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Comparative Analysis of the Effect of Fibre Architecture on the Tensile Properties of Sisal Fibre Reinforced Polyethylene Polymer Composite

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Abstract: This work investigates the effect of fibre architecture on the mechanical properties of composite laminates fabricated from natural sisal fibres reinforced with polyethylene polymer matrix. The main objective for this is to determine which architectural pattern produces the best material in terms of mechanical properties that can be employed for use in the fabrication of engineering components to replace the more expensive components produced from the highly expensive synthetic fibre materials. Four fibre architectural patterns were chosen and tailor-made for the study namely; ±45° angled ply, 0°/90° cross ply, 90° and 0° unidirectional plies. A five layered composite laminates were manufactured from the fabrics and subjected to mechanical tensile tests using Instron universal testing machine (model 4467) having 30kN load cell attached to it and an extensometer gauge length 75mm at a crosshead speed of 200mm/min. The result of the mechanical tests revealed that the 90° laminate gives the best mechanical properties such as; elastic modulus, yield strength and tensile strength amongst the fabricated composite laminates. It was followed by the ±45° angle plied laminate, the 90° unidirectional fibre laminate and lastly the 0° unidirectional fibre laminate has the lowest mechanical properties amongst all the laminates tested. SEM micrographs of the fractured surfaces reveal that the failure modes of the laminates are characterized mostly by fibre-matrix debonding, fibre delamination, fibre splitting, fibre cracking and so on.

Keywords: Natural Sisal Fibre, Unidirectional Fabric, Woven Fabric, Mechanical Tensile Test

1. Introduction

The use of natural plant fibres as reinforcement in polymer composites for making low cost engineering materials has generated much interest in recent years. Environmental and economical concerns are stimulating research in design and production of innovative materials for aeronautic, railways and automotive industries. Particularly attractive are new materials in which a good part is based on natural renewable resources, preventing further stresses on the environment. Among these materials, natural fibers-reinforced composites (NFRC) are finding much interest as a substitute for glass or carbon reinforced polymer composites. Natural fibres with biodegradability, environment friendly characteristics and low cost are presenting themselves to serve this purpose that synthetic fibres offer. Although their strengths are not comparable with high performance synthetic fibres, they, nevertheless have fairly good properties to serve in domestic and non-structural purposes [7]. These materials are used in technical applications such as the automotive industry, where mechanical properties have to be combined with low weight. In addition the introduction of new environmental legislation as well as consumer pressure has compelled manufacturing industries, particularly the automobile, construction and packaging industries to search for new materials that can substitute the conventional non-renewable reinforcing materials such as; glass fibre [8, 1]. Natural fibres, often referred to as vegetable fibres are mostly extracted from plants and are classified into three categories depending on the part of the plant they are extracted from. There are some natural fibres that are extracted from the fruits of plant, such as; cotton, lintel, coir, milkweed and kaook [5] and they are naturally light and hairy. Others like bast fibres are found in the stems of the plant and are characterized by fibres that run across the entire length of the stem. As such they are long and highly strong. While there are others that are extracted from the leaves of the plant and are naturally rough and sturdy and form part of the plant's transportation system. These are called leaf fibres [2]. In general, some of the common natural fibres that are obtained from variety of plants parts include cotton fibre, coir or coconut fibre, Jute fibre, flax fibre ramie fibre, hemp fibre and sisal fibre to mention but a few.

One of the more popular natural fibres, the main focus of this study, is the sisal fibre. Sisal fibres are obtained from the plant called Sisal. It is a ligno-cellulosic material extracted from the plant, *Agave Veracruz,* and is available in large quantity in countries such as the southern parts of India [10]. The plant resembles the pineapple plant, and it produces fibres that are tough, strong and very well resistant against moisture and heat [2]. The fibres are mostly used for making ropes, mats, carpets, sisal bags, and as cement reinforcement.

Sisal fibres have several advantages in terms of mechanical properties compared with other synthetic fibre, glass, or carbon fibre. Apart from being available in abundance the fibres are inexpensive compared to other relatively advanced man-made fibres. The advantage includes low weight, low cost, low density, high specific properties, and non-abrasive processing characteristics. As reported in literature, some of its mechanical properties include density (1.33 g/cm^3), tensile strength (600-700 N/mm^2). While its stiffness and elongation at break are 3800 N/mm^2 and 2-3% respectively [2].

In the past decade, natural sisal fibre composites have been developed, in which the fibres are used as reinforcements in place of glass or carbon fibres. In this instance, sisal fibres in combination with a suitable resin material or polymer materials can be transformed into monolithic or hybrid natural fibre composites. Composites materials are regarded as hybrid materials made of a polymer resin reinforced by fibres. Most composites have two constituent materials: matrix and reinforcement. The reinforcement is usually much stronger and stiffer than the matrix, and gives the composite its superior properties. The matrix holds the reinforcement in an ordered pattern. Because the reinforcement is usually discontinuous, the matrix also helps to transfer the load among the reinforcements [4].

Composites combine the high mechanical and physical performance of the fibres and the appearance, bonding and physical properties of the polymers resin. The resin or polymer is a liquid and when applied to the fibre materials can rapidly solidify upon drying. Whereas, the fibres add strength to the composites, the resin acts as a reinforcement agent that binds the composite fibres together.

Exhaustive researches have mostly focused on the characterization of the mechanical properties of different kinds of natural fibre reinforced polymer composites by reinforcing the natural fiber in short and random orientation form. In general, most of the investigations were carried out using jute, sisal, flax, hemp, coir and bamboo natural fibers used as reinforcement in the polymer matrix. The aim was to enhance the properties of composite material for low and medium load applications [12]. By changing the direction of the fibres in the resin, the material properties can be tailored to meet the requirement of the external loads. To optimise the construction multiple adjusted layers (laminae) can be used to form a laminate. However, unlike composites reinforced with a layer of random fibres, called mat fabric, weave reinforced composites offer some advantages such as: durability and impact resistance. Natural fibres also offer the opportunity to have different material thickness given by the number of used layers, the orientation of the layers for obtaining superior properties in certain directions and the possibility of adding other materials filling between layers to improve thermal and acoustic insulation properties and reduce weight of parts made from these materials [15].

Woven fabrics are formed, in particular, by the interlacing of fibre bundles (yarns) to form a fabric layer. Woven fabrics offer advantages in terms of good dimensional stability and high packing density [6]. The vertical yarn direction is called the warp while the horizontal yarn direction is called the weft. Woven pattern is a factor in determining the mechanical strength of composite materials [3].

2. Materials and Methods

2.1. Materials

The fibre reinforcement material used in this investigation was a natural sisal fibre woven fabric with plain weave architecture. The fabric was bought from the market in Birnin Kebbi town, Nigeria. Four fabric samples were made out of the original sisal fibre woven material and consist of two woven fabrics with fibre orientations of 0°/90° (cross ply) and ±45 fibre (angled ply). The other two fabrics are non-woven unidirectional fabrics with fibre orientations of 90° and 0° respectively. The unidirectional non-woven samples were obtained out of the plain weave (PW) fabric. For instance by pulling out the warp fibres from the PW woven fabric we can produce the 90°fibre orientation fabric and pulling out the weft fibre from the PW woven fabric we can produce the 0°fibre orientation fabric. The resin used as the matrix in this investigation was a Top-Bond brand of polyethylene polymer resin that is used mostly in bonding wooden plies. The resin was bought from the market.

2.2. Methods

Composite laminates were produced from the aforementioned samples using manual hand laying technique adopted previously [12]. The production work was carried out on the laboratory bench at the Federal University, Birnin Kebbi, Nigeria. The samples were cut out of the dimension of 300mm x 50mm x 5 mm. Each laminate was produced by stacking together 5 plies of each fabric. In order to ensure that a good adhesion is achieved between the plies and the interfacial matrix lamination was carried out by stacking the plies together one by one so that before placing the second layer on top of the first ply we ensure that the first layer was thoroughly wetted the polyethylene polymer resin and then meticulously spread all over the hills and valleys of the fibres using a manual hand roller. This ensures that complete percolation of the resin materials into the fibre reinforcements and any residual air entrapped inside the fibres was expelled. Next, the laminates were covered with a thin transparent sheet of polyethylene plastic material. The laminates were left to cure overnight at room temperature. The covering ensures that no air particle is allowed to gets injected into the fibre reinforcements. After that the composite laminates were transferred into a hot oven, which was maintained at a temperature of 60° for 2 days to ensure that the samples were completely cured.

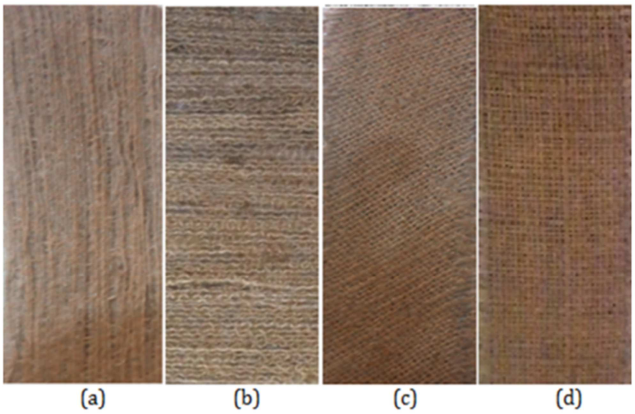

Figure 1. *Fabricated Laminated Samples of a) 90°, b) 0°, c) ±45°, d) 0/90°Orientations Used in the Tensile Tests.*

2.2.1. Mechanical Testing

Tensile tests specimens were prepared using the ASTM D5035-06 standard method. The specimens were cut into the dimensions with length 300mm, thickness 5mm, width 27 mm, gauge length 75 mm. The specimens were cut from the original composite laminates into a rectangular shape using cutting machine. Figure 2 below, show the loading direction of the tensile test specimens.

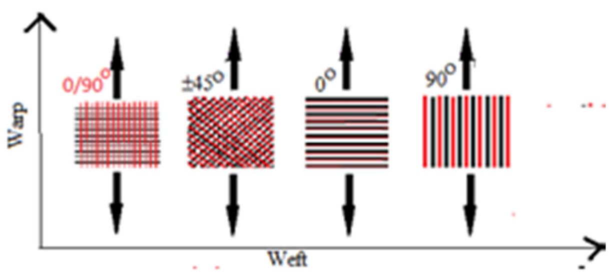

Figure 2. *Fibre Orientation and Directions of Tensile Loading of the Composite Laminates.*

2.2.2. Tensile Test

All tensile tests on the samples were carried out with the help of Instron universal testing machine (model 4467) having 30 kN load cell attached to it and an extensometer gauge length 75mm. It is to be mentioned that all tensile tests were performed at a cross-head speed of 200 mm/min. For all the laminate specimens at least 3 specimens were tested. Although, previous studies have reported that alkalization of the fibres improves the mechanical properties of the composites [9], in this investigation, the samples were tested in their natural form without undergoing any alkalization treatment. The reason was to avoid the removal of hemicelluloses in the inter-fibrillar regions and to stop softening of the inter-fibril connections. As doing so, could have an adverse affect on the stress transfer between the fibril in some loading directions, resulting in the overall stress development in the fiber under tensile deformation [14]. The specimens were clamped between the upper and the lower jaws of the Instron machine (Figure 3) and stretched using the fixed load inside the device until the specimen ruptures or breaks.

Figure 3. *Instron Tensile Testing Machine Used to Tests the Composite Laminates.*

The values of the breaking load and the elongation were recorded in the desk top computer system connected to the Instron machine. Graphical and data results of the tensile mechanical properties for each composite laminates were collected from the Computer data application system connected to the Instron machine.

2.2.3. Scanning Electron Microscopy (SEM)

After the tensile tests, composite fracture surfaces were mounted under an SEM machine and observed under a very high resolution Phenon World Scanning Electron Microscopy (SEM). All the specimens were coated with a thin layer of gold alloy prior to scanning. The SEM device utilises a high voltage of 15kV to penetrate deep into the surface of the specimen to collect the images of the fractures surfaces.

3. Result and Discussion

3.1. Tensile Test

Tensile tests of the laminates samples were carried out using the computerized universal Instron testing machine. The stress strain curves thus generated for the four samples during the tensile tests are represented in the figure shown below:

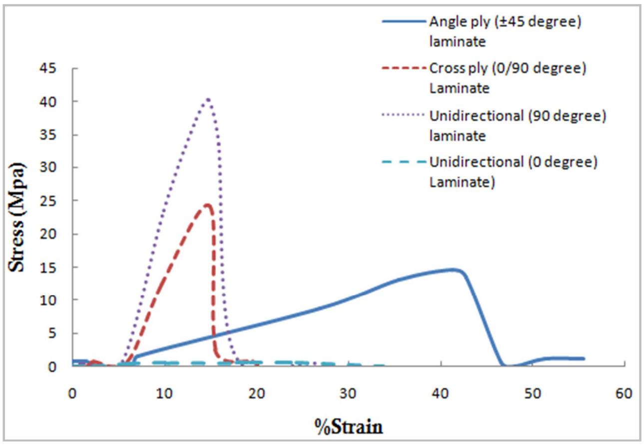

Figure 4. *Typical Sress-Strain Curve of Woven and Non-woven Sisal Fbre polyethylene composite (a) 0/90°, (b) ±45°, (c) 90° and (d) 0°.*

Table 1 also shows the summary of the mechanical properties measured during the longitudinal tensile tests conducted on the laminate samples. From the table it can be seen that the 90° laminate has the highest elastic modulus of all the laminate tested. This could be explained on the basis that this laminate has fibres arranged longitudinally or parallel to the loading direction. When fibres are arranged in this position they extend uniformly with the applied and hence, the weight of the load is uniformly distributed throughout the laminate. This means that the cumulative load on the laminate will be shared minimally on the fibres and the laminate will be able to resist and accommodate more loads before fracture. A similar study has confirmed that laminates in which the fibres are aligned in a longitudinal direction to the loading axis have recorded highest elastic modulus compared to the laminates where he fibres are either arrange in a transverse or random manner [10].

After the 90° laminate the ±45° laminate has the next higher elastic modulus amongst the composites. This laminate has its fibres oriented at an off-axis angle of ±45°. The difference with the 90° laminate is that this laminate has fibres that are oriented half way at diagonal direction to those of the 90°fibres. It is therefore expected to produce a modulus that is half the modulus of the 90° laminate, as is the modulus recorded in table 1 above (112 MPa). The nest laminate with the next higher elastic modulus is the 0°/90° laminate (36.52 MPa). The fibres in this laminate are arranged in both the longitudinal and transverse directions. As the fibres in the longitudinal directions absorb most of the load, their counterpart at the transverse direction will absorb less or even zero load, being that most of the load will be transferred to the longitudinal fibres and the matrix. The longitudinal fibres will be overwhelmed by the load and being only half of the numbers of fibres contained by the 90° laminate there will be higher tendencies for it to rapidly yield under the impact of the load. This will result in the lower value of the elastic modulus for this laminate. Lastly, the 0°laminate has recorded the lowest elastic modulus amongst the laminates. This is not surprising as the laminate contains fibres arranged transversely to the loading direction. With this type of arrangement fibres subjected to tensile force are not inclined to effectively absorb the force applied to them. Instead the large chunks of the load will be transferred to the matrix as a solid continuum which is aligned along to the loading axis. However, as the matrix is too weak to sustain the excessive force the laminate will instantaneously fail even at a smaller force, thereby producing a laminate with low elastic modulus.

Statistical analysis of variance for the mean of the elastic modulus between the groups shows there is a significant difference (P<0.05).

The result of the yield strength of the laminates is displayed in table 1. Again, the result shows that the 90° laminates again recorded the highest yield strength of all the composites investigated. The result shows that the strength of the laminate at yield is 37.18MPa. This was followed largely by the ±45° angle ply composite, which recorded yield strength of 17.36MPa. This value is only one third of the yield strength of the 90° laminate. The plain weave cross ply 0/90° laminate recorded the third highest yield strength of the composites (36.5MPa). Yield strength is the stress recorded at failure or when the laminate crosses the linear phase of the stress-strain deformation history. The result therefore, shows that the 90° laminates has the highest yield strength among the laminates. The 0° laminate again produces the lowest yield strength. The reason why these composites exhibited this type of trend in the increase of the yield strength can as well be attributed to the factors enumerated in the aforementioned paragraphs.

Table 1. *Results of the tensile tests conducted on the composite laminates.*

Parameter	Type of Laminate			
	0°	90°	±45°	0°/90°
E/M (MPa)	2.94±2.63	230.10±12.02	112.40±14.13	36.52±5.67
Y/S (MPa)	0.35±0.19	37.18±3.52	17.36±4.61	13.90±4.70
B/E (%)	51.311±15.91	23.94±3.61	33.52±8.44	54.89±1.57
T/S (MPa)	0.56±0.43	41.56±3.24	22.60±1.72	16.61±2.91
B/S (MPa)	0.03±0.02	0.17±0.02	0.94±1.26	0.47±0.56
T/E (%)	20.48±2.22	14.98±2.22	16.36±0.92	42.31±4.05
Density(g/cm^3)	1.56	1.46	1.38	1.37

E/M = Elastic Modulus; Y/S = Yield Strength; B/E = Break Elongation; T/S = Tensile Strength; B/S = Break Strength; T/E = Total Elongation.

Statistical analysis of variance for the mean of the yield strength indicates that there is a significant differences between the groups (p<0.5).

From the table 1 above the percentage elongation at break shows that the unidirectional 0° ply laminates registered the highest percentage of elongation at break (59%) than the other laminates. The reason for this is that as the fibres are not oriented parallel to the loading direction their contribution to the elongation of the laminate is very minimal. Only the matrix gets stretch along the applied load and the matrix being elastic stretches along with the load until it reaches an elastic limit, thereafter, it breaks. This resulted in the highest stretching of the laminate compared with the other laminates. After the 0° laminate the next laminate with higher elongation at break was the 0/90° laminate (56%). This laminate has all of its fibres aligned at both the 90° and 0° orientations. The 0° fibres are not contributing to the inextensibility of the laminate and the resistance to the applied load. It is only the 90°fibres that are contributing to the resistivity of the laminates. The laminate is therefore expected to elongate to higher percentage similar to the 0° laminate, but for the inextensibility of the fibres at the 90° direction.

The next laminate with the next higher elongation at break is the±45°angle-ply laminate (43%). The low extension at break of this laminate could be attributed to the fact that both the positive 45° fibres and the negative 45° fibres are contributing to the off-axis reduction of the inextensibility of the laminate. As such, the laminate will be expected to record less elongation compared with the other mentioned laminates. The last laminate with the lowest elongation at break (20%) is the 90° laminate. In this laminate, all the fibres are arranged so that the same load is being experienced by the fibres equally. As the fibres are inextensible, it means the laminates will exert a large inextensibility to the flow of the applied load. At break, the elongation of the laminate will be small in comparison to the other laminates.

Statistical analysis of variance for the mean of percentage elongation shows that there is significant difference ($P<0.05$) between the groups.

The results of the tensile strength of the laminates are also displayed in table 1. From the results the 90° laminate, again, exhibits the highest tensile strength (39MPa) in comparison with the other laminates. Tensile strength measures the resistance of a material to a force that tends to pull it apart. In previous study the fibre architecture was found to play a determining role in the tensile strength of a composite [9]. The reason for the high tensile strength of this laminate may not be unconnected to the number of the 90° fibres arrangement in the laminate. Due to their numerous quantity when the fibres are pulled apart an opposite and effective resisting force is provided by the inextensibility of the fibres in opposition to the applied load. Each fibre contributes to the overall opposing force of the laminate. The laminate exerts a strong reactive force, which is equivalent to the tensile strength of the laminate.

The next laminate with the next higher tensile strength is the ±45° laminate (21MPa). This is predictable as the fibres of the ±45° laminate are arranged both at diagonal and at the longitudinal axis of the laminate. As such the resistance of the laminate will lower than that of the 90° laminate by an amount that is equivalent to the off-axis reduced yield strength. Hence, the laminate records the next higher tensile strength.

After the ±45° laminate the next laminate with higher tensile strength is the 0/90° (16.6 MPa). Architecturally, this laminate has half of its fibres arranged horizontally and half arranged vertically and are connected at the crossover points. Only the horizontal fibres contribute effectively to the inextensibility of the laminate as the major resistive force to the tensile force. To this end, as the laminate is stretched the overall tensile strength of the laminate is provided by the longitudinal inextensibility of the fibres. The tensile strength is therefore expected to be only half of the tensile strength recorded of the 90° laminate.

Lastly, the 0° laminate displayed the lowest tensile strength (0.5MPa). This value is almost insignificant when compared with the values of the other laminates investigated. The lower value could also be attributed to the low or absence of an inextensible opposing resistive force of the fibres on the applied load. The opposing force is only provided by the matrix and as the matrix is too weak to carry the load the resistance to the applied load or the tensile strength will therefore be expected to be very low.

Statistical analysis of variance for the mean of the tensile strength indicated that there is a significant difference ($P<0.05$) across the groups.

Table 1 displays the values of the strength at break of the laminates. The strength at break measures the maximum stress a plastic material can withstand while stretched before it breaks. From table 1, the ±45° laminates has the highest breaking strength (0.94MPa) amongst the laminates.

This shows that the ± 45° laminate is the most efficient laminate that can endure more stress before it breaks. This is followed by 0°/90° laminate (0.47MPa). The 90° laminate comes next (0.17MPa). Lastly, the 0° laminate has the lowest strength at break amongst the laminates. The trend in the strength at break demonstrated by the laminates indicates that the woven materials due to the nature of the fabrics architecture produced higher strength at break compared with the unidirectional laminates.

The two woven laminates have two types of fibre orientation that are interlacing with each other at crossover points. This may have given the laminates added advantage to store residual energy while undergoing failure. On the other hand, the failure of the unidirectional fabrics results in the dissipation of all the stored energy due to the absence of interlocking crossovers to store residual energy.

Statistical analysis of variance for the mean of strength at break indicates that there is no difference between the groups ($P>0.05$).

The total elongation of the laminates was also determined as displayed in table 1. The total elongation is the measure of elongation of a material from start of deformation to start of fracture. It expresses the capability of natural plant fibre to resist changes of shape without crack formation. From the result the 0°/90°laminate recorded the highest elongation (42%) amongst the laminates. This was followed largely by the 0° laminate (20%). The ±45° laminates has the third longest total elongation (16%) and lastly the 90° laminate has the lowest total elongation (15%).

The elongation of the laminates is controlled by the architectural nature of the fibre reinforcements. In the case of the 0°/90° laminate when the laminate is stretched the deformation is controlled by the deformation of the warp and weft fibres at the crossover point. As the laminate extends, the angle at the crossover points decreases until the two crossover point jammed. At interlock, the rigidity of the laminate reaches its highest level and couple with the inextensibility of the fibres offers the laminate the ability to stretch to longer dimension before it can finally break. In contrast, the inextensibility of the 0° fibres did not play a major role in opposing the elongation of the laminate, rather the elongation was dominated by the yielding of the matrix.

Being in a rubbery state the elongation of the laminate will be dominated by the elongation of the matrix, which is extensible. As such, the 0° laminate is expected to record longer extension compared with the other two laminates, but with lowest tensile strength. In the case of the ±45° laminate being a woven material its extension is similar the 0°/90° laminate, even though, with smaller interlocking angles. As such, it would be predicted to record lower total elongation than the 0°/90° woven laminate. With regard to the 90° laminate since the fibres are all aligned along the longitudinal direction they are projected to have uniform extension that was dictated by the inextensibility of the fibres. As the inextensibility is large, the fibres when stretched become hard and brittle and any small force will cause the failure of the laminate but with a reciprocal high tensile strength.

Statistical analysis of variance for the mean of total elongation indicates that there is no difference between the groups ($P>0.05$).

Lastly, the densities of the samples were also determined and presented in table 1. The bulk density of the specimen in grams per cubic centimetre was calculated using the following formula: D=WS/V, adopted elsewhere [13]. From the table it can be seen that there are small variations in the densities of the laminates. This is because for each plies equal weight of the fibres and bonding materials were used in the fabrication of the laminates.

3.2. Microstructural Morphological Analysis

The investigation also examined the micrographs of the laminates subjected to the tensile tests to determine the failure mode of each fibre orientation. These micrographs are displayed in figure 5 below.

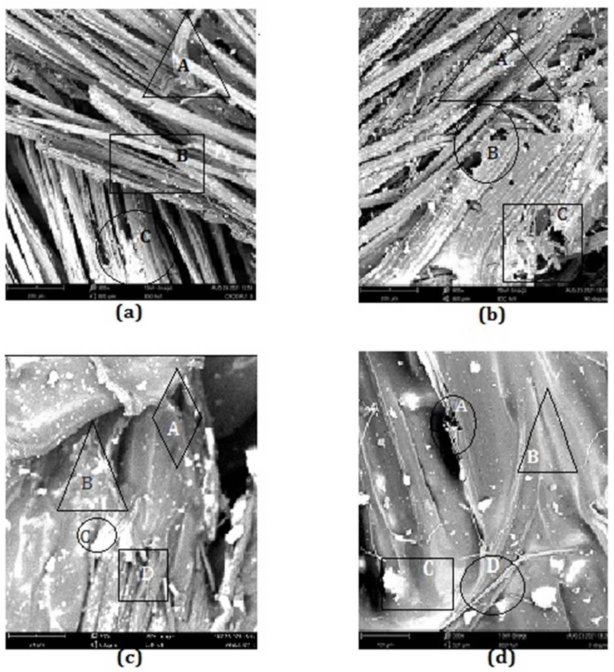

Figure 5. SEM Photo-micrographs of (a) 0/90° Cross ply composite; (b) 90° Unidirectional; (c) ±45° Angled Ply and (d) 0° Unidirectional Composite Laminates Fractured Surfaces Subjected to Tensile Loadings.

3.2.1. Cross ply (0/90°) Fibre Reinforced Laminates

Figure 5(a) represents the photo-micrographs of the fractured surface of the cross ply (0/90°) composite. It is visible from the marked areas that the mode of failure of the laminate is predominantly by fibre pullout (Area A), with a clear indication of fiber-matrix interfacial failure followed by extensive fiber pull-out from the matrix [1, 11]. The micrograph also exhibited fibre splitting and tearing (Area B), and fibre-matrix delamination (Area C). Other types of failures observed are fibre separation and matrix debonding, which is indicated by the presence of matrix powder on the surface of the fibres. This demonstrates that the bond formed between the fibre and the matrix is a weak one.

3.2.2. Unidirectional (90°) Fibre Reinforced Laminates

Figure 5(b) is a photo-micrograph of the fractured 90°fibre orientation composite laminate. The Image shows that the failure mode of this laminate is predominantly by fibre cracking and spherulitic fibre failure. The surfaces consist of lots of matrix deposition signifying extensive matrix-fibre debonding. This is also a clear evidence of lack of strong bonding between the fibres and the matrix.

3.2.3. Angled ply (±45°) Fibre Reinforced Laminates

Figure 5(c) is the photo-micrograph of the fractured ±45° angled ply composite laminate under a longitudinal tensile force. The image showed that the type of failure mode for this laminate is characterised mainly by fibre splitting (Area D), spherulitic failure (Area B), matrix debonding (Area C) and fibre cracking (Area A). On close observation other types of failures that were observed include fibre separation and matrix sputtering.

3.2.4. Unidirectional (0°) Fibre Reinforced Laminates

Figure 5(d) is photo-micrographs of 0° unidirectional composite reinforced laminates fracture surface subjected to tensile stress. The image shows visible grey areas of the failed laminate whose mode of failure are dominated by fibre tearing (Area A), matrix shattering (Area C), fibre folding (Area B). Others include fibre-matrix debonding and fibre peeling out.

4. Conclusion

This investigation reveals that the mechanical properties of sisal fibre can be improved by rocessing the fibres into composite laminates. The study also demonstrates that by producing fabrics with different architecture the mechanical properties of fabricated natural fibre composite laminates can be greatly altered to advantage in fabrication of specific low load carrying components. While conventional synthetic composites may offer better quality products with higher mechanical properties than the non-woven fabrics [11], our investigation revealed that this may not be so. As was revealed from the SEM micrographs, (figure 5), the study also found that the bonding between the fibre reinforcements and the matrix did not achieve the desired bond strength expected nevertheless, there are good prospects for using natural fibres in low-tech structural applications. Conclusively, the study opens a window for the possibility of combining high quality bonding resins [6] in the fabrications of composite from natural fibre reinforcements.

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