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WEAR AND THERMAL PROPERTIES OF HYBRID PALM KERNEL FRUITREINFORCED POLYESTER COMPOSITES

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Abstract: Particles from the shell of the nut of palm tree and the strand were used to reinforce polyester resin after it has been pulverized and sieved to 45µm with the aid of laboratory ball mill and sieves respectively. The particle and the strand were treated separately using 1 M NaOH solution maintains at 50 ^{0}C for 4 hours. The particulate palm kernel shell and the palm fruit strand were used to develop composites by mixing the reinforcements and the matrix in predetermined proportions via open mould casting method. Wear and thermal properties of the developed composites were investigated using Taber Abrasers and Lees' disk apparatus respectively. The results showed that both properties were enhanced by the addition of these reinforcements into the polyester matrix. However, particulate reinforced composites gave the best outcome with 2 wt% followed by 4 wt% and 10 wt% producing the optimum wear resistance and thermal conductivity results respectively while the insulating property was best in3 wt% (P+S)and 2 wt% (P+S) hybrid composites respectively. Surface morphology of the composites as shown by scanning electron microscope revealed that the reinforcements were well dispersed and properly bonded in the polyester matrix.
Keywords: Hybrid composites, Wear properties, Thermal properties, Polyester, Palm kernel fruit

1. INTRODUCTION

Presently, polymer matrix composite is the only bridge for harmonizing the need of the present day technology with material property requirement [1].The desired properties that are lacking in today's technology are often found in Fiber Reinforced Plastics (FRP). Globally, the technology of transforming waste into wealth is a vibrant path to economic growth. In most countries, agriculture plays a pivotal role in its economic growth [2] as such after harvest; large quantities of wastes are generated. These wastes constitute environmental pollution. Today these wastes have found a place in the Reinforced Plastic Industry where value has been added to it. Natural fibers, as reinforcement, have recently attracted the attention of researchers because of their advantages over other established materials. They are environmentally friendly, fully biodegradable, abundantly available, renewable and cheap and have low density. Natural fiber composites are used in place of glass mostly in non– structural applications. A number of automotive components previously made with glass fiber composites are now being manufactured using environmental friendly composites materials [3]. This may be attributed to low–weight ratio of the composites.

Palm tree is grown solely for its oil content. A matured tree can grow up to 20m with leaves 3–5mlong. A young tree will produce about 30 new leaves a year while a 10 year–old tree will produce about 20 leaves a year. After flowering, the fruit takes 5–6 months to mature. The reddish fruit grows large bunches. Each fruit contains a single seed called the palm kernel which is surrounded by a soft oily pulp. The oil is extracted from the pulp to produce palm oil. The largest world producer of palm oil today is Malaysia. There are several types of fibers that can be obtained from a palm kernel tree [4–5].

The interface between the reinforcing agent and the matrix plays a pivotal role in determining the mechanical properties of composite materials. Research efforts have shown that the major problem associated with natural fiber–polymer matrix composite is that of the interface [6–7]. Natural fiber is hydrophilic while polyester is hydrophobic making it impossible for the two bodies to naturally bond together without any form of treatment [8–10].

This research was carried out to earnest the potentials that are imbedded in these natural source of reinforcements and to further encourage the use of agro–waste as a substitute for synthetic fibers which have been observed to be costly and not environmentally friendly. For this purpose, palm kernel strand (fiber) and shell were selected and used in order to examine the possibility of the potential use of these agro–wastes for engineering applications.

2. MATERIALS AND METHODS

2.1. Materials

The major materials that were used for this research were; palm kernel fiber and shell, unsaturated polyester resin, distilled water, analytical sodium hydroxide (NaOH) pellets.

2.2. Palm kernel fiber and shell procurement and treatment

The palm kernel fiber and shell were obtained from the farm plantation after the extraction of palm oil from the fruits. The fiber and the shell were washed with water to remove sand and dirt. The shell was pulverized with laboratory ball mill followed by sieving to obtain 45µm particle size. Chemical treatment with 1 molar solution of sodium hydroxide in a shaker water bath at a temperature of 50 ^{0}C for 4 hours was carried out on both the fiber and the pulverized shell. After treating the fiber and the shell, they were washed with ordinary water before washing them with distilled water to ensure neutralization status and finally sun dried for 5 days. The treatment was performed to remove some of the impurities in the fibre and the shell which was rich in cellulose, hemicellulose and lignin.

2.3. Production of particulate and hybrid palm kernel shell and fiber reinforced polyester composites

The composites were developed by using open mould method. Three hundred and twenty gramme (320g) of polyester resin was weighed and was mixed with 4g each of both the catalyst and accelerator to form the matrix. The matrix was stirred thoroughly before the alkaline solution treated PKS and the PKS/PALM FRUIT STRAND (fiber) were added separately to produce particulate and hybrid composites respectively. Both the particulate PKS and the strand were to act as reinforcement in the unsaturated polyester. These were added in pre–determined proportions as 2, 4, 6, 8 and 10% weight. Some samples were developed for particulate reinforcement while some were developed for the hybrid (particulate palm kernel shell (P) and palm fruit strand (S) in the following order; (1%P+ 1%S), (2%P+ 2%S), (3%P+ 3%S), (4%P+ 4%S) and (5%P+ 5%S). The mixture was properly stirred using a rod for 3 minutes and later poured inside the mould and left for about 10minutes for proper curing and later shakeout of the moulds. The samples after production were allowed to further cure for 27 days in the laboratory before analysis was carried out.

2.4. Property Tests – Wear Test

The wear resistance test was carried out with Taber Abrasers, Model ISE–A016. Taber tests involve mounting a flat specimen approximately 100 mm^2 or round to a turntable platform that rotates on a vertical axis at a fixed speed. The standard material thickness that can be evaluated with the Taber Rotary Abraser is 6.35 mm. Two genuine Taber abrasive wheels, which are applied at a specific pressure, are lowered onto the specimen surface. Characteristic rub–wear action is produced by contact of the test specimen against the sliding rotation of the two abrading wheels. As the turntable rotates, the wheels are driven by the sample in opposite directions about a horizontal axis displaced tangentially from the axis of the sample. One abrading wheel rubs the specimen outward toward the periphery and the other, inward toward the center while a vacuum system removes loose debris during the test. The wheels traverse a complete circle on the specimen surface, revealing abrasion resistance at all angles relative to the weave or grain of the material. The resulting abrasion marks form a pattern of crossed arcs in a circular band that cover an area approximately 30 cm^2.

Weight (Mass) Loss – This technique measures how much material has been removed by abrasion, and is usually reported in milligrams.

$$L = A - B \quad (1)$$

where; L – weight loss; A – weight (mass) of specimen before abrasion; B – weight (mass) of specimen after abrasion

When performing the weight loss method, loose particulate may adhere to specimens during testing. It is critical that you clean off the test specimens as best as possible prior to weighing.

Three samples each were tested for each composition from where the average value was taken as the representative values.

2.5. Lee's Disk Apparatus (LDA)

Lee's disk apparatus was used to determine the thermal properties of the composites. The apparatus employed electrical heating without the need for cooling measurements. This consists of three copper discs (A, B and C) with drilled hole to accept glycerin and liquid–in–glass thermometers to determine temperature T_A, T_B and T_C. As shown in Figure 1, 6 W electrical plate heater of the same diameter as the copper disc was inserted between disc B and C. The samples already machined to a disc shape of 41 mm diameter and 3 mm thickness was placed between copper discs A and B. The clamp screw was tightening to hold all the discs and sample together firmly. The machined samples used were as shown in Figure 2.

The set–up was connected across 0 – 15 V dc LEYBOLD HERAUS dual power supply and Milton Keynes 2.8A, 25Ω rheostat. The whole set–up was placed in an enclosure to minimize the effect of draughts and the ambient temperature $T_{ambient}$ was also taken. Current (I) and Voltage (V) across the system was monitor at interval of 10 minutes via 0–2.5A EM–407 and AVD–830D respectively.

At the beginning, the rheostat was adjusted to supply current that raised the temperature of the system to thermal equilibrium of T_A, T_B and T_C. At this thermal equilibrium temperature, the rheostat was readjusted to reduce current across the system and falling temperature was recorded at 10 minutes interval until a new thermal stability was attained. When the temperature of disc A, B and C had been stable to within ±0.1 °C variation for 10minutes, thermal conductivity (λ) of the specimen of thickness d and radius r was calculated at this thermal equilibrium temperature using MATLAB computer program from equation 2.

$$\lambda = \frac{ed}{2\pi r^2 (T_B - T_A)}\left(a_S \frac{T_A + T_B}{2}\ 2a_A T_A\right) \tag{2}$$

The equation 2 was derived as follows;

The heat transfer between an object and its surroundings depends on the exposed surface area of the object and the temperature difference between the object and its surroundings. If e joules of energy is emitted from the exposed surface area (measured in m^2) per second per °C above ambient temperature. The temperature of the specimen (T_S) is the mean temperature of discs A and B. Therefore, the total heat emitted from the apparatus is

$$H = ea_A T_A + ea_S \frac{T_A + T_B}{2} + ea_B T_B + ea_C T_C \tag{3}$$

Where a_A, a_B, a_C and a_S are the exposed surface areas of disc A, B, C and the specimen respectively. The heat (H) supplied by the electrical heater is given by

$$H = VI \quad Js^{-1} \tag{4}$$

Where V is the potential difference across the heater and I is the current which flows through it.

From conservation of energy, equate equation (3) and (4)

$$e = VI\left(a_A T_A + a_S \frac{T_A + T_B}{2} + a_B T_B + a_C T_C\right)^{-1} \tag{5}$$

From the standard equation for conduction of heat through an object, the heat flowing through the specimen S is

$$h_S = \lambda \pi r^2 \frac{T_B - T_A}{d} \tag{6}$$

where r is the radius, d the thickness and λ the thermal conductivity of the specimen. Equation (7) gives the total heat energy emitted from the exposed area of the specimen and the disc A

$$h_{BS} = ea_S \frac{T_A + T_B}{2} + ea_A T_A \tag{7}$$

The heat leaving S for A is that which is emitted by disc A alone is given in equation (8)

$$h_{SA} = ea_A T_A \tag{8}$$

The mean of these two is

$$h_S = \frac{e}{2}\left(a_S \frac{T_A + T_B}{2} + 2a_A T_A\right) \tag{9}$$

Thus from (6) and (9)

$$\lambda \pi r^2 \frac{T_B - T_A}{d} = \frac{e}{2}\left(a_S \frac{T_A + T_B}{2} + 2a_A T_A\right) \tag{10}$$

Therefore by substituting the value for e in equation (5) into equation (11) the thermal conductivity of the specimen can be determined.

$$\lambda = \frac{ed}{2\pi r^2 (T_B - T_A)}\left(as \frac{T_A + T_B}{2}\ 2a_A T_A\right) Js^{-1}m^{-1}{}^{\circ}C^{-1} \tag{11}$$

From the above computing λ from equation (5) and (11) manually appear to be very laborious hence, the calculations were performed using a MATLAB computer program.

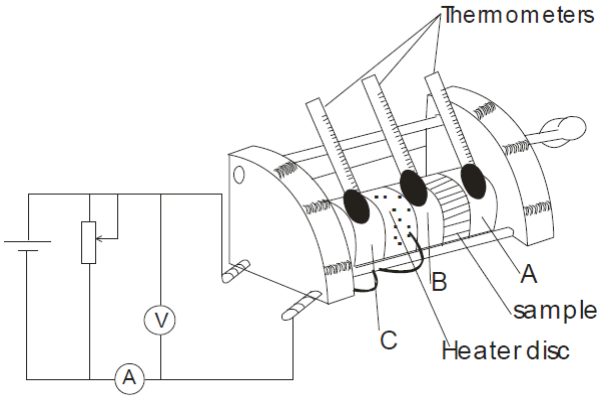

Figure 1. Lee's Thermal Conductivity Experiment Set–up

Figure 2. Lee's Thermal Conductivity Test Specimens

2.6. Scanning Electron Microscope (SEM)

The distribution of the palm kernel strand (PKS) and particulate palm kernel shell (PPKS) in the polyester composites were investigated using Quanta 200 Environmental Scanning Electron Microscope (ESEM) under high voltage of 20kV at magnifications x 5,000. The surface morphology of the hybrid palm fruit strand/particulate and particulate palm kernel shell reinforced polyester matrix composites were examined with scanning electron microscope. The ESEM images the sample surface by scanning it with a high – energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample thereby producing signals that contain information about the composition of the composites.

3. RESULTS AND DISCUSSION

3.1. Wear resistance property of the developed composites

Figure 3 show the graph of the variation of wear resistance with the reinforcement content of the developed composites and the control. Wear is the progressive loss of material due to relative motion between a surface and the contacting substance or substances [11]. Wear resistance is the ability of a material to resist the gradual wearing away caused by abrasion and friction. Since these materials are usually subjected to wear challenges from the environment, there is need to understand the behavior of these materials and to how they will respond to this encounter in service. From the graph, sample denoted as 2P which contains 2 % particulate reinforcement posed the highest resistance to wear with value of 0.008 g followed by sample 2(P+S) which contain 2 % particulate + 2 % strand reinforcements with a value of 0.016 g and sample denoted as 4p which contain 4 % particulate reinforcement with a value of 0.0169 g. A critical look at the graph revealed that the particulate reinforced composites show very wear resistance compared to the hybrid and control. The control was observed to have a wear resistance value of 0.025 g. The results show that low weight fraction gave better performance compared to high weight fraction and the control. The reason for this was that the particles were able to feel the pores within the matrix but at higher weight fraction there was fibre touching which may led to weak interfacial bonding strength and low wear resistance. Therefore, composites with low weight fractions will possess more tendency to withstand wearing and abrasion. Also, due to high hardness property of the palm kernel shell which was one of the main reason for using the palm kernel shell, the particulate reinforced samples were observed to possess high wear resistance than the hybrid where the strand were added. However, still at the low weight fraction the hybrid was noticed to have good performance. This is likely due to the existence of the reinforcements in appropriate proportions in the composite.

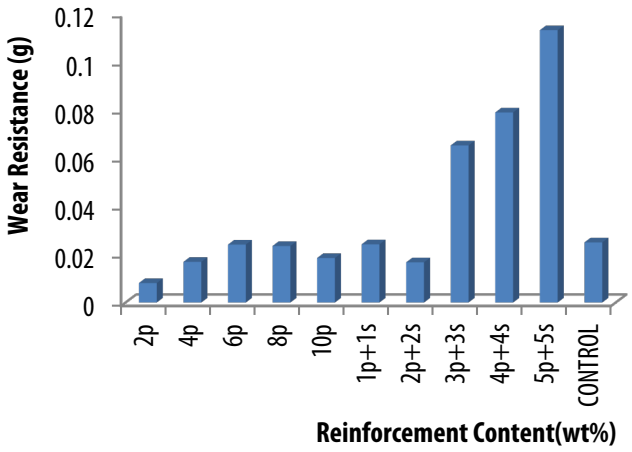

Figure 3. Plots of the variation of the wear resistance with the reinforcement content of the developed composites and the control

3.2. Thermal Properties of the Developed Composites

» **Thermal conductivity property**

The thermal properties of the developed composites were investigated using Lee's Disk apparatus. The graph in Figure 4 show that, the particulate reinforced composites gave the best thermal conductivity values where sample denoted as 2P which contains 2 % particulate reinforcement possess the highest value of 0.177 $Wm^{-1} K^{-1}$ followed by composite with 10P which contains 10 % particulate reinforcement with a value of 0.162 $Wm^{-1} K^{-1}$ compared to the neat (control) sample with a value of 0.122 $Wm^{-1} K^{-1}$. With these results, the thermal conductivity of the polyester material has been enhanced by 45 %. Comparatively, the hybrid composites exhibit low thermal conductivity capability than the particulate reinforced composites. The results revealed a common trend for both particulate and hybrid composites where

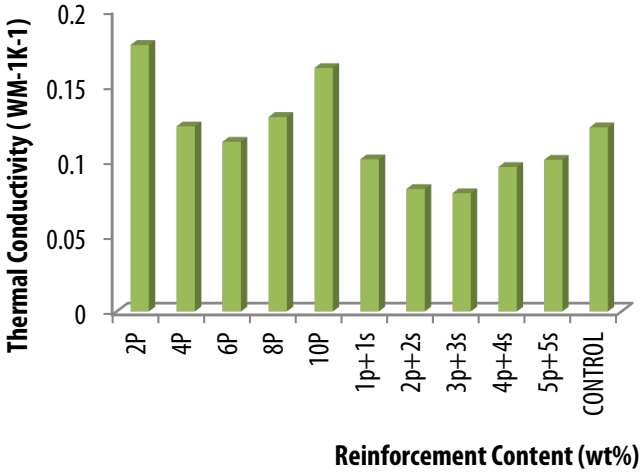

Figure 4. Plots of the variation of thermal conductivity with the reinforcement content of the developed composites and the control

the thermal conductivity were noticed to decrease from 2 – 6 wt % followed by an increase from 8– 10 wt %. From the results, it was obvious that the addition of the particles have a tendency to increase the thermal conductivity of the polyester material except at 6 wt % which was marginally reduced. Thus, it implies that the particles are more conductive than the strand and the addition of the strand to the particles tend to suppress this affinity.

Considering the insulating properties of the developed composites, the hybrid composite; 3 % (P+S) which contain 3 % particulate + 3 % strand possess the least thermal conductivity value of 0.078 $Wm^{-1} K^{-1}$ followed by composite with 2 % (P+S) which contain 2 % particulate + 2 % strand with a thermal conductivity value of 0.081 $Wm^{-1}K^{-1}$. With these results, it follows that the insulating property of the polyester has been enhanced by 56 % which indicates that the hybrid composites have better insulating properties.

» **Temperature variation with respect to time for the developed composites**

Temperature variation is the manner in which each of the material responds to temperature changes with respect to time. This property aid the understanding of the maximum temperature and time the material can withstand before thermal equilibrium was attained. Figure 5 shows the temperature (°C) and time in (minutes) relationship. From the graph, all the samples show a linear temperature variation with respect to time behavior. However, 1P+1S hybrid composite show the best capability to absorb heat with a value of about 52 °C at 130 minutes followed by 10P particulate composite with a value of 49 °C at 120 minutes. Particulate composites developed with 2 and 4 wt% possess the highest times of 170 and 160 minutes at their respective temperatures of 43 and 41 °C respectively. This simply means that these materials can operate at these temperatures for a longer time than others at their respective temperatures.

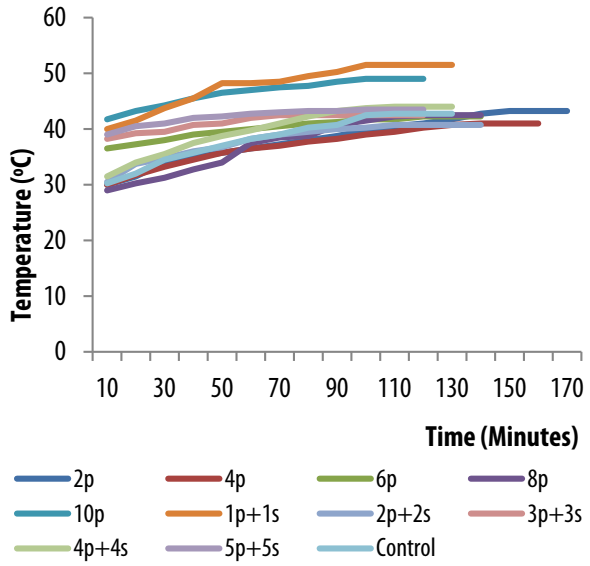

Figure 5. Plots of the variation of temperature with time for the developed composites and the Control

The control sample was observed to operate at 43 °C for 130 minutes. Comparing this with the developed composites, it was observed that, the hybrid composite 1P+1S was able to withstand more heat than the control sample at the same maximum time of operations while the 2P was able to withstand the same temperature with control sample for more time.

The results also showed that 8P which contains 8 % particulate reinforcement absolved the smallest amount of heat up to 50 minutes after which 2P which contains 2 wt% particulate reinforcement and 4P which contains 4 wt% particulate reinforcement starts absolving the list amount of thermal energy until the equilibrium is attained for all the samples produced. The particulate reinforced composites with 2, 4 and 8 wt % reinforcement possess the least amount of thermal energy absorption capability compare to the hybrid composite samples with respect to time. This observation may be due to the high conductivity of the particulate composites which may cause early incineration and failure for the materials unlike the hybrid which does not permit easy flow of heat, thereby able to withstand more heat in comparison.

» **Scanning Electron Microscope image of the fractured surface of the developed composites**

The scanning electron microscope (SEM) images of the fractured surfaces for the particulate and hybrid composites were shown in Figures 6–7.

From Figure6, the dark spot show the matrix while the white spot show the particulate palm kernel shell (PPKS). The particles were seen to be well dispersed with clustering of the particles in some locations. The existence of these two phases may be the reason for the observed properties which are good wear resistance and thermal conductivity respectively. The cluster phase is expected to enhanced wear resistance while the phase with well dispersed particles will enhanced the thermal conductivity property.

Also, from Figure 7, similar image was observed with the addition of dark spots that show the palm kernel strands (PKS). The addition of the strand causes the reduction of the white spot considerable. This was the reason for the observed thermal conductivity properties of the hybrid composites where the thermal conductivity was seen to be reduced as the strand was added to the polyester material.

From the Figures, it was observed that the PPKS (white) and PKS (dark spot) were uniformly dispersed in the polyester (black). The image revealed that there was proper wetting of the particles and the palm kernel strands by the matrix and the reason for adequate load transfer from the polyester to the palm kernel shell particles and palm kernel strand that serve as reinforcements.

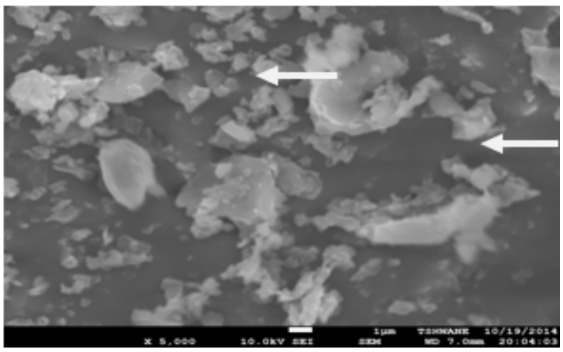

Figure 6. SEM Image of Particulate Palm Kernel Shell Polyester Composites

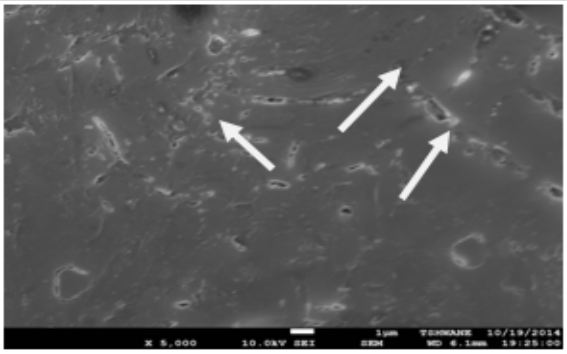

Figure 7. SEM Image of the mixture of Particulate Palm Kernel Shell and Palm Kernel Strand Hybrid Composites

4. CONCLUSION

The research have shown that these agro–wastes are better alternative to synthetic fibers been used for the improvement of wear and thermal properties of polyester material. It was observed that the developed composites possess better properties in all the properties considered compared to the unreinforced polyester matrix that serve as control. From the results, the following conclusions were deduced;

The use of particulate palm kernel shell as reinforcement in polyester was found to be a promising way of enhancing both the wear and thermal conductivity properties of the developed composites. From the results, it was established that 2 wt % particulate palm kernel shell reinforced composite was the best. However, if the material is to be considered for insulating purpose, the hybrid composites were found to be the best.

The results of temperature variation with time revealed that, the hybrid composite was able to absorbed more heat than the control (neat) material at thermal equilibrium temperature while the particulate was able to withstand the same amount of heat for longer period than the neat at the thermal equilibrium temperature.

The adoption of low weight fraction from both particulate and hybrid reinforced composites will lead to good results since this was the range 2–6 wt% that ensued into best performance in all the properties evaluated.

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