Effect of Iron Ore Tailings Particle Sizes on the Thermal Properties of Epoxy and Polypropylene Matrix Composites

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Abstract- Thermal properties of materials such as plastic matrix composite is one of the important parameters for determining their behaviour and relevant applications. This present work focuses on determining the thermal behaviour of epoxy and polypropylene (PP) matrix composite reinforced with iron ore tailings (IOT) particulates of sizes 150 µm, 212 µm and 300 µm at various loadings of 5%, 10%, 15%, 20%, 25%, and 30%. The thermal behaviour of the developed composites was investigated experimentally using a KD2 pro thermal analyser. The results obtained from the experiment showed that increasing filler loading in epoxy leads to increased specific heat capacity and thermal resistivity. The maximum values recorded for the thermal resistivity and specific heat capacity were 0.592°C.mK/W and 2.352 J/kgK respectively. Thermal conductivity and thermal diffusivity of values 0.168W/mK and 0.089 mm²/s respectively were the lowest obtained for the epoxy matrix composite. It was also observed that addition of IOT in PP had significant effect on the thermal properties of the PP composite. Thermal conductivity and thermal diffusivity were found to increase with increased particle loading compared to the pure PP sample; the highest value being 2.235 W/mK and 5.51 mm²/s for thermal conductivity and thermal diffusivity respectively while low values of 0.05 Cm/W and 0.371 J/kgK was recorded for thermal resistivity and specific heat capacity. The presence of iron ore tailings reduces the thermal conductivity and diffusivity in epoxy but increases the conductivity and diffusivity in polypropylene.

Keywords- Composite, Epoxy, IOT, Polypropylene, Thermal Conductivity

1 INTRODUCTION

The functional requirement of a material is normally expressed in terms of its properties. Properties of materials are the link between basic structure, composition of the material and service performance. Various fillers such as fibers, talc, sisal, bamboo, coconut fur, jute, glass fibers, or particles are added to some plastic matrix materials to create plastic matrix composites (PMCs) in order to enhance, modify or advance their properties and application (Ouyang, 2005). Determination of viable properties of composites is a basic requirement for material selection and many engineering applications (Van Dommelen, Brekelmans, and Baaijens, 2003). These properties are affected by size, nature, and spatial distributions of the reinforcement (Ravichandran and Liu, 1995). Iron ore tailing (IOT) is a waste produced during exploration of Iron ore by mining industry. This exploration process lessens solid impurities bonded to iron ore, consequently, generating an ore of greater iron composition but leading to excessive percentage of tailings (Adepoju and Olaleye, 2001). The disposal or recycling of these waste materials have become an environmental problem (Brown and Milke, 2016) and there is a growing concern in search of its alternative use to produce high value added products (Hwang, 2015) putting it into significant use as fillers in matrix material can offer a way to solve these pollutant problem.

Several research works have been performed on the thermal behaviour of several materials. For instance, a study was done by Boudenne et al, (2005) on the electrical and thermal behaviour of copper particle filled polypropylene composite and the findings was evaluated in term of particulates size and volume ratio, stressed on the possibility of high heat transferal capacity of the composite including the smaller particles of polymer filled composites.

Onitiri and Akinlabi (2017) developed a model to experimentally analysed the impact of particulate size and volume loading on tensile strength and stiffness of epoxy and polypropylene filled with iron ore tailing (IOT) particles and the results were compared with different theoretical models. It was deduced from the result that the composites increased in stiffness as the volume content of the iron ore tailings particles were increased.

Katsura, Kamal and Utracki (1986) conducted a study on the properties of polypropylene polymer matrix filled with metallic fibers. The result of the work shows that at filler loading of 8 to 10 percent, the composite exhibit improved thermal conductivity. Also, the volume resistivity of the composite was around 10 ohm-cm which later dropped to a value of 1 to 2 ohm-cm at an inclusion of 20 % of steel fibers. Brito and Sanchez (2000), carried out an investigation on the effect of metallic fillers on the mechanical and thermal behaviour of epoxy matrix composites and their results showed that the 1:1 epoxy-amine ratio with no metallic filler has the highest breaking strength. Boron nitride (BN) was used by Watthanaphon et al (2012), as a functionality filler for boosting the thermal conductivity of Polypropylene (PP). It was discovered that Polypropylene filled with boron nitride composite with larger particle size and increased percentage loading have high conductive properties.

Valorization of ore tailings is significantly desired while composites with useful thermal properties will find application in a variety of industries. This paper report the thermal behaviour of epoxy and polypropylene (PP) matrix composites modified with iron ore tailings (IOT) particulate sizes of 150 µm, 212 µm and 300 µm at loadings of 5%, 10%, 15%, 20%, 25%, and 30%.
2 METHODOLOGY

2.1 MATERIALS
In the production of the two composite materials studied in this paper, the matrix materials were epoxy resin and polypropylene. The epoxy resin was produced by the reaction of epichlorohydrin and bisphenol A by the Adedolorunsho Technical Enterprises in Nigeria, and it was branded “virgin epoxy”. The pellet form of polypropylene (PP, brand name - SEETEC PP H1500), a homopolymer with a density of 0.91mg/m3 was manufactured by the Lotte Daesan Petrochemical Corporation, South Korea. The reinforcement was iron ore tailings (IOT), an irregular shape by-product of iron ore (Fe2O3) beneficiation plant in Itakpe, Nigeria.

The Epoxy and polypropylene matrix materials were made into different particle sizes of 150 μm, 212 μm, and 300 μm and mixed separately with IOT particles loading of 5%, 10%, 15%, 20%, 25% and 30%. Table 2 summarized the mixing ratios of the composites.

2.2 IRON ORE TAILINGS PREPARATION
The iron ore tailings used for the development of the polypropylene and epoxy matrix composites was dried for about 40 hours at room temperature prior to testing. Standard ASTM laboratory sieves was used for the gradation of the ore tailings into different particle size of 150 μm, 212 μm and 300 μm. Table 1 shows the chemical composition of the iron ore tailings as obtained in literature (Adedayo and Onitiri, 2012). The percentage filler loadings 5%, 10%, 15%, 20%, 25%, and 30% was adopted in this work.

2.3 DEVELOPMENT OF IRON ORE TAILINGS FILLED -EPOXY AND -POLYPROPYLENE COMPOSITES
The procedure for the development of iron ore tailings reinforced -epoxy and -polypropylene composites had been discussed elsewhere (Adedayo and Onitiri, 2012a) and (Adedayo and Onitiri, 2012b). The iron ore tailings loading is presented in Table 2.

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Table 1. Chemical Composition of the Iron Ore Tailings

| S/NO. | Composition             | (%)   |
|-------|-------------------------|-------|
| 1     | Moisture                | 0.1487|
| 2     | Total organic carbon    | 0.6442|
| 3     | Total organic matter    | 0.7598|
| 4     | Fe2O3                   | 0.2312|
| 5     | Copper                  | 0.0061|
| 6     | Zinc                    | 0.0018|
| 7     | Nickel                  | 0.0013|
| 8     | Sodium                  | 0.0051|
| 9     | Silicon oxide           | 61.4771|
| 10    | Calcium oxide           | 11.8924|
| 11    | Potassium               | 0.0012|
| 12    | Magnesium oxide         | 4.1640|
| 13    | Chromium                | 0.0017|
| 14    | Cadmium                 | 1.65E-06|
| 15    | Magnesium               | 0.0025|
| 16    | Aluminium oxide         | 20.6630|

Table 2. Experimental Layout

| Particle Size | Polypropylene P (%) | Epoxy E (%) | IOT Particle (%) | Code |
|---------------|---------------------|-------------|------------------|------|
| 100           | 100                 | 0           | 0                | A    |
| 150µm (B)     | 95                   | 95          | 5                | B5   |
| 85            | 85                   | 15          | 10               | B10  |
| 80            | 80                   | 20          | 20               | B20  |
| 75            | 75                   | 25          | 25               | B25  |
| 70            | 70                   | 30          | 30               | B30  |
| 212µm (C)     | 100                  | 100         | 0                | A    |
| 100           | 100                  | 25          | 25               | C10  |
| 85            | 85                   | 15          | 15               | C15  |
| 80            | 80                   | 20          | 20               | C20  |
| 75            | 75                   | 25          | 25               | C25  |
| 70            | 70                   | 30          | 30               | C30  |
| 300µm (D)     | 100                  | 100         | 0                | A    |
| 100           | 100                  | 20          | 20               | D5   |
| 90            | 90                   | 10          | 10               | D10  |
| 85            | 85                   | 15          | 15               | D15  |
| 80            | 80                   | 20          | 20               | D20  |
| 75            | 75                   | 25          | 25               | D25  |
| 70            | 70                   | 30          | 30               | D30  |

2.4 EXPERIMENTAL APPARATUS
The thermal behaviour of the composite was determined using thermal properties analyser (Decagon Devices Inc. with brand name KD2 Pro.) This experimental apparatus can be used for different types of materials such as polymers, rubber, glasses, ceramics, and composites including metals with low to moderate thermal properties.

KD2 Pro thermal properties analyser uses the transitory line heat source technique to determine the thermal diffusivity, thermal resistivity, thermal conductivity, and specific heat capacity of materials. The KD2 Pro is designed to measure specific sample types and it has three separate sensors. The approach employed by this apparatus is known as the transient line heat source where series of needle probes are used for transient line source measurements. The concept behind this technique is the infinitely small and long line source with constant heat rate. Equation (1) describes the temperature change of the source at a radial distance and time interval, t.

\[
\Delta T = \frac{q}{4\pi\alpha} E_i \left(\frac{-r^2}{4\alpha t}\right)
\]

where q is the heat at a constant rate, \( \lambda \) represents the thermal conductivity of the sample wherein the needle probe is fixed, \( \alpha \) is the thermal diffusivity of the sample, \( r \) is the radial path along the heat source while \( E_i \) is the exponential integral, a transcendental mathematical function. (Olukayode and Akinyemi, 2012).
A drill bit was used to make a hole on the epoxy and polypropylene composite and the sensor needle was inserted into the holes in the plastics composites. After making sure that all was set as it should be, the experiment was conducted and the measurements were taken.

3 RESULT AND DISCUSSION

Figure 2 demonstrates the relationship between the thermal properties of pure epoxy and polypropylene. The result shows that epoxy has higher thermal conductivity and thermal diffusivity compared to polypropylene while thermal resistivity was higher for polypropylene. The value for specific heat capacity was almost the same.

Figures 3-5 compares epoxy composites with those of pure epoxy. From figure 3, EB25 has the highest thermal conductivity with value 0.895 W/mK, while EB10 had the lowest value of 0.209 W/mK. For Thermal Diffusivity, EB25 has the highest value with 0.782 mm²/s and EB10 has the lowest value of 0.089 mm²/s. Specific heat capacity was highest for EB10 with 2.352 J/kgK but lowest for EB5 with value 1.303 J/kgK. Thermal resistivity is highest for EB5 with value 0.478 °C·cm/W and lowest for EB25 with 0.112 °C·cm/W.

It can be observed from figure 4 that composite EC30 had the highest value of 0.835 W/mK while EC5 had lowest of 0.835 W/mK for thermal conductivity. For Thermal Diffusivity, EC30 had the highest value 0.630 mm²/s and EC10 had the lowest of 0.276 mm²/s. The value for specific heat capacity was highest for EC30 with 1.326 J/kgK but lowest for EC5 with 0.283 J/kgK. Thermal resistivity is highest for EC5 with 0.596 °C·cm/W and lowest for EC30 with 0.120 °C·cm/W.

Figure 5 shows that composite ED5 had the highest value of 0.711 W/mK while EB15 had lowest value of 0.204 W/mK for thermal conductivity. For Thermal Diffusivity, ED5 had the highest of 0.864 mm²/s and ED20 had the lowest of 0.301 mm²/s. For specific heat capacity, the value was highest for ED20 with 1.323 J/kgK but lowest for ED15 is 0.366 J/kgK. Thermal resistivity is highest for ED15 with 0.490 °C·cm/W and lowest for ED5 with 0.141 °C·cm/W. From Figure 3-5 it can be deduced that increasing the filler loading of iron ore tailings tends to
reduce the thermal conductivity and diffusivity of the epoxy, this is due to weak cohesive force inhibiting the filler and the polymer matrix bonding. EB25, EC30 and ED5 falling outside the trend with increased properties could be attributed to strong interaction along the direction of heat flow that favours improvement of the thermal conductivity. Also, the particle size had significant impact on the thermal behaviour. Lowest particle size of 150µm had the highest specific heat capacity with optimal at EB10, this is as a result of increase in interfacial area resulting in thermal loss.

Figure 6 shows that composite PB20 had the highest value of 1.168 W/mK while PB30 had lowest value of 0.126 W/mK for thermal conductivity. For Thermal Diffusivity, PB20 had the highest of 0.597 mm²/s and PB10 had the lowest value of 0.116 mm²/s. For specific heat capacity, the value was highest for PB10 with 3.410 J/kgK but lowest for PB25 with 0.371 J/kgK. Thermal resistivity is highest for PB30 with value 0.470 °C-cm/W and lowest for PB20 with value 0.086 °C-cm/W. As seen from figure 7, PC5 had the highest value of 2.235 W/mK while PC30 had lowest value 0.223 W/mK for thermal conductivity. For Thermal Diffusivity, PC5 had the highest of 2.393 mm²/s and PC25 had the lowest value of 0.087 mm²/s. For specific heat capacity, the value was highest for PC25 with 6.644 J/kgK but lowest for PC5 with 0.934 J/kgK. Thermal resistivity is highest for PC30 with value 0.448 °C-cm/W and lowest for PC5 with 0.045 °C-cm/W.

Figure 8 shows that composite PD15 had the highest value of 2.021 W/mK while PD20 had lowest value of 0.260 W/mK for thermal conductivity. For Thermal Diffusivity, PD15 had the highest with 5.510 mm²/s and PD30 had the lowest value with 0.234 mm²/s. For specific heat capacity, the value was highest for PD5 with 2.734 J/kgK but lowest for PD15 with 0.376 J/kgK. Thermal resistivity is highest for PD20 with value 0.384 °C-cm/W and lowest for PD15 with value 0.376 °C-cm/W. Figure 6-8 shows that the presence of fillers led to improvement in the thermal conductivity and thermal diffusivity of the composites and this is as a result of the strong bond between the particulate fillers and the polymer matrices, and filler cohesion resulting in better surface contact. The value of thermal conductivity was high for PB20, PC5 and PD15 because of strong interaction along the path of heat flow. Likewise, a slight reduction in thermal conductivity of PD20 is attributable to the large particle size which results in reduction in the surface area of particles contacting each other. Particle size of 212µm had the highest specific heat capacity. Figure 3-8 shows some inconsistency in trend which is due to the heterogeneous nature of the filler (See Table 1) with a significant impact on the behaviour of the composite produced.

4 CONCLUSION

The result obtained for all epoxy composites showed that the inclusion of iron ore tailing fillers leads to reduction in the thermal diffusivity and thermal conductivity of epoxy. This could be attributable to the weak interfacial connection between the particulate inclusion and the polymer matrix. Epoxy composite with particle size 150µm at 25% loading, 212 µm at 30% and 300 µm at 5% with thermal conductivity 0.895 W/mK, 0.835 W/mK and 0.835 W/mK respectively falls outside the trend which implies a strong connection at the filler-matrix interface along the path of heat movement that favours improvement of the thermal conductivity. In contrast, that the addition of iron ore tailing fillers tends to increase the thermal conductivity and thermal diffusivity of polypropylene owing to the strong filler-polymer matrix interface interaction. The value for thermal conductivity was highest for polypropylene with particle size 212 µm at 5% with
2.235 W/mK and lowest for particle size 150 µm at 30% with 0.126 W/mK. The result for thermal diffusivity was found to be directly proportional to the thermal conductivity but inversely proportional to thermal resistivity and specific heat capacity which conformed with the relation stated by (Rutkowski et al, 2013). The particulate filler of 5% volume content and 212 µm size is the perfect blend that can be added to polypropylene to enhance a better thermal conductivity and diffusivity. Epoxy composite can be applied for thermal insulation because of the low conductive properties.

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