polymers to form composite materials, and based on their mechanical, thermal, and physical properties, they could be used in different applications. The implementation of these eco-friendly materials in various applications will not only benefit the environment but also could generate revenue and job opportunities. Sugar palm, flax, hemp, jute, sisal, kenaf, banana, are some of the examples of natural fibres obtained from plants. In this experimental study, hybrid composites were made with sisal fibre and sugar palm fibre, and their mechanical properties were analyzed.

2.1. Sisal fibre

Agave sisalana, commonly known as sisal, is a well-known source of hard fibre with an estimated annual production of 400,000 tons in the world. The fibres are obtained from the leaves of the plant and are one of the most widely used natural fibres. Figure 1.2 shows sisal plants with some of their leaves chopped. These fibres are cheaper and pose no health hazards. Composite materials made up of sisal fibres are found to be more promising in reducing the weight of the vehicle. Sisal plants with chopped leaves are shown in Figure 1.

Figure 1. Sisal plants with some of their leaves chopped

2.2. Sugar Palm fibre

Sugar palm fiber (SPF) is a natural lignocellulosic fibre. It is characterized by high tensile strength, low degradation rate, and durability. Sugar palm fibre is low priced, and it is plentiful in nature. In the field of composite materials, many research studies have been reported about the utilization of sugar palm fiber as a reinforcing agent with the polymer matrix. The results indicated that sugar palm fibers have the potential to be used in many applications, especially those requiring high water resistance. Figure 2 shows a bunch of sugar palm fruits.

Figure 2. Sugar palm with fruits

2.3. Hybrid Composite Preparation

Sisal fibre, which is extracted from the leaves of the sisal plant, was taken. Figure 3 shows the untreated sisal fibre. Untreated fibre has poor surface properties and possesses less strength.

Figure 3. Untreated Sisal fiber

Sugar palm fiber was obtained from the outer sheath of the sugar palm fruits, which is naturally available in fiber form, and the untreated fiber is shown in Figure 4.

Figure 4. Untreated Sugar palm fiber

In order to overcome the high degree of moisture absorption and poor dimensional stability of the natural fibers, they are subjected to chemical treatment. The chemical treatment of the fiber is aimed at improving the adhesion between the fiber surface and the polymer matrix. It will not only modify the fiber surface but also increase fiber strength. The water absorption of composites is reduced, and their mechanical properties will be improved. Sisal and sugar palm fibers were treated with a NaOH solution of 20% concentration. The fibers were treated with the NaOH solution for 3 hrs, and they were allowed to dry at room temperature for 8 hrs.

Figure 5. Treated Sugar palm Fibre

Figure 5 shows the treated Sugar palm fiber. NaOH treatment increases the strength of the fibers. It also improves the adhesion between the fiber surface and the matrix. Treated sisal fiber is shown in Figure 6.

Figure 6. Treated Sisal fibre

Composite plates were made by the compression moulding technique. A wax coating was given as a releasing agent so that the composite plates could be removed easily after compression moulding. Then epoxy resin was applied, and Sisal and Sugar palm fibers were placed over the resin with random orientation at appropriate proportions; again, resin was applied over it. Similarly, 3 layers of fibers were placed. The hybrid composites were compressed in the compression moulding setup for 2 hrs. The compression mould cavity was maintained at 120 degrees Celsius as the curing temperature, and a pressure of 10 bar was maintained.

Plates were removed from the mould. Since a wax coating was provided as a releasing agent, the plates were easily removed. Thus, composite plates of 5mm thickness were made. Two plates were made with chopped fibres of length 20mm and 30 mm with the matrix as epoxy resin.

Three hybrid composite plates were made with the matrix-fibre proportions as per the following:

- **Sample 1 : 70% resin + 10% Sisal fibre + 20% Sugar palm fibre**
- **Sample 2 : 70% resin + 20% Sisal fibre + 10% Sugar palm fibre**
- **Sample 3 : 70% resin + 15% Sisal fibre + 15% Sugar palm fibre**

3. Mechanical Properties

To conduct the mechanical tests like the tensile, Izod, and flexural tests, the specimen has to be cut according to ASTM standards as mentioned in Figure 7. So the composite specimens were marked with dimensions according to ASTM standards, and then they were shaped using the cutting machine shown in Figure 7. The edges were polished using salt paper.

3.1. Tensile test of the hybrid composite specimen

The tensile strength of a material is the maximum amount of tensile stress that it can take before failure. Five specimens of treated fiber-reinforced composites were tested, and the mean values were taken. The tensile test was performed according to ASTM D 638 {m/13/}. The tensile test specimens were tested in an Electronic Tonometer – Model PC 2000 operated with a 20kN load cell with a digital load controller and extension microprocessor-based elongation measurement set up. The crosshead speed was 5 mm/min, and the gauge length was maintained at 50mm.

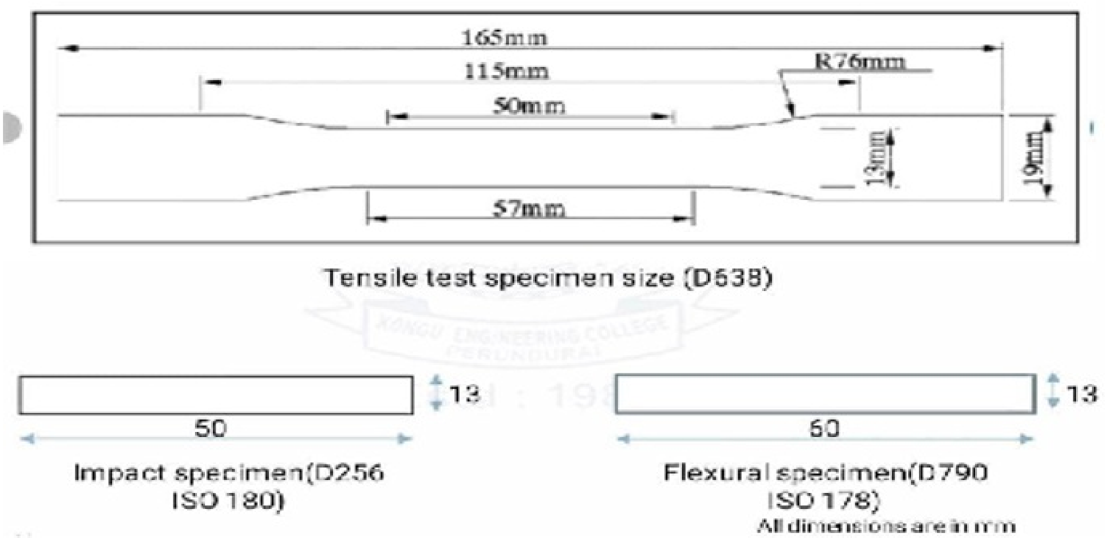

Figure 7. ASTM standard for test specimens

3.2. Flexural Test

Flexural strength is the ability of a material to resist deformation under a bending load. The flexural test was performed by the three-point bending method according to ASTM-D 790 [2&18]. The size of the specimen was 127 mm × 13 mm × 5 mm. The Kalpak universal testing machine KIC-2-0200-C, with a capacity of 20 kN, was used for conducting the flexural test at 28 °C and at a relative humidity of 50 ± 2%. The crosshead speed was 2 mm/min.

3.3. Impact Test

Impact properties of untreated and 5% alkali-treated sugar palm sprout fiber reinforced composite specimens were tested using an IZOD digital impact tester according to the ASTM D 256 standard. The specimen was tested to determine the impact resistance and impact strength of the composites at room temperature. The test specimen was supported by a vertical cantilever beam and was broken by a single swing of a pendulum. The size of the specimen is 50 x 13 x 5 mm^3, and the specimens were notched. The Izod digital impact tester, Frank–53568, was employed for conducting the impact test at room temperature.

3.4. Water Absorption Test

To study the behaviour of water absorption of the hybrid composites, water absorption tests were carried out according to ASTM (D1037). Before immersing the sample into water, the composite is heated in the oven at 50 degrees centigrade for 24 hrs. and cooled to room temperature. Hybrid composite samples were immersed in a water bath (deionized, 23°C) during a time period until the saturation was reached. Five specimens from each fiber volume fraction with dimensions (152mm× 152mm × 5mm) (tensile samples) and (152mm× 152mm × 5mm) (flexural samples) were cut from composite panels. After 24 , the samples were removed from the water and were weighed (mass) using a digital scale immediately after they were dried with a dry cloth. This process was repeated to weigh the specimens regularly (mass) over 4 days of water immersion

The amount of water absorbed by the composites (in percentage) was calculated. The percentage of water absorption is the ratio between the change in weight of the specimen to the original weight of the specimen.

4. Results and Discussions

4.1 Tensile Strength

The tensile strength of a material is the maximum amount of tensile stress that it can take before failure. The commonly used specimen for the tensile test is the flat bar type. During the test, a uniaxial load is applied through both ends of the specimen. The sample was cut into a flat bar shape (165x19x5) mm, in accordance with ASTM standards. Typical points of interest when testing a material include: ultimate tensile strength (UTS) or peak stress; offset yield strength (OYS), which represents a point just beyond the onset of permanent deformation; and the rupture (R) or fracture point where the specimen separates into pieces. The tensile test is performed on the universal testing machine (UTM) Kalpak KIC-2-1000-C, and the results are analyzed to calculate the tensile strength of hybrid composite samples. The following Figure 8 shows the tensile strength of the three samples. Sample-1, with 10% sisal and 20% sugar palm hybrid fibers, gives the least value of tensile strength of 50 N/mm^2 , and the highest tensile strength of 76 N/mm^2 for sample 3, which contains 15 % of sisal and 15 % of sugar palm fiber. The Sample-2 hybrid composite shows 65 N/mm$^{2\ of}$ tensile strength , which contains 20 % sisal and 10 % sugar palm fiber.

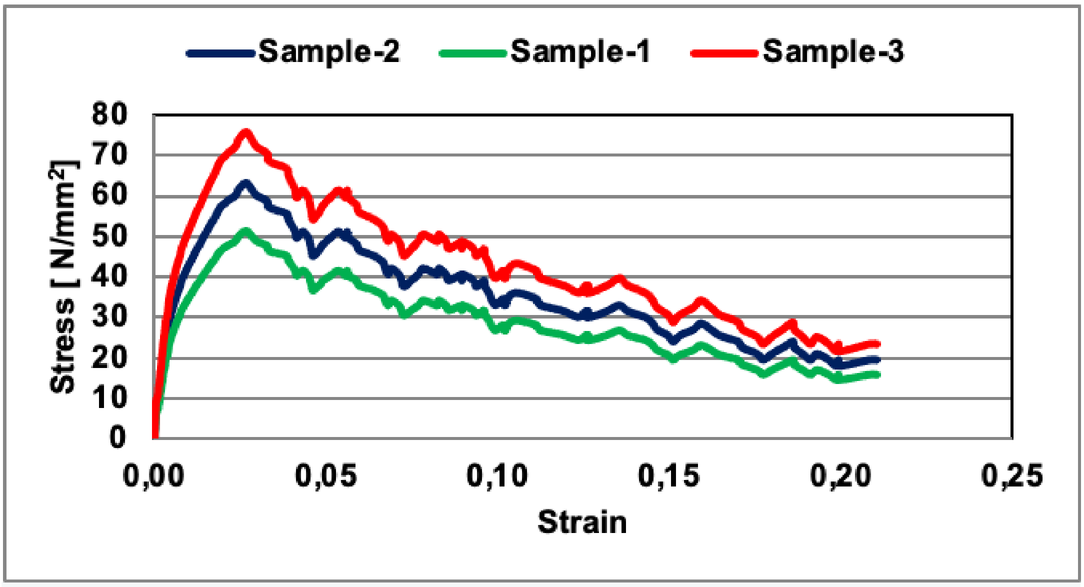

Figure 8. Tensile strength of the hybrid composites

4.2. Flexural Strength

The test was performed according to the American Society for Testing and Materials (ASTM) standard D 790. The rectangular-shaped samples were prepared for the experiment. The flexural load was applied until complete fracture. The flexural load versus elongation was recorded for analysis. It is measured by loading the desired shape specimen with a span length at least three times the depth. The flexural strength or modulus of rupture is expressed in MPa. The flexural MR is about 10 to 20 percent of the compressive strength, depending on the type, size, and volume of coarse aggregate used. However, the best correlation for specific materials is obtained by laboratory tests for given materials and mix design.

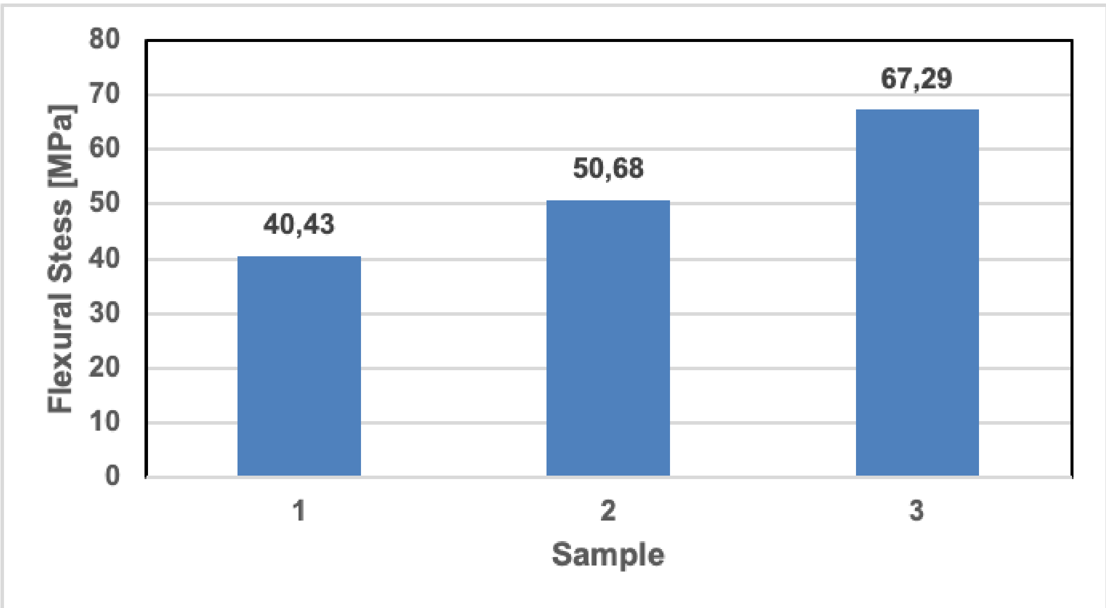

Figure 9. Flexural stress

From above Figure 9, it has been observed that the flexural strength of sample 1, sample 2, and sample 3 is 40.43 MPa, 50.68 MPa, and 67.29 MPa respectively. Again, in the flexural strength test, sample 3 gives the maximum flexural strength; hence, the equal amount of sisal and sugar palm fiber (15%) gives the better results.

4.3. Impact Test

The test was performed according to ASTM standard D 256. The rectangular-shaped samples of size 50mm x 13 mm x 5 mm were prepared for experiments. The impact load was applied until complete fracture occurred. The impact load was recorded manually from the digital readout. A small notch was created in the specimen and fixed to the table of the impact testing machine. The impact pendulum was activated, and the reading was recorded in the digital meter. Table -1 shows the impact values of different samples. From Table-1, it is clearly noted that sample 3 gives the maximum impact strength of 42.46 J/m, which contains the equal percentage of 15% sisal and sugar palm fibers.

Table 1. Impact test values of three different sample specimens.

Hybrid Composite specimen	Fracture Energy in J	Width in m	Impact value in J/m
Sample -1	0.442	0.013	34.26
Sample 2	0.083	0.013	6.38
Sample-3	0.552	0.013	42.46

4.4. Water Absorption Test

The water absorption test was conducted according to ASTM (D1037), which investigates the increase in material weight after being immersed in water. The composite samples with size (152mm× 152mm × 5mm) were measured for their weight for every 24 hours of the immersion period. The weight of the specimen was measured before immersion into water. After 24 hours, the specimen was taken out from the water and wiped with a dry cloth, and weighed immediately.

The specimens were submerged for 4 days. Three specimens of each composite sample were tested in a conditioning room with room temperature and 65% RH. The amount of water absorbed by the composites (in percentage) was calculated using Equation 1.

$$\%W = \frac{Wt - W_0}{w_W} \times 100$$

Where W is the percent water absorption, Wo and Wt are the oven-dried weight, and the weight of the specimen after time t, respectively. Table- 2 shows the percentage of water absorption of three specimens.

Table 2. Water Absorption Test values of three different sample specimens.

Hybrid Composite specimen	Day-1	Day-2	Day-3	Day-4	Day-5	%w Day-2	%w Day-3	%w Day-4	%w Day-5
Sample-1	30	36	38	40	40	20	26.6	33.3	33.3
Sample-2	36	38	38	38	40	5.5	5.5	5.5	11.1
Sample-3	38	44	44	46	48	15.7	15.7	21	26.3

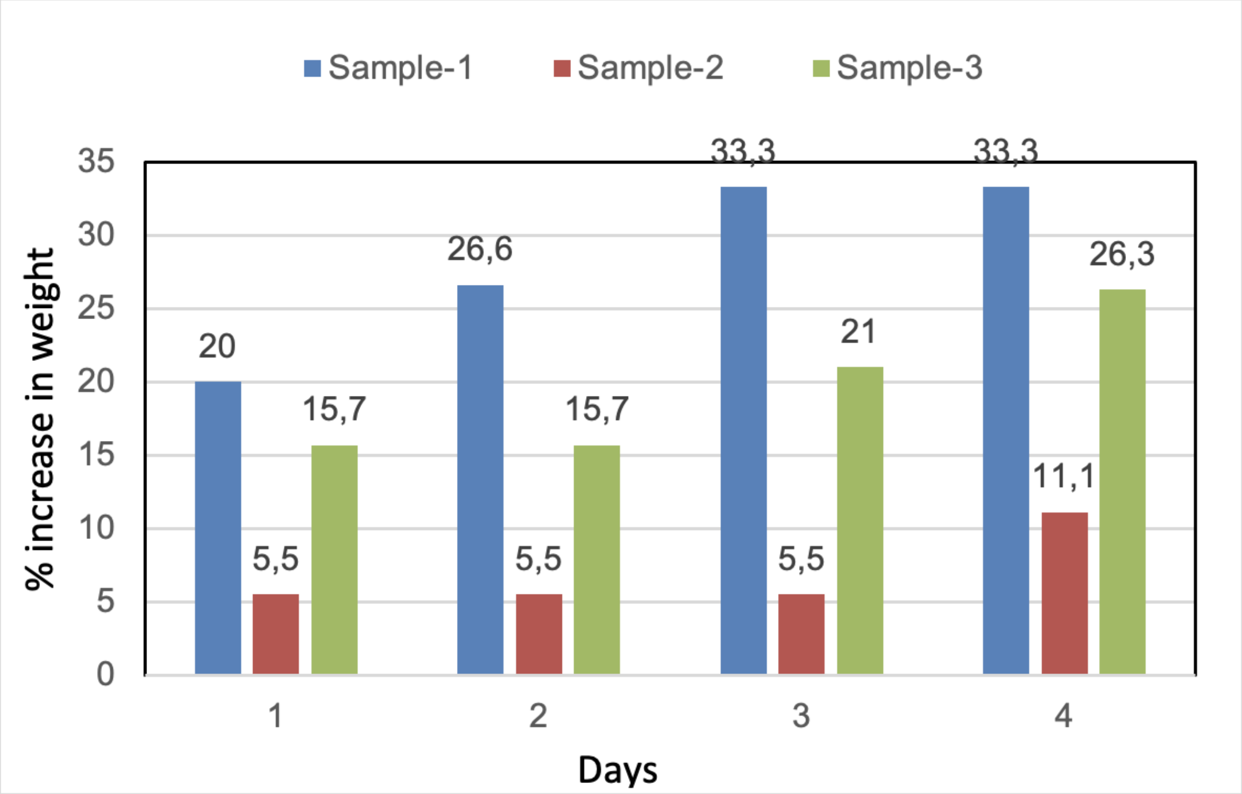

Figure 10. Percentage of water absorption

Figure 10 shows the percentage of water absorption with respect to the number of days. The initial weights of sample 1, 2, and 3 are 30 g, 36 g, and 38 g respectively. The low percentage of water absorption is observed in sample-2 and is maintained for the first three days equal to 5.5 %, and on the fourth day, it increased to 11.1 %. The reason for absorbing a low percentage of water is due to the less amount of sugar palm fibers and their stability during the heating process. Sample-3 has the next lowest water absorption of 15.7% and is maintained the same for the first two days, and then increased to 21 % and 26.3 % for the third and fourth days respectively. While sample-1, the percentage of water absorption is increased to 20 % on the first day and then to 26.6 % on the second day. After that, it increased to 33.33 % on the third day and maintained the same value for the fourth day. This shows that the maximum water absorption is 33.3 % in the 10 % sisal fiber and 20% sugar palm fiber hybrid composites. The maximum percentage of water absorption is due to the more amount of sugar palm fibers.

5. Conclusion

Hybrid composites of treated sisal and sugar palm fibre with different proportions of weight percentage and constant fiber length have been prepared, and mechanical tests like the tensile test, flexural test, impact test, and water absorption tests were carried out on the hybrid composite samples. From the experimental work and testing of the hybrid composites, the following conclusions are arrived at.

i. Sample - 3 exhibited better tensile properties, and the tensile stress of 76 N/mm^2 was higher compared to the other specimens.
ii. Sample- 3 showed better performance in flexural strength, with a flexural stress value of 67.29 MPa compared to the other specimens.
iii. Sample - 3 indicated better performance with the impact test, and the value of 42.46 J/m in the Izod test was higher than that of the other specimens.
iv. Sample- 2 performed well in the water absorption test. The water absorption, at only 11.1%, was observed after four days of immersion of the hybrid composites into the water.

From the above mechanical test results obtained by the hybrid composites, sample 3 has given better results as compared to the other specimens. Sample-3 has a fibre combination of sisal with 20% and sugar palm fibre with 10%; by increasing the sisal fibre percentage, the specimens showed better mechanical properties.

References

1. ^*Alemayehu Z, Nallamothu RB, Liben M, Nallamothu SK, Nallamothu A.K.: Experimental investigation on characteristics of sisal fibre as composite mate-rial for light vehicle body applications Materials Today: Proceedings 38, 2439-2444 (2021).*
2. ^*Muniraju Muralidharan, Thottyeapalayam Palanisamy Sathishkumar, Nagara-jan Rajini, Palanisamy Navaneethakrishnan, Shanmugam Arun Kumar, Sikiru Oluwarotimi Ismail, Krishnasamy Senthilkumar, Suchart Siengchin: Evalua-tion of tensile strength retention and service life prediction of hydrothermal aged balanced orthotropic carbon/glass and Kevlar/glass fabric reinforced polymer hybrid composites, 139(6), 51602, (2021)*
3. ^*Getu, D., Nallamothu, R.B., MasVresha, M., Nallamothu, S.K. and Nallamothu, A.K.: Production and characterization of bamboo and sisal fibre reinforced hybrid composite for interior automotive body application, Materi-als today: proceedings, 38, 2853-2860 (2021).*
4. ^*Sandeepkumar, Krishan Kanth Singh Mer, Brijesh Gangil, and Patel vina-ykumar: Synergy of rice- husk filler on physico-mechanical and tribological properties of hybrid Bauhinia-vahlii/sisal fibre reinforced epoxy composites. Journal of Materials Research and technology, 8(2) No.2, 2070-2082 (2019)*
5. ^*Sandeepkumar, Krishan Kanth Singh Mer, Brijesh Gangil, and Patel vina-ykumar:.: Synergistic effect of hybrid Himalayan Nettle/Bauhinia-vahlii fibres on physico-mechanical and sliding wear properties of epoxy composites. De-fence Technology, 16 (4), 762-776 (2020).*
6. ^*Dananjay R. Mishra Bajaj, A. and Bisht, R: Optimization of multiple kerf quality characteristics for cutting operation on carbon–basalt–Kevlar29 hy-brid composite material using pulsed Nd: YAG laser using GRA. CIRP Jour-nal of*

Manufacturing Science and Technology, 30, 174-183 (2020).

7. ^*Oladele, I.O., Ibrahim, I.O., Adediran, A.A., Akinwekomi, A.D., Adetula, Y.V. and Olayanju, T.M.A.: Modified sugar palm kernel shell fi-bre/particulate cassava peel hybrid reinforced epoxy composites. Results in Materials, 5, 100053 (2020).*
8. ^*Patrick Ehi Imoisil.i, Kingsley Ukoba and Tien-Chien Jen.: Physical, mechan-ical and thermal properties of high frequency microwave treated plantain (Mu-sa Paradisiaca) fibre/MWCNT hybrid epoxy nanocomposites. Journal of Mate-rials Research and Technology, 9 (3), 4933-4939 (2020).*
9. ^*Selvan, E.V., Ponshanmugakumar, A., Ramanan, N. and Naveen, E,: Deter-mination and investigation of mechanical behaviour on kenaf-sisal hybrid composite. Materials Today: Proceedings (2020)*
10. ^*Tottyeapalayam Palanisamy Sathishkumar, Palanisamy Navaneethakrishnan, Ponnuswamy Maheskumar,: Thermal Stability and Tribological Behaviors of Tri-fillers Reinforced Epoxy Hybrid Composites, 14(4), 727-737 (2021),*