IOSR Journal of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 10, Issue 5 Ver. II (Sep. – Oct. 2018), 51-57
www.iosrjournals.org

Determination of The Thermal Properties of Groundnut Shell Particles Reinforced Polymer Composite

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Abstract:*Natural fibers in recent times find useful application in both the manufacturing and construction sector. These fibers when reinforced with polymers form composites materials which possess excellent thermal properties suitable for thermal insulation. The composites can be well applied in the packaging, industrial and household thermal shield. The thermal properties of groundnut shell were successfully optimizedand characterized using Leeds Apparatus and calorimetry. The composite specimens were prepared with different weight percentages of randomly distributed groundnut shell particles in polymer matrix. Composites were prepared by varying the percentage of groundnut shell. We observed that the thermal conductivity of groundnut shell reinforced polymer composite (GSPC) decreased (0.355 – 0.221 W/mK) with increasing weight percentage (wt%)of the groundnut fiber (GF); while the thermal resistivity increases. Thermal diffusivity decreases with additional particles content.*

Keywords:*Composite, polymer, thermal properties, natural fiber.*

Date of Submission: 23-09-2018 Date of acceptance: 08-10-2018

I. Introduction

Natural fibers have received intensified interest in recent times due to their easy availability nature in the environment. Most of the fibers are disposed by farmers as agricultural waste material. The nutritional content of these fiber makes it suitable as animal feed. Some natural fibers like rice contain high amount of silica which can be extracted for advanced industrial applications.

Natural fibers are a class of biomass which is an agricultural waste. Groundnut shell is a biomass which is good as energy source since it is renewable and available in most countries and can replace fossil fuel [1]. It can also be used as animal feed due to its nutritional value, and can well be tailored into advanced synthetic fibers. According to [2], natural fibers are now believed to be an option to synthetic fibers such as glass fiber and carbon fiber. Lignocellulosic bio-fibers as reinforcing material are being utilized worldwide for the manufacture of eco-friendly bio-composites. The identification of different techniques of manipulating local fibers makes it viable as reinforcement material in composites considering their low cost, durability and easy maintenance.

Poor conducting materials are excellent agent for thermal insulation. Natural fibers such as groundnut shell which is often times disposed as waste by local farmers can be collected and processed into useful composite for construction and other thermal insulating applications in the industry. Asserted by [3], natural fiber-containing composites are more environmentally friendly and are used in various applications such as automobile, aerospace, railway coaches, military applications, building and construction as ceiling paneling, partition boards, and packaging and consumer products.

Composites made of rubber can have their properties altered when local fibers are added to enhance their properties. As stated by [4], it is no surprise that 50% of all chemists, physicists, mechanical engineers and many material scientists are involved with research or developmental work with polymer composites.

Groundnut is the second most important leguminous crop in the world after soya beans as it provides food for human and livestock and forms valuable dietary protein components in the absence of meat [5]. Groundnut kernel often the most valuable to humans as the shells are disposed of as waste into our environment. We chose groundnut shell in this research because of its commonness and availability, light weight and good thermal behaviour. Also, a similar research method has not yet been conducted on groundnut shell.

II. Material and Methods

Materials

Groundnut shell, CY-230 and HY-951 araldite, Leed's apparatus, 1.0 mm sieve, mould, veniercalipe and weighing balance.

Sample collection

Unknown mass of groundnut shell was collected from Wadata market, Benue State. It was poured into a polythene bag and transported to the Advanced Physics Laboratory, University of Agriculture, Makurdi, Nigeria.

Sample pre-treatment

The dried groundnut fiber was initially washed with water to remove sand and other unwanted matter in it. The washed shells were soaked in 5.0% solution of sodium hydroxide for five hours and then washed several times to eliminate all the alkali present. Washing with the alkali was done to remove protein from the fiber which might utter the thermal properties of the shells. Following, the shells were solar dried and ground with pestle and mortar to reduce the particle size. The ground particles were passed through a 1.0 mm sieve to obtain the desired particle size for the composite.

Sample preparation

The clean and sieved groundnut fiber was finally weighed into various percentages using a digital balance. The percentages 20%, 30%, 40% and 50% were separately weighed and labeled accordingly. The respective percentages of fibers were separately added into matrix mixtures of epoxy resin and stirred thoroughly for 10 minutes to have a homogeneous mixture.

Composite fabrication

A circular mould of diameter 110.89 mm and height 12 mm was used to cast the composites. The mould was first covered with aluminum foil to prevent the specimens from sticking to the mould upon removal. The prepared mixtures of groundnut shell and epoxy resin were taken in a beaker and placed in the moulds by the hand-lay-up technique and allowed to cure for 24 hours before removal. The specimens were carefully removed to avoid cracking. Composite specimen with 20% shell was labeled sample A, the 30% fiber composite was labeled sample B, 40% as sample C and that of 50% as sample D.

Table no 1: Mixing ratio of the composite materials

Sample name	Weight (%)	Polyester resin (%)
A	20	85
B	30	90
C	40	95
D	50	100

Determination of thermal conductivity of the groundnut shell composite

The various dimensions and parameters of the fabricated composites were determined using micrometer screw gauge and weighing balance respectively. The various components of the Leed's apparatus were coupled together and the groundnut shell composites placed between steam chamber and the brass disc. The mass of the brass was determined using a weighing balance while its diameter was obtained using a vernier caliper.

Heating of the specimen was started by sending steam through the heating chamber. The steady temperature was reached by monitoring the two thermometers $T_1 and T_2$ respectively. The sample was removed after the steady temperature and the metallic disc was made to have direct contact with the brass disc for direct heating. The brass disc was heated to atleast 10^0C above the steady state temperature T_1 following which heating was ceased by removing the steam camber. The sample was returned and placed in contact with the brass disc. Temperature drop was monitored in the time interval of 60sec to a point of 5^0C below the steady temperature T_1. The above procedure was repeated for all samples. The thermal conductivity was calculated by the formula,

$$K = \frac{ms\left(\frac{dT}{dt}\right)x}{A(T_2 - T_1)} \quad (1)$$

Where m is mass of brass disc, s is the specific heat capacity of brass disc, A is cross sectional of the specimen, x is thickness of sample, $\frac{dT}{dt}$ is the time rate of cooling of sample and $T_2 - T_1$ is temperature difference across the specimen [6].

Determination of specific heat capacity

The mass of empty calorimeter was measured with the aid of electronic weighing balance and recorded as m_c while the mass of groundnut shell composite (GSC) was measured and recorded as m_s. The empty calorimeter was half filled with water and weighed as m_{cw} meanwhile temperature of content was recorded as θ_1. The composite was taken to a furnace and heated to a temperature of θ_2. It was then withdrawn from the furnace and quickly transferred to the cold thermometer to avoid heat lost in the air. The mixture was stirred for even distribution of heat and the final temperature was noted as θ_3. All requisite precautions were taken to obtain accurate results. Following, the principle of heat transfer which states that heat lost by hot object equals heat gain be cold calorimeter and content was adapted to calculate the specific heat capacity. The mathematical relation was used,

$$m_s c_s(\theta_2 - \theta_3) = m_c c_c(\theta_1 - \theta_3) + m_w c_w(\theta_1 - \theta_3) \quad (2)$$

Where mass of water m_w = m_{cw} - m_c, specific heat capacity of water, c_w = 4200J$kg^{-1}k^{-1}$, specific heat capacity of calorimeter, c_c = 400 J$kg^{-1}k^{-1}$, and the specific heat capacity of GSC, c_s is to be determined from the equation above [7].

Thermal diffusivity and resistivity

The thermal diffusivity was calculated from the formula,

$$\propto = \frac{k}{\rho c} \quad (3)$$

Where $\propto$ thermal diffusivity of the material, k is thermal conductivity, ρ is density of the material and c is specific heat capacity.

Density of the material ρ was obtained from

$$\rho = \frac{mass}{volume} \quad (4)$$

where volume of the material = cross sectional area x thickness

Cross sectional area, A = $\frac{\pi d^2}{4}$ (5)

Thermal resistivity, R was calculated from

$$R = \frac{1}{k} \quad (6)$$

where k is thermal conductivity

Time rate of water absorption

The composite is weighed in air and the mass is recorded as W_a. The sample is placed in water for 1 minute and weighed as W_0. Specimen is returned and placed in water and weight W_a is recorded after every minute up to the 10th minute. The water absorption is calculated from,

$$W_{ab} = \frac{W_b - W_a}{W_a} \text{ x } 100 \quad (8)$$

where W_{ab} is water absorption, W_b weight in water and W_a is weight in air.

The bulk density was determined from the formula,

$$D = \frac{W_a}{v} \quad (9)$$

where D is bulk density and v is volume of sample.

Plate no 1: Experiment set up of Leed's apparatus

Plate no 2: Groundnut shell composite in mould

III. Results

The fabricated composites have their measurable quantities determined and tabulated in the various tables. Further presentation of the results is shown on various graphs for ease of understanding of the behaviour and variation of the physical quantities.

Table no 1: Cooling rate of groundnut shell composites

Time (s)	Temperature (^{0}C)			
	20%	30%	40 %	50 %
0	80676564			
60	786664	63		
120	776663	62		
180	756562	60		
240	73646159			
300	71635958			
360	70625857			
420	70615756			
480	68605655			
540	67595554			

Tableno 2: Steady state temperatures of the composites

GSC (%)	$T_1(^0C)$	$T_2(^0C)$
20	73	90
30	67	96
40	65	97
50	64	97

Tableno 3: Dimensions and thermal properties of prepared GSC

GSC (%)	Thickness (m)	Diameter (m)	Volume $\times 10^{-5}(m^3)$	Mass (kg)	Density (kg/m^3)	Thermal Conduc. heat $(Wm^{-1}k^{-1})$	Specific heat $(Jkg^{-1}k^{-1})$	Thermal resistivity (mkW^{-1})	Thermal diffusivity $(m^2s^{-1})10^{-7}$
20	0.008	0.111	7.399	0.049	662.25	0.355	2238	2.857	2.395
30	0,009	0.111	7.826	0.052	664.45	0.269	2385	3.717	1.697
40	0.010	0.111	10.103	0.071	702.76	0.241	2480	4.149	1.383
50	0.012	0.111	11.475	0.088	767.84	0.221	2517	4.525	1.144

Table no 4: Effect of water absorption on GSC

Time (s)	Mass of composite after water absorption (g)			
	20%	30%	40%	50%
0	48.5	51.9	70.6	77.6
60	62.4	64.8	101.0	110.0
120	65.2	85.8	117.2	124.8
180	67.4	98.3	142.6	146.1
240	66.4	112.4	143.5	175.2
300	70.1	106.5	153.4	167.2
360	68.9	102.2	145.1	169.5
420	67.3	100.4	145.1	170.9
480	67.0	100.2	144.9	170.5
540	67.2	101.3	145.0	171.1

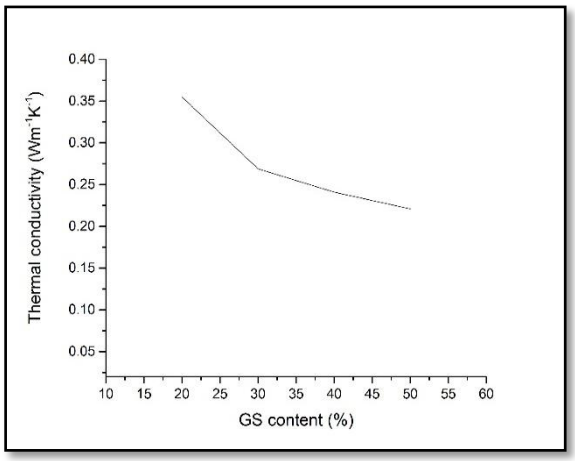

Figure no 1: Variation of thermal conductivity with GS content

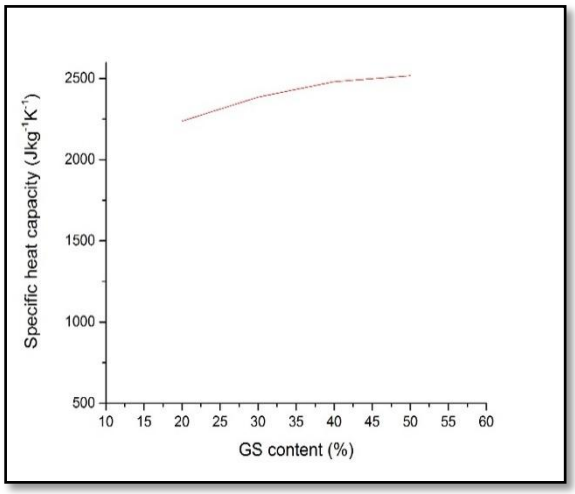

Figure no 2: Variation of specific heat capacity with GS content

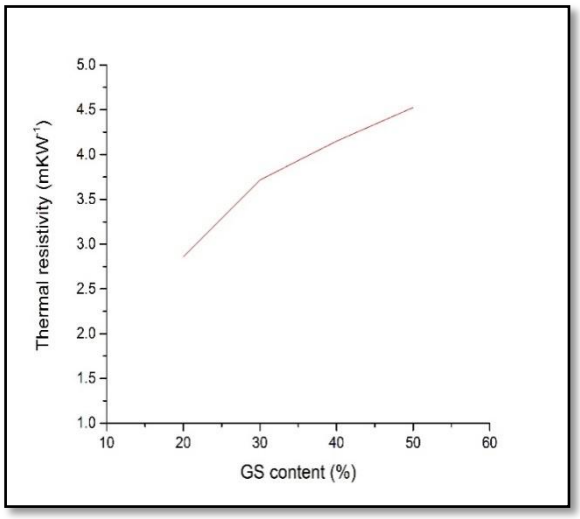

Figure no 3: Variation of thermal resistivity with GS content

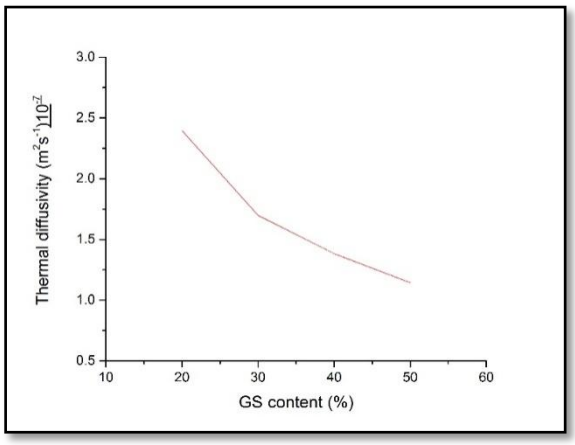

Figure no 4: Graph of thermal diffusivity against GS content

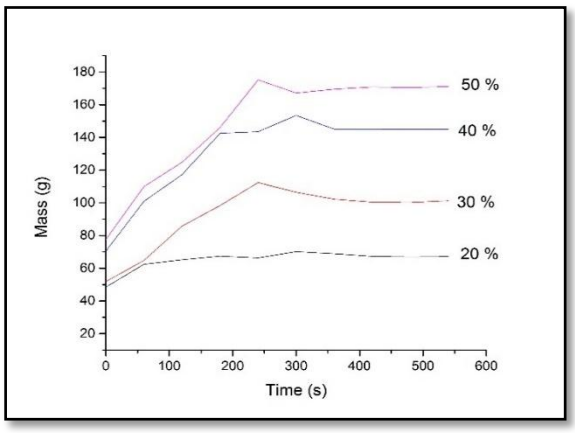

Figure no 5: Water absorption rate of GS composite

IV. Discussion

Thermal properties

Thermal conductivity quantifies the heat that can flow in a unit time through a unit area of a layer of a material.The thermal conductivity oftheGSC decreased(0.355 – 0.221 W/mK) with increasing fiber wt % as shown in Table 3 and Fig. 1.This is as a result of steady heat supply over increasing composite mass and volume. The heat is distributed over increasing number of particles. The thermal resistivity is observed to increase with additional mass of particles (see Table 3 and Fig. 3) and hence is inversely proportional to the

thermal conductivity. Decreasing conductivity implies increasing resistivity since resistivity gives a quantitative opposition to heat conduction in a material.

Thermal diffusivity is the quantity that measures the change in temperature produced in unit volume of the material by the amount of heat that flows in unit time through a unit area of a layer of unit thickness with unit temperature difference between its face[8]. This measures the speed at which heat is transferred through a material. The speed with which heat travels through the composite is observed to decreases with increasing wt % of GS particles from 2.395 – 1.144 m^2/s as presented in Table 3 and Fig. 4.

The specific heat capacity is the energy that can be added to a unit mass of a material to produce a unit increase in temperature. The heat required to raise the temperature of a unit of the composite was found to be directly proportional to the mass or wt % of the groundnut shell.

Water absorption

The rate at which water is taken up by the composite is proportional to the wt % of the GS content in a specimen. On the average, each composite irrespective of the fiber content reaches saturation at the 5th min. and absorbs no significant amount of water afterwards as can be seen in Table 4 and Fig. 5. The absorption affinity of composite is wholly dependent on the particle content present.

IV. Conclusion

The thermal properties of groundnut shell particles reinforced polymer compositeweresuccessfully determined. Both the thermal conductivity and diffusivity of the composites were found to decrease with increasing fiber content. Meanwhile, the specific heat capacity and thermal resistivity experienced a decrease with increasing composite weight. Water absorption capacity of composites is directly proportional to the groundnut fiber content.

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Peverga Rex Jubu"Determination of The Thermal Properties of Groundnut Shell Particles Reinforced Polymer Composite" IOSR Journal of Applied Physics (IOSR-JAP) , vol. 10, no. 5, 2018, pp. 51-57.