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DEVELOPMENT AND CHARACTERIZATION OF TREATED PALF-SISAL FIBER REINFORCED EPOXY COMPOSITES

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Abstract

The present work investigates the influence of mechanical and physical properties of Epoxy composites by reinforcing SISAL- PALF fiber at different loadings (00:50, 10:40, 20:30, 30:20 wt.% of fiber). The fiber was first treated with 0.5 M NaOH solution at a room temperature for 1 hr. It improved the surface morphology and modified the mechanical properties of the fiber reinforcements were used for composite development through the hand layup molding technique and the samples were subjected to mechanical and physical properties tests in accordance with standards. Analysis of the results revealed that tensile, flexural, hardness, morphology, and hydrophobicity of the developed hybrid composites were improved. The flexural strength of composites from T-1(00:50) to T-4(30:20) were enhanced by 32%. Young's modulus and ultimate tensile strength were increased by 34% and 43%, respectively. Thereby, a blend of these by-products could potentially be used to develop prosthesis application.

Index terms: *PALF, Flexural Strength, Impact Strength, Morphology, NaOH.*

Abbreviations:

PALF: Pineapple Leaf fiber

1. INTRODUCTION

Natural fibers have unique attributes and several advantages over synthetic fibers which make an attractive to traditional materials. They have specific desirable properties, such as biodegradability, ecofriendly, low density, and low energy input in their manufacture, as well as being derived from a renewable resource and easily recycled [1]. Nowadays, due to simultaneous awareness increase on environment and energy, increasing attention should be paid to natural fiber with a view to conserving energy and environment [2]. Which will be able to improve people's standard of living particularly in the rural sector. The pineapple tree is non-climatic and third most widely cultivated, it is considered as one of the tropical fruits of world and amongst few monocotyledonous fruits like banana. Originated in Brazil, it is spread to the other tropical parts of the world. Asia (Thailand, Philippines, Indonesia, India, and China), Africa (Nigeria and South Africa), South Central America (Costa Rica, and Brazil). Pineapple production across the globe was recorded 23.33 million Metric tons (MT). Pineapple leaves are utilized as a huge scale, and the fibers extracted are used in a variety of application [3].

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Composites materials have significantly varied physical and chemical properties. However, naturally occurring fibers viz. jute, hemp, sisal, bamboo, pineapple etc. were environmentally mapped with synthetic fiber, mainly because they reduce the environmental impact of natural fiber production and reduce quantities of environmentally harmful polymers [4], [5]. Tensile strength of sisal fiber ranges from 347 MPa in Kenya and China to 400-700 MPa in India. In general, the tensile strength of treated fiber composites is greater than that of untreated fibers [6]. Earlier research report indicates alkali treated short fiber's tensile strength and flexural strength higher than the long fiber [7]. Though PALF as highest percentage of cellulose content and smaller microfibril angle, which is responsible factor to enhance the tensile properties [8]. The chemical composition of fiber varies with places, age, type, soil, rainfall, and farming methods. However, sisal fiber constituents include 6-7% lignin, 10% pectin, 12% hemicellulose, and 71% cellulose. The proportion of fibers varies from 10% to 40%. In general, fiber orientation includes chopped, unidirectional, and random dispersion. Hence tensile strength of 30% wt. of sisal fiber-polyester composite is 25 to 59 MPa [9], [10]. Experimentations were conducted on sisal fibers-based epoxy and polyester resin [11]. Generally, natural plant fibers contain a higher % of cellulose, which are mainly responsible for absorbing the moisture, some spirally wound cellulose microfibers and are bound together through an amorphous lignin matrix. However, it plays a role in resisting biological attacks and provides strength [12]. The alkali treatment of mixed sisal, glass fiber, polymer composite's the impact strength, flexural strength and tensile strength were determined [13], [14]. Although sisal fiber with non-polymer composites were observed [15]. Earlier research defines the different weight percentages of PALF composite materials is reinforced with Polyvinyl alcohol completely biodegradable, also enhances better mechanical properties and so find applications in agriculture and packaging [16]. The need to explore other viable low-cost alternative materials as reinforcement in the production of polymer matrix composites (PMCs) lead to the use of abundantly available natural and mineral fiber as reinforcements. The composites stimulate the studies of different products combining these raw materials [17]. However, these natural and mineral fibers have a wide range of mechanical and physical properties governing their various applications.

Several works have been reported on the use of fibers as single reinforcements or in hybrid forms [3], [4], [8], [9]. However, in this research work studied the PALF-SISAL fiber alkaline treatment (NaOH), and Investigation of mechanical characterization for fabrication of different wt. % (0:50, 10:40, 20:30 and 30:20) of PALF-SISAL fiber reinforced epoxy composites by hand layup technique. The tensile strength of the produced specimens was measured, and micrographic study for alkaline treatment of fiber by SEM. Most research efforts have not been focused on the use of only waste; hence, this paper promotes the development of new composite materials from only waste raw materials. The attempt proposes an innovative strategy to mitigate the environmental effect of improperly discarded waste natural fiber and converting it to environmentally acceptable commodities. Furthermore, alternate uses and zero tolerance for waste are encouraged.

2. MATERIALS AND METHODS

2.1 Materials

The materials used for this research were pineapple fiber and sisal fiber. The fibers were extracted through a process called decortication, where leaves are crushed and beaten manually by smooth edged stick so that only fiber will remain. Then fibers washed with excess of water to remove the wastes such as chlorophyll, leaf juices and adhesive solids (hemicellulose). Epoxy LY556 was used as a matrix and HY951 as hardener.

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2.2 Fiber treatment

Alkaline treatment of PALF-SISAL fiber, 20 g of NaOH pellet (alkali) was added in 500 ml distilled water and agitated in the magnetic stirrer at 60 ^{0}C for 10 min. thereafter 2.5 g of sisal fiber was placed in the solution. The similarly alkali treatment of pineapple fibers were also kept in the same ratio. Both fibers were kept separately in alkaline solution (NaOH) for 1hr after which fiber was taken out and again washed in distilled water then dried at 60 ^{0}C for 4 h duration.

2.3 Composite Development

The PALF and SISAL fiber reinforced epoxy composites were manufactured using hand layup technique. Compounding of samples were carried out rectangular mold of dimension 260 x 210 x 3 mm^3. The working conditions to produce composites were 27^{0}C at atmospheric pressure. Compounding of samples was carried out to ensure an even distribution of the reinforcement in the matrix and a proper blend, followed by reproduction of the sample using the same working parameters. The respective molds for the properties to be examined were used at this stage. In this way, composite samples filled with various weight fractions of PALP-SISAL treated fiber (*00:50,10:40,20:30,30:20 wt.% of fiber*) were developed. Fibers are chopped in length between 10 to 25 mm. However, tensile, flexural and impact specimens were prepared according to ASTM standard.

Figure 1: Weighting of Chopped treated PALF FIBER

Figure 2: Fabricated rectangular mold.

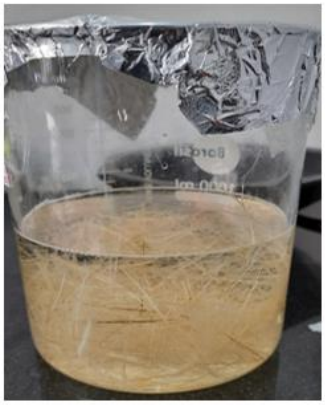

Figure 3: Fiber 4% wt. of alkaline (NaOH) treatment

3. EXAMINATIONS OF MECHANICAL AND PHYSICAL PROPERTIES

3.1 Morphological characterization

Morphological and structural changes of the Palf and Sisal were investigated using scanning electron microscopy (SEM). It is an important tool for observing the surface morphology of untreated and treated fiber. Studies of the PALF-SISAL surface morphology could provide information on the level of interfacial adhesion that would exist between the PALF-SISAL and the matrix. However, it expected that the surface morphology of untreated Palf, Sisal will be different to that of treated Palf, sisal particularly in terms of their level of smoothness and roughness of the fiber [18].

Figure 4. And Figure 5. Show the surface of untreated Palf and Sisal fiber respectively. The surface of the untreated fiber is covered with a layer of substances; these may include pectin, lignin, and other impurities. The surface was smooth, spread with nodes and irregular stripes. Features of the treated (boiled and washed) Palf and Sisal surfaces are shown in Figure 6. And Figure 7. A comparison between the untreated and treated Palf-Sisal fibers reveals morphological changes because the removal of low molecular weight compounds by boiling and washing fiber resulting in a formation of a rough surface

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as well as leading to the formation of many voids. The morphological change is an increment of the surface area of washed and treated Palf-Sisal fiber.

The alkaline (NaOH) treatment modifies the texture of the and principally its accessibility in an aqueous media. Consequently, the boiled and washed coir has a greater moisture absorption capacity and more reactivity to aqueous chemical reagents leading to enhance the extent of fiber/matrix adhesion. Therefore, voids will promote better mechanical bondage between the Palf-sisal fiber and matrix [2].

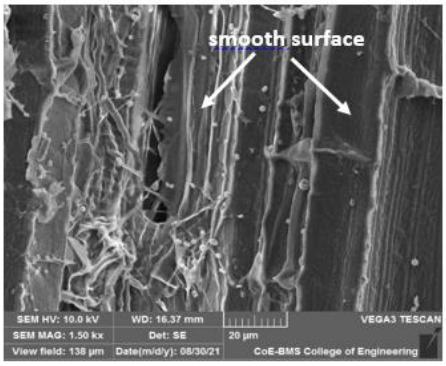

Figure 4: SEM micrograph Untreated PALF Fiber

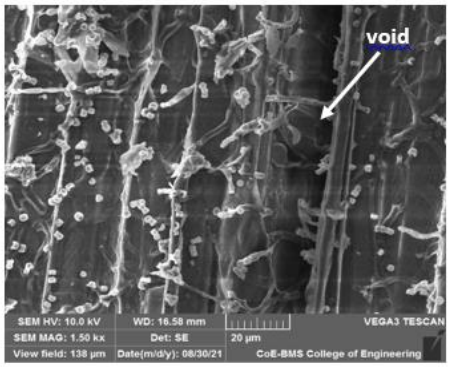

Figure 5: SEM Micrograph Sisal Untreated Fiber

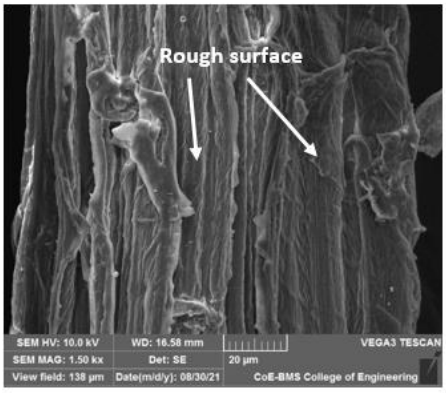

Figure 6: SEM micrograph treated PALF Fiber

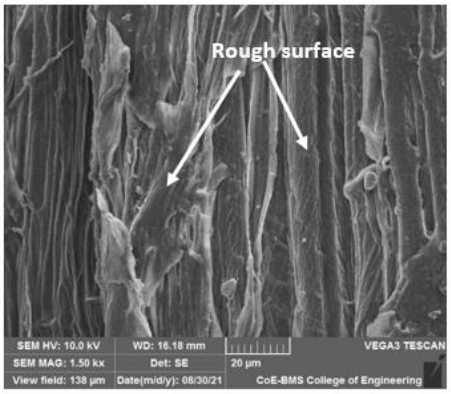

Figure 7: SEM micrograph treated SISAL Fiber

3.2 Tensile test

The tensile test was carried out using an MTS Universal Tensile Testing Machine as shown in Figure 8. In accordance with ASTM D-3039 standards. The test was conducted at the applied load of 25 KN at a crosshead speed of 5 mm/min. Three samples were tested from where the mean value was evaluated.

3.3 Flexural test

Flexural test was carried out using MTS Universal Testing Machine in accordance with ASTM D790. Each sample was firmly mounted on the machine and as the sample stretched, the computer generates the graph as well as the desired parameters. Three samples were tested from where the average value was determined.

3.4 Impact test

The test was carried out on a Charpy impact testing machine (Instron CEAST 9050), in accordance with ASTM-D256 standards. Samples were placed horizontally on the machine with the notched surface directly opposite the swinging pendulum. The initial reading of the sample gauge length and the

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thickness were entered into the computer system attached to the machine. The pendulum of the machine swung freely through angle 150° and fractured the sample. Three samples were tested from where the mean value was evaluated.

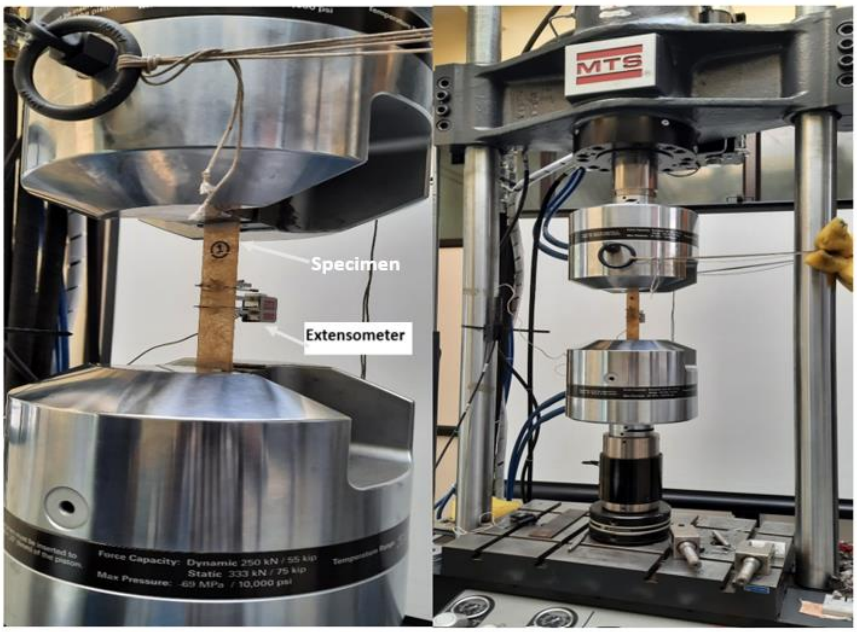

Figure 8: Digital Universal Testing Machine (MTS Capacity 250KN)

3.5 Water absorption test

The water absorption tests were carried out in accordance with ASTM D570-10. The weight of the dry samples was reported as the initial weight of the composites. The samples were then placed in distilled water maintained at room temperature and at time intervals of 2 h, the composite samples were removed from the water, cleaned using a dry cloth and weighed. The weight measurements were taken periodically at time intervals of 24 h up to 168 h. The composite samples had been noticed the water saturation level.

The amount of water absorbed by the composites (%) was calculated using the equation (1)

$$\%w = \frac{w_t - \omega_0}{\omega_0} x100 \qquad (1)$$

3.6 Scanning electron microscope Observation

Scanning Electron Microscope (SEM) of Model TESCAN-VEGA3 LMU was used for the morphological characterization of the composite sample surfaces. This was carried out to investigate the miscibility of the fiber. Air-dried, and glued on sample holder before coated with gold sputter ion coater and observed.

3.7 Hardness Test

The Hardness test was conducted on the sample using Vicker hardness tester following ISO 868:2003.23 the samples were placed on the flat surface of the tester stand and indented. Four values were obtained by indenting the samples in four different places and the average value was used for analysis.

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4. RESULT AND DISCUSSION

4.1 Tensile properties

It is observed from Figure 9. That SISAL-PALF fiber reinforced epoxy hybrid composites were able to withstand higher stress than that of the sisal fiber reinforced epoxy composites. It observed that 20:30 wt.% SISAL-PALF fiber reinforced composite has the highest stress value while sample with 0:50, 10:40 and 30:20 wt.% SISAL-PALF fiber reinforced composite have the highest strain value. This is due to the fiber–matrix interfacial bonding which is highly dependent on the fiber orientation and distribution, as well as the surface roughness of the fibers [1]. Hence, it's noticed that higher PALF fiber content aid the enhancement of tensile properties of the developed composites than low fiber content reinforced samples. The dust particles on the other hand may fill up the polymer voids but not have sufficient particle-matrix bond strength, and as such may experience de-bonding at lower tensile load than the SISAL-PALF fiber reinforced composites. The deformation behavior of SISAL-PALF fiber reinforced composites shown in Figure 10. to progress in three stages; an initial stage characterized by elastic deformation in which the material still obeys Hooke's law, followed by a second stage characterized by yielding in which the material undergoes Visco-elastic deformation and Then the last stage which characterized by a region of plastic deformation where the plastic strain increases at a constant plastic (yield) stress until total failure occurs and the stress the material can withstand reduces to zero [19]. It, therefore, means that both the deformation mechanism of SISAL-PALF fiber and dust particles plays a significant role in the deformation behavior of the developed composites.

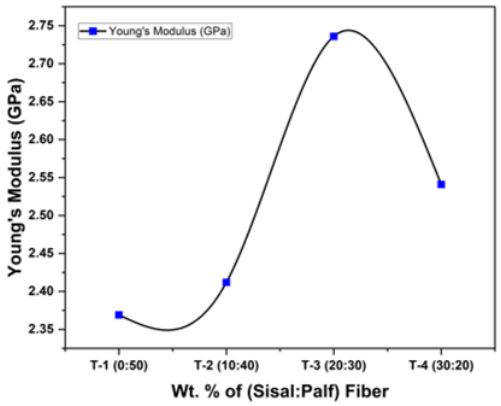

Figure 9: Variation of ultimate tensile strength with wt. % of SISAL-PALF Fiber

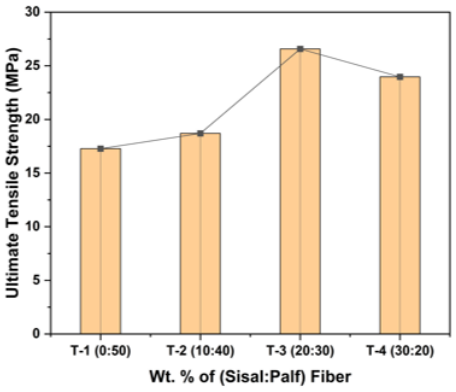

Figure 10: Stress – Strain curve for various wt. % of SISAL-PALF Fiber reinforced composites

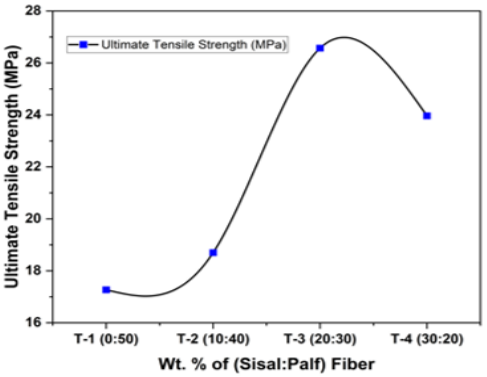

Figure 11: Variation of tensile modulus with wt. % of SISAL-PALF Fiber reinforced composites

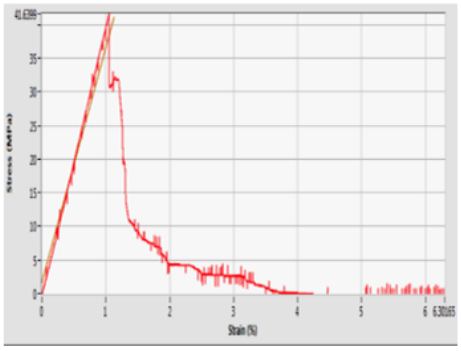

Figure 12: Variation of Ultimate tensile strength with wt. % of SISAL-PALF Fiber composites sample

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4.1.1 Ultimate Tensile Strength

The variation of ultimate tensile strength (UTS) with composite sample was as shown in Figure 12 which was an extract from Figure 9. It was discovered from the results that the addition of SISAL-PALF fiber enhances the ultimate tensile strength of the composite samples reinforced with epoxy. There is a linear relationship between the reinforcement and the UTS in an inverse proportion for the two reinforcements. It is observed that while UTS tends to increase as PALF fiber increases, it tends to decrease as stone-dust particle increases. The UTS was optimum at T-3 (20:30) wt.% for SISAL-PALF fiber bio-composites with a value of about 26.57 MPa. Parts of the reason for this could be because tensile loading is directional, fibrous materials are more resilience to tensile pull than particles. Besides, having treated the SISAL-PALF fiber, the strength and surface morphology has been improved. The 9.82% decrease in UTS at T-4 (30:20) wt.% of fiber reinforcement content might arise because of agglomeration of the fiber which usually occurs at higher weight fraction as shown in Figure 11.

4.1.2 Tensile Modulus

Figure 11. Illustrates the variation of tensile modulus with composite samples. It was observed from the result that the addition of both reinforcements enhances the tensile modulus of the developed bio-composite samples. All the developed bio-composite samples had better tensile modulus among T-3 composites sample with a value of 2.736 GPa. However, sisal-palf fiber reinforced composite samples exhibited better tensile modulus compared with their counterpart palf fiber reinforced epoxy composites T-1 (00:50) wt. %. Furthermore, Sisal fiber reinforced composite samples revealed a linear increase in tensile modulus of composite samples with an increase in sisal fiber content, this was in agreement with the work of [5] and [20] which reported that an increase in sisal fiber content resulted to an increase in the tensile modulus and storage modulus of the composite samples, respectively. On the other hand, its optimum result at 20 wt. % sisal fiber. Comparatively, Palf fiber reinforced composite sample (T-1) and Palf-Sisal fiber reinforced composites as 20 wt. % of sisal fiber (T-3) increased tensile modulus by 15.5%. However, at 30% sisal fiber composites (T-4) decreased the tensile modulus by 7.8%.

4.2 Flexural Properties

It has been established that flexural strength shows the aptitude of material to oppose the applied bending forces under three-point loading conditions while flexural modulus is used as an indication of a material's stiffness when flexed.

4.2.1 Flexural strength

Figure 13. Illustrate the variation of flexural strength at varies wt. % of sisal fiber and Figure 14. Illustrate stress strain curve for flexural composites. It was observed that the flexural strength at peak for the composites tends to decrease linearly as the reinforcement contents increases. This showed that optimum results could be achieved at T-4 composition as 30% of sisal fiber. Lower reinforcement content probably due to adequate filling of pores within the polymer and less agglomeration at this level of reinforcement loading.

The reason for the superlative strength from stone dust may be due to superior interfacial adhesive strength at the particle–matrix interface in the stone-dust particles reinforced composite which was more pronounced compared to those observed at the fiber–matrix interface in the counterpart composite reinforced with bagasse fiber in agreement with the report of Daramola et al. Likewise, the presence of elements like Silicon, Iron, Calcium, and Magnesium in high proportion as shown in Table 1 could also aid improved strength. Similarly, treated Sisal-Palf fiber with improved cellulosic strength was also responsible for the observed enhancement from the sisal-palf fiber reinforced composites.

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Both reinforcements gave improved flexural strength at peak values compared to the T-1 composites. Hence, T-4 composites sample with 30 wt.% sisal reinforcement gave the best result with a value of 59.18 MPa. The flexural strength looks at the best sample from T-3 to T-4 composites showed that about 32% improvement was attained.

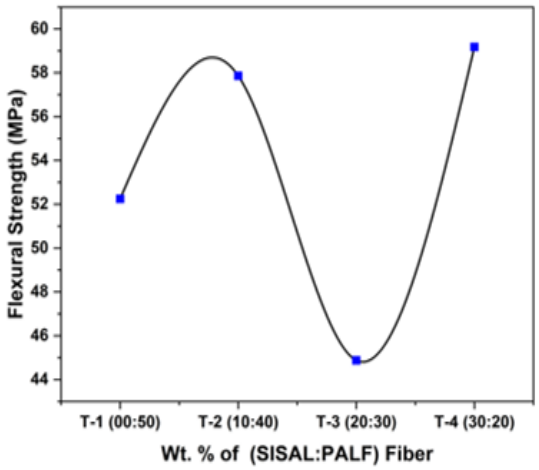

Figure 13: Variation of Flexural strength with wt. % of SISAL-PALF Fiber composites sample

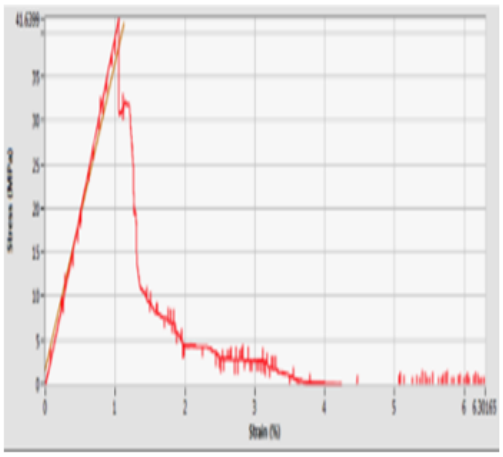

Figure 14: *Stress-strain curve,* for flexural strength with wt. % of SISAL-PALF Fiber composites sample

4.3 Impact strength

Figure 15. Illustrate the variation of the impact strength with various wt. % of composite samples. It was observed from the result that the addition of fiber reinforcements enhances the impact strength of the developed composite samples seeing that all the developed composite samples within which T-3 composites resulted as highest impact strength is 50.45 J/m. Moreover, SISAL-PALF fiber reinforced composite samples show a steady increase in impact strength of the bio-composite samples with an increases with an alkaline treatment and increase SISAL fiber content which agreed with the work of [4] was reported that an increase in SISAL fiber content may result in a slow but steady increase in the impact strength of composite samples and Figure 16. Defined the failure of composites sample. Also, a similar trend was observed in the SISAL-PALF Fiber reinforced composite samples. Composite samples with T-2 (10:40), T-3 (20:30) wt.% (SISAL: PALF) reinforcements in both cases gave the optimum results with values of 47.3 KJ/m and 50.45 KJ/m respectively. Thus, this culminated in about 6.7% improvements from each bio-composite.

The result showed that both reinforcements gave equal enhancement in impact strength from both fibrous and particulate reinforced epoxy composites. According to a report by [21] it was revealed that fiber reinforced polymer composites are generally accompanied with sufficient voids inherited due to the human errors that may occurred during manufacturing process. These voids can serve as stress raisers and accelerate the crack initiation and propagation. They further emphasized that nanoparticles could act as interlocking pins in the interphase of matrix and fiber, which strengthens the interfacial adhesion and contributing to the enhancement of impact energy. Hence, inclusion of dust in polymer will aid the filling up of voids and efficiently hinder the micro-cracks initiation and propagation in composites [19]. Moreover, dust particles could absorb higher energy due to the larger surface to volume ratio and this may also be the reason behind the improvement in the impact strength.

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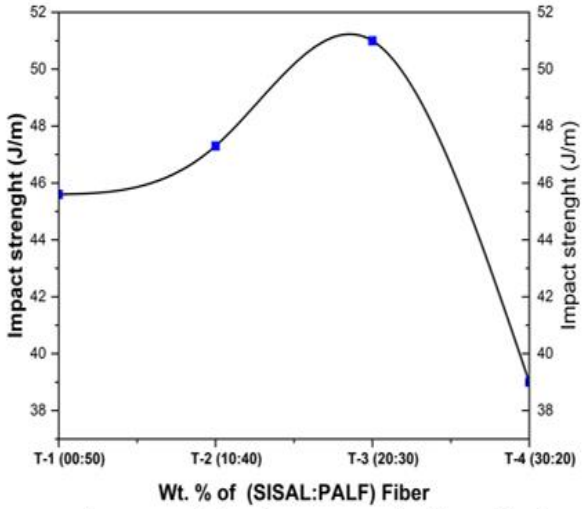

Figure 15: Variation of Impact strength with wt. % of SISAL-PALF Fiber composites sample

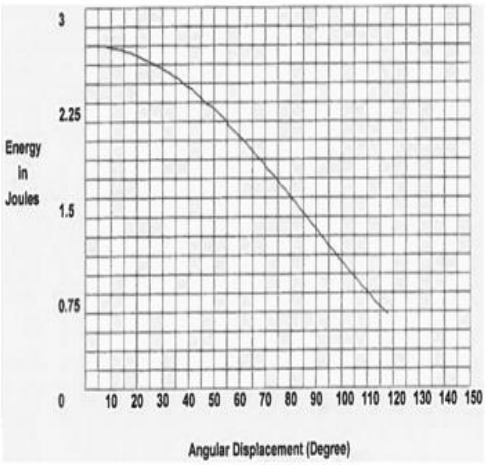

Figure 16: Charpy testing Failure of composite sample.

4.4 Hardness Property

Hardness property is the ability of a material to withstand/ resist surface indentation. Figure 17-18 illustrates the hardness property of the developed composite samples. From the results, it was observed that the developed hybrid (Palf-sisal fiber) reinforced composites had better hardness property than the Palf fiber reinforced epoxy composites. Similar to previous results, linear relationship was observed in both reinforcements with respect to the hardness where the values tend to increase as the reinforcement fiber increases [22]. The result further revealed that T-3 (20:30) composite samples had better hardness property than their T-1, T-2 fiber reinforced composites. This improved property from dust reinforced recycled high-density polyethylene can be linked with the elemental constituents that are present in the stone dust as shown in Table 1 and other reasons as stated in the discussion of Figure 8. Besides, stone dust is a hard phase. The best result was obtained from T-2 (10:40 wt. %) of sisal-palf fiber reinforced composite sample with a value of 57 HS while the best from the same content of T-3 (20:30 wt. %) of sisal-palf fiber was with a value of 68 HS. The percentage of increment is 20% from the developed composites sample T-2 and T-3.

Table 1: Composition of Palf Fiber

Element	Weight %	Atomic %
Carbon	48.17	56.12
Magnesium	0.42	2.1
Calcium	2.82	0.83
Zinc	0.72	0.21

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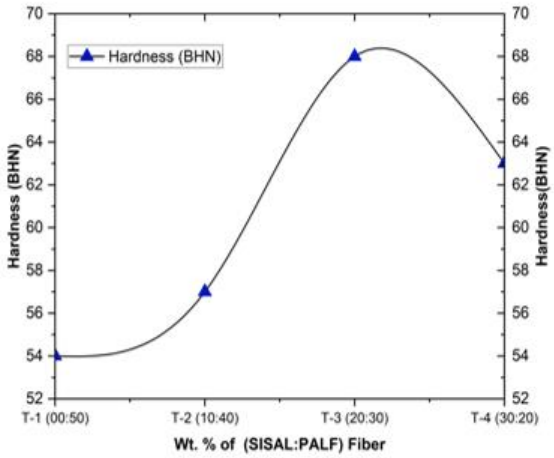

Figure 17: Variation of hardness with wt. % of SISAL-PALF Fiber composites sample

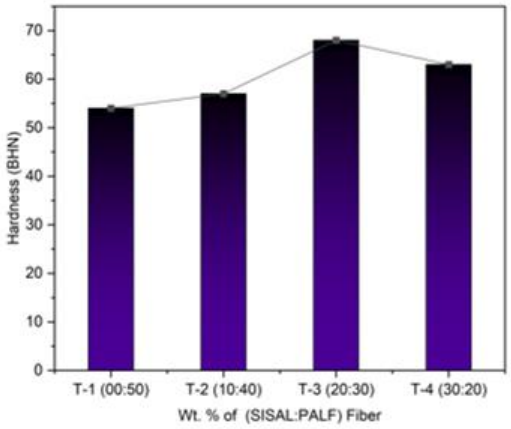

Figure 18: Hardness of fiber composites with wt. % of SISAL-PALF Fiber.

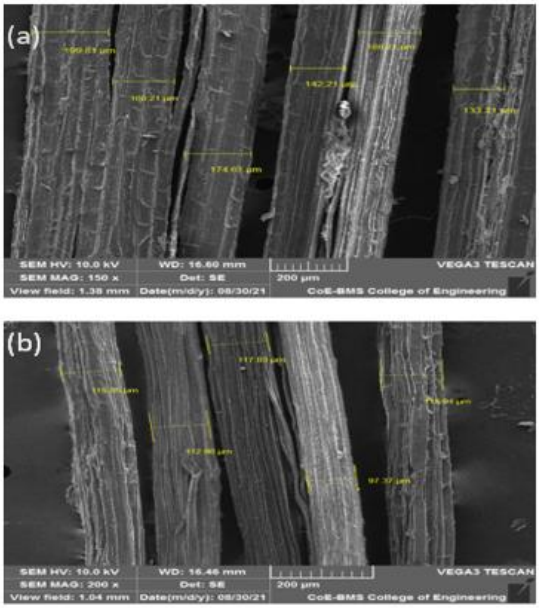

Figure 19: SEM micrographs of Longitudinal View PALF fiber (a) Untreated PALF fiber (b) Treated PALF fiber.

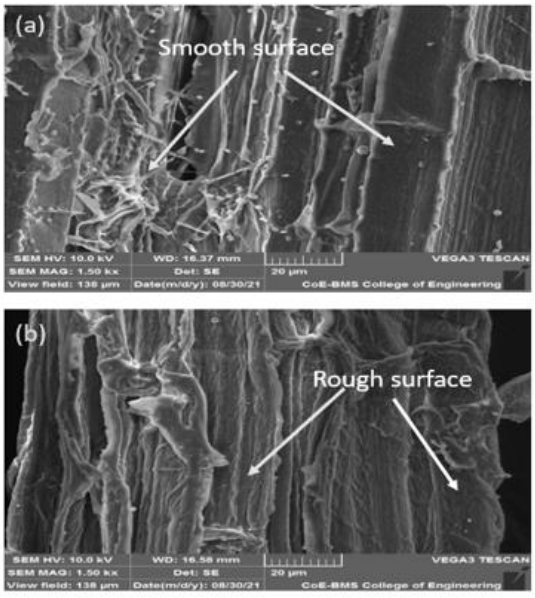

Figure 20: SEM micrograph of surface morphology PALF fiber (a) Untreated PALF fiber (b) Treated PALF fiber.

4.5 Fiber Morphology

Figures 19-20. Illustrates the surface appearance of the PALF fiber before and after the alkali treatment, respectively. Figure 19 (a) and Figure 20 (a) are untreated fibers that show the surface of the PALF fiber circumference is covered with a layer of substance, which are pectin, lignin, and other impurities. So that surface of the fiber is smooth, on the other side PALF fiber is treated with NaOH, after treatment PALF fiber surface becomes rough due the alkaline treatment lignin, pectin and dust particles are removed. Therefore, it is resulting in a rougher surface. There are rows of pits on the surface. The agreed with work [5] reported that would increase the mechanical bonding between the SISAL-PALF fiber and the matrix in the composite fabrication.

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4.6 Water absorption test

In the composites, the percentage of water absorption depended on two factors, the fiber quality, and ambient temperatures. Figure 20. Illustrate the absorption of water increased with changes in fiber content. To assess the water resistance, the samples are subjected to water absorption checks. Initially, the samples are measured, and the weight is noted. The specimens were fully submerged in deionized water. The specimens are removed from the water at an interval of every 24 hours, cleaned using tissue paper and weighed. The weight difference shows the amount of absorption of water. The same proceedings are repeated for 48 hours and 72 hours, The least absorption was achieved in 10 wt. % composition which may be due to the lower fiber content in the composite and the treatment of fiber which as reduced amount of hemicellulose responsible for water retention in the fiber in concordance with the result earlier reported by [23].

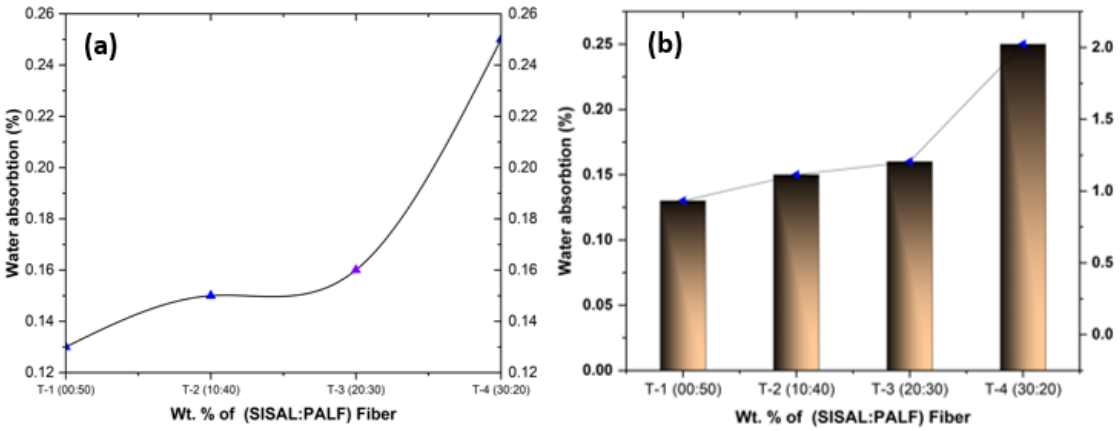

Figure 21: water absorption (a) variation of wt. % of Sisal-palf fiber (b) variation of water absorption along with increases with fiber.

5. CONCLUSION

In this present study a novel hybrid (SISAL-PALF) bio-composite was developed with Sisal-Palf fiber reinforced with epoxy matrix. The results obtained from this study is encouraging as fabricated hybrid bio-composites prepared by hand layup techniques and Sisal-Palf fiber shows improved mechanical properties without addition of coupling agent. The research outcome revealed that tensile, flexural, hardness, impact, and hydrophobicity properties of T-3 (20:30) bio-composites were better enhanced than their T-1 (00:50), T-2 (10:40) bio composites. Most of the improved properties from composites are from both 30 and 40 wt.% of PALF Fiber composites. While it illustrates that only at high reinforcement content that Palf fiber-based bio composites properties were improved. Morphological analysis by SEM clearly revealed that circumferential diameter reduced by 50% by removing dust and lignin content to aid improve mechanical properties. Hence, PALF-SISAL fiber are potential biomaterials for the development of bio-composites. Thus, it can conclude that the developed hybrid bio composites will acts as low cost, light weight, and environmentally friendly composites to be used as a prosthesis material in medical application, automobiles, and other areas where abrasion and friction are prominent, on account of their better morphological and mechanical properties.

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Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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