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A Preliminary Study on the Effect of Reinforcing Polyesters with Kenaf and Sisal Fibres on Their Mechanical Properties

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Abstract: *Kenaf and Sisal fibres generally have some advantages such as their eco-friendly nature, biodegradability, renewable nature are lighter than synthetic fibres. The aim of this study is to evaluate the potentials of using weaved and un-weaved indigenous sisal and kenaf fibre to reinforce polyester resin based on the physical and mechanical properties obtainable from the resulted composites. The composites materials and sampling were prepared in the laboratory by introducing 10g of the fibre which is about 20% fibre content into the matrix using 1) the hand lay-up method for un-weaved samples, and 2) coating method for weaved samples, with the aid of a mechanical roller. Samples were prepared based on ASTM: D3039-08 for tensile test. Properties such as tensile strength and modulus, hardness, impact strength, flexural strength, density and water absorption were analysed. The results of the characterization showed that density of the material reduced on introduction of fibres while the rate at which the material absorbs water increased though sisal fibre reinforced materials absorbed more. This was due to the void content of composite which increased due to the fibre inclusion within the composite. The results also show that the flexural strength of the composite material developed increased with fibre introduction, though weaved fibre possesses more strength than un-weaved ones. Finally, no particular composition possesses optimum value for all the properties measured.*

Keywords: *Kenaf; Sisal; Polyester; Fibre; Composite, Physical Properties; Mechanical Properties*

1. Introduction

The need for the world to fully become environmentally friendly and to fight the sometimes painful instability and non-availability of petroleum based thermoplastics, coupled with the need to make manufactured products more accessible and affordable to consumers have necessitated incessant efforts into processing and production of natural fibre composites, which can result in reduction of production cost to companies and impart greater mechanical properties to polymeric materials (Wambua et al., 2003). The use of natural fibre as reinforcement for polymeric matrix has recently attracted attention of researchers because of their advantages over other established materials (like ceramics, metals etc.). They are environmental friendly, fully biodegradable, abundantly available, renewable, have low density and are relatively cheap (Shibata et al., 2006). The need to start reinforcing resin has arisen due to the high need for the exhibition of improved mechanical characteristics of composite materials (Larbig et al, 1998).

Kenaf (*Hibiscus cannabinus*, L. family *Malvaceae*) is seen as an herbaceous annual plant that can be grown under a wide range of weather conditions; for example, it grows to more than 3 m within 3 months even in moderate ambient conditions with stem diameter of 25-51 mm. It is also a dicotyledonous plant, meaning that the stalk has three layers; an outer cortical also referred to as (‘bast”) tissue layer called phloem, an inner woody (“core”) tissue layer xylem, and a thin central pith layer which consists of sponge-like tissue with mostly non-ferrous cells (Ishak 2007; Ishak et al., 2009).

A number of components, in particular, structural materials, interior of aircrafts, automotive components previously made with glass fibre composites are now being manufactured using environmental friendly composites consisting of natural fibres due to their thermal properties, low density, flexibility, low cost, lightweight and apparently their environmental superiority compared to glass fibre composites (Liu et al., 2007).

The use of natural plant fibres as reinforcement in polymer composites for making low cost engineering materials has generated much interest in recent years. New environmental legislation as well as consumer pressure has forced manufacturing industries (particularly automotive, construction and packaging) to search for new materials that can substitute for conventional non-renewable reinforcing materials such as glass fibre. Recently, car manufacturers (such as Bavaria Motor Works (BMW)) have started manufacturing non-structural components such as foot paddle using kenaf fibres for the 5 series model of the brand due to their higher specific strength and lower price compared to conventional reinforcements (Mattoso et al., 1997).

The results of a study of the mechanical properties such as tensile, flexural and impact properties of sisal bast and core fibre reinforced unsaturated polyester composites carried out showed that the optimum fibre content to obtain the highest tensile strength and flexural strength for both sisal bast and core fibre composites were 20%wt (Mukherjee and Satyanarayana, 1984).

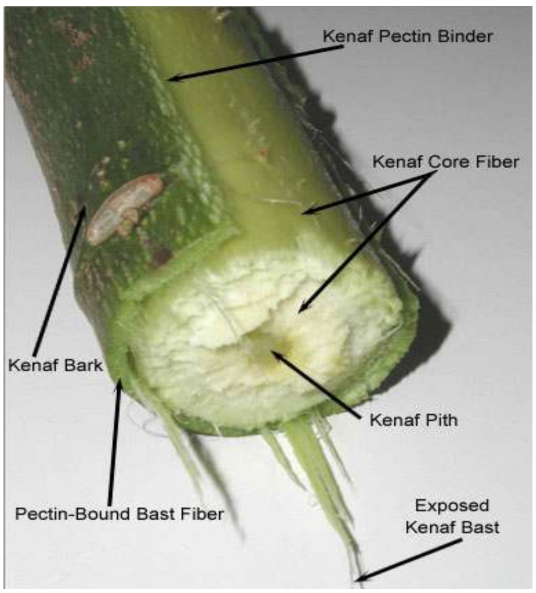

Figure 1: Exposed physical appearance of kenaf
Source: Nilsson (1975)

Sisal plants look like giant pineapples, and during harvest the leaves are cut as close to the ground as possible. The soft tissue is scraped from the fibres by hand or machine. The fibres are dried and brushed to remove the remaining dirt resulting in a clean fibre. Sisal produces sturdy and strong fibres. Sisal fibre is one of the prospective reinforcing materials whose use has been more experimental than technical until now. The use of 0.2% volume fraction of 25 mm sisal fibres leads to free plastic shrinkage reduction. Sisal fibres conditioned in a sodium hydroxide solution retained respectively 72.7% and 60.9% of their initial strength after 420 days. As for the immersion of the fibres in a calcium hydroxide solution, it was reported that original strength was completely lost after 300 days (Tara and Jagannatha, 2011). Figure 2 shows a typical sisal plant.

Hence, the essence of this research work is to carry out preliminary studies into the potentials of using indigenous sisal and kenaf fibre as reinforcement for polymeric composite material and the effect of weaving the fibres before introduction on the physical and mechanical properties of the composite. Therefore, the specific objectives of the research work are as follows:

1) To prepare and treat the reinforcing fibres.
2) To produce the composites.
3) To investigate the physical properties of the composites.
4) To investigate the mechanical properties of the composites, and
5) To compare the properties of weaved and un-weaved reinforced composite.

Figure 2: Typical Sisal Plant

2. Literature Review

Other researchers (Ochi, 2007; Madugu, et al., 2010; Nishino et al., 2011) have carried out separate work using kenaf and sisal fibres as reinforcements for composite production from which some are developed for particular application. So many researchers attempted to make bio-composites by using different natural fibres and different polymer matrix which could be thermoset and thermoplastic. They investigated bio-fibre composite in terms of water absorption, interfacial bonding, mechanical (tensile, flexural, impact, compressive and shear strength) properties in different fibre volume content and different ratio, recyclability, durability, chemical treatment effects and more (Chow, 2007; Bachtiar et al., 2008; Pasquini et al., 2008; Gu, 2009; Chen et al., 2009; Seki, 2009; Xue et al., 2009). The use of kenaf bio-composites in industry is increasing due to good properties of kenaf fibres and its contribution to environmental sustainability and eco-friendly products. The performance of materials is always presented in terms of their mechanical characteristics, such as tensile properties, flexural properties, compression properties, impact properties and tears behaviour (Akil et al., 2008).

Ochi (2008) reported that unidirectional kenaf fibre reinforced PLA (Poly-lactic acid) composites at a fibre content of 70% have high tensile and flexural strength of 223 MPa and 254 MPa, respectively. An extensive study was done by Rassmann et al. (2010) who used un-woven kenaf mat with three thermoset polymers including epoxy, unsaturated polyester and vinyl ester to make KFRP (Kenaf polymer reinforced) samples. The study utilised resin transfer molding (RTM) fabricating method in various fibre volume contents. The mechanical and water absorption properties of the composites were monitored for the study. It showed that the composite properties were influenced by the polymer type and the fibre volume content. Unsaturated polyester composites have higher modulus and impact properties as compared to other resins, while epoxy composites exhibited higher strength values and vinyl ester composites displayed higher water absorption characteristics. In 2004, this was the first time any group of researchers try to fabricate oil palm based hybrid bio-composites by hybridization of oil palm fibres with other natural fibres by the unique combination of sisal and oil palm fibres reinforced rubber composites (Jacob 2004a, 2004b). The researchers studied the effect of fibre loading, fibre ratio, and treatment of fibres on mechanical properties of sisal/oil palm fibre reinforced hybrid composites (Jacob, 2004a).

Results indicated that increasing the concentration of fibres reduced tensile and tear strength, but enhanced tensile modulus of the hybrid composites. They also reported that 21 g sisal and 9 g oil palm based hybrid composite show maximum tensile strength and concluded that tensile strength of hybrid composites depend on weight of sisal fibres rather than oil palm fibres due to high tensile strength of sisal fibres. It was also observed that the treatments of both sisal and oil palm fibres causes better fibre/matrix interfacial adhesion and resulted in enhanced mechanical properties. Similar studies carried out on the influence of fibre length on the mechanical properties of untreated sisal/oil palm fibre based hybrid composites reported that increase in fibre length decreases the mechanical properties of hybrid composites due to fibre entanglements (Jacob, 2004b).

Satyanarayana et al. (1984) studied the mechanical properties of chopped sisal fibre – polyester composites. Chopped sisal fibre-polyester composites were prepared by the compression molding technique. It was found that the specific modulus of the composite was 1.90 as compared to 2.71 obtained from glass fibre reinforced plastics, while the specific strength was of the same order as that of polyester resins (i.e., of 34-41 MPa). The impact strength was 30 Jm^{-2}, which is three times higher than that of polyester and 30% less than glass fibre reinforced plastics. Accelerated testing revealed that there was little change in initial modulus, and reductions of ultimate tensile strength by 5%, flexural strength by 16% and water absorption by 5.4% within the material. A lot of research work have been done in the area of development and characterization of eco-friendly bio-composite materials, but more must still be done.

3. Materials and methods

3.1 Materials

Materials used for this research include:

1) Unsaturated polyester resin,
2) Kenaf fibre,
3) Sisal fibre,
4) Methyl ethyl ketone (catalyst),
5) Cobalt naphthalene (accelerator), and
6) Sodium Hydroxide (NaOH).

3.2 Methods

3.2.1 Preparation of Sisal Fibre

Sisal leaves were obtained from sisal plant at Botanical Garden, Ahmadu Bello University Zaria-Nigeria. The sisal leaves were beaten until the fibres were separated from them. A knife was then used to scrape the surface of the leaves to remove the fibres into strands. The extracted fibres were washed with water to remove the cellulose on their surfaces. The fibres were then sundried for ten (10) hours, after which they were soaked for six hours in a prepared 6% concentration solution of NaOH and then washed under a running tap. It was then dried under room temperature for 24 hours.

3.2.2 Preparation of Kenaf Fibre

Kenaf plants, on the other hand, were obtained from National Research Institute for Chemical Technology (NARICT), Zaria-Nigeria. The kenaf plants were soaked in water for a week and then beaten against the floor to separate the bast from the core. The kenaf bast fibre were then drawn into strands and treated like sisal.

3.2.3 Composite Production

Unreinforced isophthalic polyester resin was cured by adding one percent (1%) of cobalt naphthalene (accelerator) and Methyl ethyl ketone peroxide (catalyst) and then stirred until it became homogeneous. This was allowed to cure in the presence of sun light. This served as a control sample for the research. Ten grams (10 g) of weaved and un-weaved sisal and kenaf fibres which is approximately 20% volume fraction were then introduced separately into the resin using hand laying method for the un-weaved and coating method for the weaved sample. The volume fraction was chosen based on findings reported in earlier research (Mukherjee and Satyanarayana, 1984). They were then cured as the unreinforced resin.

3.2.4 Physical Properties Determination

3.2.4.1 Density

Rectangular samples were cut out neatly from the prepared samples. The mass (m) of the samples were measured with the aid of digital weighing balance while their volumes (v) were calculated using the product of their length, width and thickness. Three (3) samples of same composition were tested to obtain an average. The densities of the samples were obtained using the relation shown in Equation 1.

$$\rho = \frac{m}{v} \quad (1)$$

Where ρ = density (g/cm^3);

3.2.4.2 Water Absorption

Water absorption test is a physical test that gives detail of the level at which the material absorbs solvents when placed in such environments. Samples were weighed initially using a digital weighing balance and recorded as W_1 then they were soaked in water in an enclosed container for 24 hours. The soaked samples after being removed from water were cleaned with a damp towel then reweighed and recorded as W_2. The percentage water absorption was obtained from the relation shown in Equation 2 (Chow, 2007).

$$A = \frac{w2 - w1}{w1} \times 100 \quad (2)$$

Where A= Percentage water absorption (%)

3.2.5 Mechanical Properties Determination

Two (2) samples of same composition were subjected to each of the mechanical properties tested for in this study. This was done to find average values.

3.2.5.1 Tensile Strength Test

Tensile strength indicates the ability of a composite material to withstand forces that pull it apart, as well as the capability of the material to stretch prior to failure. Tensile tests were carried out using a Hounsfield Tenso-meter (TMER3), with maximum load of 20 KN. The standard specimens were mounted by their ends into the holding grips of the testing apparatus. The machine is designed to elongate the specimen at a constant rate, and to measure the instantaneous applied load and the resulting elongations simultaneously using an extensometer. The ASTM standard test method for tensile properties of polymer composites with the designation D3039-76, 2000 was used. The samples ultimate tensile strength (σ) and young's modulus (ε) were determined and recorded.

3.2.5.2 Hardness Test

The hardness test of composites is based on the relative resistance of its surface to indentation by an indenter of specified dimension under a specified load. In Rockwell test, the depth of the indenter penetration into the specimen surface is measured. The indenter universal hardness testing machine 8187.5 LKV model B, an electronic digital machine was used to measure the hardness of the samples at different spots and the results were displayed on the screen. The indenter used is a hardened steel ball diameter 1/16". Loading procedure starts from applying a minor load of 10 kg and then the major load of 60 kg.

3.2.5.3 Impact Test

The impact tests of the composites sample were conducted using a fully instrumented Avery Denison test machine. Charpy impact tests were conducted on notched samples. Standard square impact test samples of dimensions 70 x 10 x 10 mm with notch depth of 2 mm and a notch tip radius of 0.02 mm at angle of 45^0 were used. The value of the angle through which the pendulum has swung before the test sample was broken corresponds with the value of the energy that will be absorbed in breaking the sample. This was read from the calibrated scale on the machine. The test is widely applied in industries, since it is easy to prepare and conduct. Results can also be obtained quickly and cheaply.

3.2.5.4 Flexural Test

The flexural test method measures the behaviour of materials when subjected to simple beam loading. Flexural test is often done on relatively flexible materials such as polymers, wood and composites. A 3-point bending test was carried out on the samples. The flexural strength was determined for each sample using the relation shown in Equation 3 (Samotu et al., 2012).

$$\sigma f = \frac{3Pl}{2bt^2} \quad (3)$$

Where;
σf = Flexural stress (MPa)
P = Load (N)
l = Support span (mm)
b = Width of test beam (mm), and
t = thickness of test beam (mm)

3.2.6 Sample Labelling

The format by which the samples are labelled is summarised in Table 1.

Table 1: Sample Labelling

s/n	Sample Type	Sample Label
1.	weaved kenaf	(KW)
2.	un-weaved kenaf	(KUW)
3.	weaved sisal	(SW)
4.	un-weaved sisal	(SUW)
5.	unsaturated polyester	(UP)

4. Results

4.1 Physical Properties

4.1.1 Density

The densities of the samples determined are summarised in Table 2, while the comparison based on average is shown on Figure 3.

Table 2. The Densities of the Samples

Sample	ρ_1	ρ_2	ρ_3	$\rho_{average}$	Standard Deviation.
(KW)	1.12	1.15	1.21	1.16	0.05
(KUW)	1.15	1.18	1.18	1.17	0.02
(SW)	1.14	1.17	1.17	1.16	0.02
(SUW)	1.17	1.21	1.04	1.14	0.09
(UP)	1.20	1.19	1.21	1.20	0.01

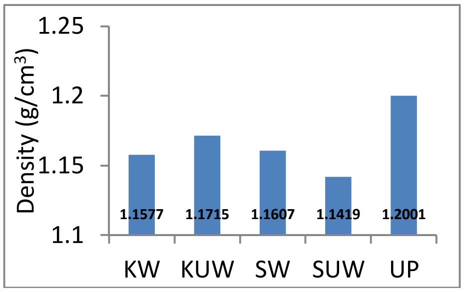

Figure 3. Composite Density

4.1.2 Water Absorption

The rate at which samples absorb water is summarised in Table 3, while the comparison based on average values is shown on Figure 4.

Table 3. The rate at which samples absorb water

Sample	A_1 (%)	A_2 (%)	A_3 (%)	$A_{average}$ (%)	Standard Deviation.
(KW)	1.09	0.68	0.92	0.90	0.21
(KUW)	0.78	1.10	0.75	0.88	0.19
(SW)	1.48	1.37	1.46	1.44	0.06
(SUW)	1.05	1.00	1.10	1.05	0.05
(UP)	0.39	0.36	0.35	0.37	0.02

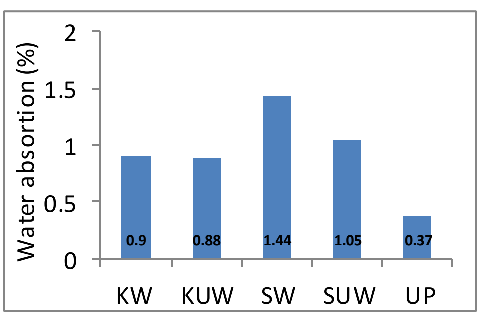

Figure 4. Composite Water Absorption

4.2 Mechanical Properties

4.2.1 Tensile Strength

The tensile strength (σ) and young's modulus (ε) for the two samples tested are summarised in Table 4, while the comparisons based on average values are shown on Figures 5 and 6.

Table 4. The tensile strength and young's modulus for the samples

Sample	σ_2 (N/mm^2)	σ_1 (N/mm^2)	$\sigma_{average}$ (N/mm^2)	$\varepsilon_{average}$ (N/mm^2)	Standard Deviation.
(KW)	16.29	15.74	16.02	73.52	0.28
(KUW)	26.16	17.24	21.70	110.40	4.46
(SW)	4.11	5.56	4.99	77.73	0.73
(SUW)	18.23	16.47	17.35	77.84	0.88
(UP)	12.32	20.60	16.46	102.88	4.14

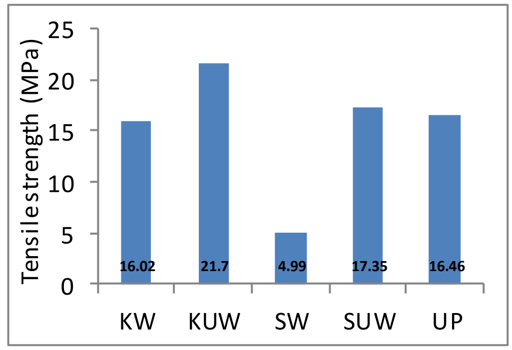

Figure 5. Composite Tensile Strength

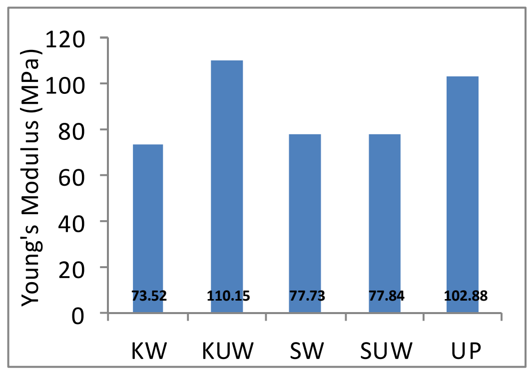

Figure 5. Composite Young's Modulus

4.2.2 Composite Hardness

The hardness numbers for the samples are summarised in Table 5, while the comparison based on average values is shown on Figure 7.

Table 5. The hardness numbers for the samples

Sample	HN_1 (HRF)	HN_2 (HRF)	$HN_{average}$ (HRF)	Standard Deviation.
(KW)	9.67	9.35	9.51	0.16
(KUW)	10.55	10.89	10.72	0.17
(SW)	25.80	25.40	25.60	0.20
(SUW)	18.82	18.98	18.90	0.08
(UP)	17.75	17.85	17.80	0.05

4.2.3 Impact Property

The Impact energies for the samples are summarised in Table 6, while the comparison based on average values is shown on Figure 8.

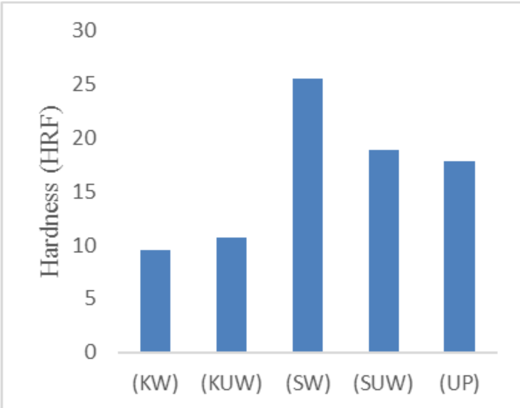

Figure 7. Composite Hardness Number

Table 6. The Impact energies for the samples

Sample	IE_1 (KJ/m^2)	IE_2 (KJ/m^2)	$IE_{average}$ (KJ/m^2)	Standard Deviation.
(KW)	14.00	13.18	13.59	0.41
(KUW)	10.00	9.20	9.60	0.40
(SW)	16.00	16.02	16.00	0.01
(SUW)	15.60	14.40	15.00	0.60
(UP)	4.00	4.40	4.20	0.20

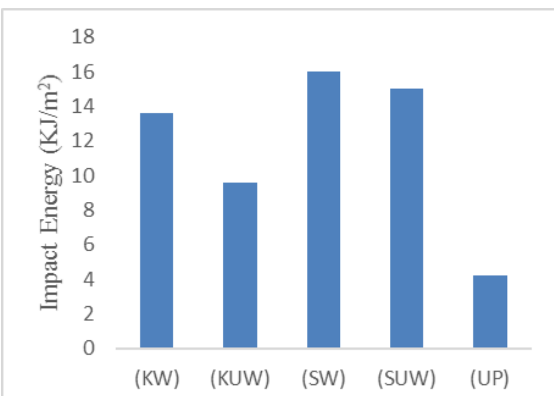

Figure 8. Composite Impact Energy

4.2.4 Flexural Property

The flexural strengths for the samples are summarised in Table 7, while the comparison based on average values is shown on Figure 9.

Table 7. The flexural strengths for the samples

Sample	σ_{f1} (N/mm^2)	σ_{f2} (N/mm^2)	σ_{f3} (N/mm^2)	$\sigma_{f\,average}$ (N/mm^2)	Standard Deviation.
(KW)	48.31	43.86	44.63	45.60	1.94
(KUW)	39.00	42.86	39.67	40.51	1.68
(SW)	41.55	41.20	41.77	41.50	0.24
(SUW)	33.33	35.42	31.25	33.33	1.70
(UP)	18.10	19.70	17.8	18.53	0.83

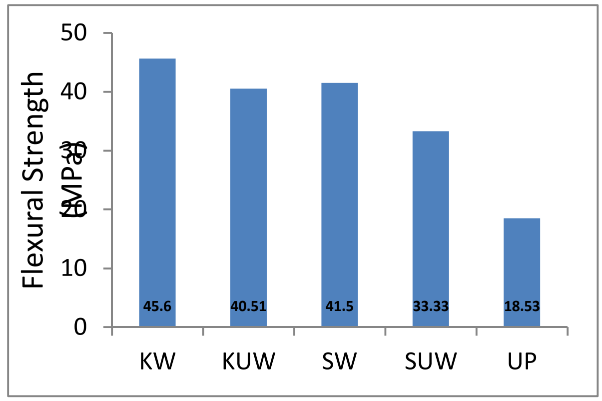

Figure 9: Composite Flexural Strength

5. Discussion of Results

From the results of the characterisation, it can be observed that introduction of reinforcement lowers the density of the composite material as unsaturated polyester has density of 1.2 g/cm^3, which reduced to 1.16 g/cm^3 and 1.17 g/cm^3 obtained from KW and KUW respectively, and 1.16 g/cm^3 and 1.14 g/cm^3 obtained from SW and SUW, respectively. This implies that both reinforcing fibres are less dense that the matrix (see Figure 3). Weaving of the fibre before introducing them into the matrix does not affect the density of the composite as the density results with weaved and un-weaved fibre are close to each other.

Moreover, from the results summarised in Table 3 and Figure 4, weaving of the reinforcement increased the percentage water absorption for both fibres used but the effect is well pronounce in the sisal fibre reinforced composite as compared to samples reinforced with kenaf fibres. This shows that weaving the fibre contributed to the creation of pores within the samples. The result also implies that the sisal fibres are more hydrophilic in nature than the kenaf fibres. Moreover, introduction of reinforcement generally increased the rate at which the composite material absorbed water.

On the mechanical properties measured, weaving the reinforcement lowers the tensile properties for both fibres used. This can be clearly seen on Figures 5 and 6 as the values of tensile strength and Young's modulus of weaved fibre reinforced samples are lesser than that of the un-weaved reinforced ones. This can be associated to poor bonding between the reinforcements and the matrix for both fibres used despite the treatment in sodium solution before using them. Introduction of kenaf fibre into the matrix lowered the hardness of the material, although weaving the fibre does not significantly affect the hardness value. On the other hand, weaving sisal fibre increased the hardness of the composite significantly even more than the hardness value of the control samples (see Figure 7). Materials with high hardness value are expected to be less tough which accounts for the lower impact energy obtained from sisal fibre reinforced composite. This implies that kenaf fibre reinforced materials are tougher than those reinforced with sisal fibre and the unreinforced samples (Control). This variation also agrees with the findings of early researchers (Ishak, 2007; Bower, 2009).

Finally, the introductions of reinforcements increase significantly the flexural strength of the composite material. This is due to the role played by the reinforcing fibre in carrying load that acts transversely to their axes. Moreover, weaved fibre reinforced composite samples possessed higher flexural strength than the un-weaved fibre reinforced ones. However, the tensile strength reduces on the introduction of the fibre, this can be associated to low inter phase bonding between the fibre and the matrix as stated earlier. But the values of the tensile strength and modulus are within the acceptable range of polymer composite materials (Samotu et al., 2012).

6. Conclusions

From the results of the tests and analyses carried out, it could be concluded that kenaf and sisal fibre, weaved or un-weaved can be used to reinforce polyester resin. Introduction of reinforcement lowers the density of the composite material developed although weaving them does not affect the density. Besides, introduction of reinforcement increases the rate at which the composite material developed absorbs water, though sisal fibre reinforced materials absorb more.

Moreover, introduction of reinforcement increases the flexural strength of the composite material though weaved fibre possesses more strength than un-weaved ones. However, no particular composition possesses optimum value for all the properties measured. With systematic and persistent research there will be a good scope and better future for sisal/kenaf fibre -polymer composites in the coming years.

Future research work should be done on proffering the best control during fabrication. The assumptions about composite materials behaviour may not perfectly match to the actual behaviour of materials. Based on the assumptions of composite materials, the material could carry load perfectly till one of the component reach its ultimate strength or strain, then the composite material fails due to the increment of load. This assumption needs the best control during fabrication in order to produce the best characteristics of composites such as perfect interfacial bonding between fibre and matrix, interfacial bonding between layers, zero void content and good impregnation of fibres.

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