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Evaluation of the Mechanical and Electrical Properties of Carbon Black/Carbonized Snail Shell Powder Hybridized Conductive Epoxy Composite

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ABSTRACT

In this present study, the mechanical and electrical properties of carbon black/carbonized snail shell powder reinforced epoxy composite were investigated. The composites samples were prepared according to ASTM International standards, with fillers (carbon black and carbonized snail shells powder) partial replacement, at a proportion of: 2 wt%, 4 wt%, 6 wt%, 8 wt%, and 10 wt%. The tensile, electrical resistivity and electrical conductivity properties of the produced composite samples were determined according to ASTM D 3039, ASTM B193 and ASTM D6343 – 14 recommended procedures. Results obtained from the laboratory tests revealed that the tensile strength of the composite samples was enhanced up to 8wt% loading, before it started to decline. While the electrical resistivity and electrical conductivity of the composite samples were enhanced up to 6 wt% loading, before they started to decline. The lowest tensile strength (28.5 MPa) was recorded at 2 wt% fillers loading; while the highest tensile strength (58.4MPa) was recorded at 8 wt% fillers loading. Similarly, the electrical resistivity of the composite produced with 6 wt% filler loading had the lowest electrical resistivity of 425000Ωm; while the composite produced with 10 wt% fillers loading, had the highest electrical resistivity of 492000Ωm. Additionally, the composite sample produced with 6 wt% fillers loading, had the highest electrical conductivity of 2.35 x 10^{-6} S/m; while the composite sample produced with 10 wt% fillers loading, had the lowest electrical conductivity 2.03 x 10^{-6} S/m. This study results had revealed that, if the fillers volume in a composite was controlled, then the mechanical and electrical properties of composite samples can be controlled.

Keywords: Carbonized, electrical properties, hybridized, mechanical properties, snail shell

INTRODUCTION

Composite is the combination of two or more materials (primary reinforcement) and a matrix, which are combined in a specific ratio to produce a new material. The new material produced (composite), usually exhibit a wide range of engineering properties; which are in most cases, superior to the engineering properties of the individual constituents (Lee and Waas, 1999). The primary reinforcement materials can be synthesized materials (carbon fibre, glass fibre, Boron fibre, etc.) or natural materials (animal fibres, plant fibres, etc.). The utilization of plants fibres in composite production has become a growing trend recently, due to their biodegradability, availability, non-toxicity and acceptable engineering properties.

The global increment in the demand of electrical materials, had led to an increased demand for improvised materials; having high mechanical properties, improved dielectric strength, high dielectric constant, high resistivity, lower density, lower costs, light weight etc. (Omah *et al*., 2018). According to Edafiadhe *et al*. (2019), agricultural materials and other natural fillers (powder) reinforced epoxy or polyester composites are widely utilized in engineering applications. Epoxy resin, which is one of the commonly used matrix in composite production, is widely used in the electrical materials production, due to their good mechanical and electrical properties, durability, and high resistance to chemical attacks (Composites, 2016). Appropriate utilization of suitable agricultural waste and other natural fillers in composite production, will lead to the production more suitable electrical/electronic components. Giant African snail (*Achatina achatina*) is a wild animal that thrives in damp areas (Adeyemo and Borire, 2002). The shell of a matured giant African snail contained about 90% Calcium Trioxocarbonate (IV) (CaCO3), and a minute amount of sodium oxide (Na_2O) and silicon dioxide (SiO_2) (Tepsila and Suksri, 2018).

Researches on fillers/epoxy reinforced composite dielectric systems are gathering momentum due to their preferred electrical properties (Singha and Thomas, 2008). Conductive composites have numerous engineering applications, but their electrical properties are influenced by the volume of the conductive filler (s) used Li *et al*. (2008). The use of large volume of the conductive fillers in conductive composites production helped to satisfy the high electrical conductivity requirements; however, excess filler volume can negatively affect the mechanical and electrical properties of the composites, due to weak interaction between the matrix and the fillers (Yi *et al.*, 1998). Previous studies results had shown that fillers reinforced epoxy composites can be used confidently in the production of electrical/electronic components, due to their improved mechanical and electrical properties. According to Yung *et al*. (2010) aluminum nitride/ boron nitride/hollow glass microsphere reinforced epoxy composite, had better thermal conductivity and dielectric properties; which varied directly to the volume and composition of the fillers. Shu-Hui *et al*. (2004) reported that aluminum nitride powder reinforced polyimide matrix composite, developed a better thermal and electrical properties; as their thermal conductivity and dielectric constant were enhanced. Dutta *et al*. (2007) studied some electrical and dielectric properties of polypyrrole–silica reinforced composites. They reported that the values of the electrical conductivity varied with increment in the reinforcement volume and the temperature of the composite. Ayatollahi et al. examined the influence of carbon nanotubes (CNT) aspect ratio on the electrical conductivity of CNT powder reinforced epoxy composites, and observed that the CNT powder containing higher aspect ratio had the presented higher electrical conductivity (Ayatollahi *et al*., 2011). The effect of calcium carbonate in Polypropylene/CNT nanocomposites were studied by Bao (2008), and reported that the reinforcement of the composite with calcium carbonate reduced the electrical percolation threshold in PP/CNT nanocomposites (Backes *et al*., 2018).Omah *et al*. (2018) investigated the electrical properties of pulverized cattle bone reinforced epoxy composite; and the authors reported that electrical resistivity of the composite produced decreased as the cattle bone powder volume increases. Tepsila and Suksri (2018) reported that electrical properties of natural fillers reinforced composites were better, than those of inorganic fillers reinforced composites. They stated that the composite produced using 30% organic filler had better insulating properties, when compared to the composite produced using 30% of inorganic filler volume. Electrical resistivity and conductivity of materials are vital factors that determined the application of the material in the electrical field. This is because the electrical resistance of any material is highly influenced by the electrical resistivity of the material (Omah *et al*., 2018).

Concerning the mechanical properties of natural fillers reinforced epoxy composites, several researchers have on it. Navdeep *et al*. (2012) and Uguru and Umurhurhu (2018) reported that chemical treatment of the natural fillers enhanced the interface cross linkages of the fillers; therefore, increasing their mechanical properties. Nyior *et al*., (2018) stated that sodium hydroxide (NaOH) modification of raffia palm fibre, increased the tensile strength of the hybrid raffia palm fibre/groundnut epoxy composite from 1.88 MPa to 9.56 MPa; while the composite Modulus of rupture (MOR) increased from 1.92 MPa to 41.6 MPa. According to Lopattananon et al. (2008), alkali (5% w/v NaOH solution) modification of PALF increased the shear strength of the PALF reinforced epoxy composite by about 100% , which they attributed to the enhanced interfacial adhesion of the modified PALF. Furthermore, alkali treated PALF at loading of 30%, caused significant increase in the flexural strength, tensile strength, and impact strength of PALF reinforced polyester composite. Carbon nanotubes (CNT)/ carbon fiber (CF)hybrid epoxy composite had been reported to have better mechanical properties, with Young's modulus ranging between 0.27TPa and 0.95 TPa, and the tensile strengths ranging between of 11GPa and 63 GPa (Hanizam *et al*., 2019).John and Samuel(2010)investigated the prospective of using carbonized bagasse as reinforcement material in composite production, and observed that as the filler volume increased the tensile strength, abrasion resistance, and hardness of the composite increases. Although numerous researchers have discovered that using natural fillers can improve the engineering properties of epoxy composites. However, information on the hybridization of carbon black and carbonized snail shells powder in composite production is still scanty. Therefore, the main objective of this research is to evaluate the mechanical and electrical properties of carbonized giant African snail shells powder and carbon black reinforced epoxy composite.

MATERIALS AND METHODS

Materials

The Giant African snail shells

The snail shells were obtained from a local food vendor at Ughelli, Delta State, Nigeria. The snail shells were sorted and the premature shells were removed

The Matrix

The Epoxy (LY 556) and hardener (HY951) used for this study were purchased from local chemical shop, located at Ughelli, Delta State, Nigeria.

Carbon black

The carbon black used for this study was purchased from local chemical shop, located at Ughelli, Delta State, Nigeria.

Methods

Snail Shells Preparation

The giant African snail shells were washed under pressurized running tap water, to remove all the sand and other dirt. Then the washed snail shells were oven-dried at 100^{0}C for 10 hours to remove all moisture content. The dried snail shells were later carbonized at a temperature of 700°C, before they were pulverized using a high powered plate mill. The pulverized snail shells were then sieved with a 150 µm gauge stainless steel sieve to obtain fine powder.

Configurations of the composite sample

The required materials were weighed out using an electronic weighing balance. The composite samples were produced with primary reinforcement fillers (carbon black and carbonized snail shells powder), at volume proportions of: 2wt%, 4wt%, 6wt%, 8wt%, and10wt%, as presented in Table 1. The reinforcement fillers (carbon black and carbonized snail shell powder) were prepared, by mixing the carbonized snail shell powder and the carbon black in the ratio of 1:1. Then the matrix used for the composite produced was prepared by mixing the epoxy resin and the hardener together at a ratio of 8:2.

Table 1: Compositions of the epoxy composite samples

Code	Constituents
Sample 1	98% matrix + 2wt% of powder loading
Sample 2	96% matrix + 4 wt% of powder loading
Sample 3	94% matrix + 6wt% of powder loading
Sample 4	92% matrix + 8wt% of powder loading
Sample 5	90% matrix + 10wt% of powder loading

Composite Preparation

The composite samples were prepared by the simple hand lay-up technique. A wooden mould of dimension 150 × 20 × 3 mm^3 was used for the casting. Wax was first applied to the mould, to facilitate the discharge of the composite from the mould. In the composite production, measured quantity of snail shells powder, carbon black and the matrix were poured into a container and stirred carefully for 20 minutes to obtain a near homogeneous mixture. Then, the right volume of the hardener was added to the mixture, and then stirred carefully again for and 10 minutes. The mixture was then poured into the already prepared mould, and was placed under a dead load of 15kg at ambient temperature for 12 hours. This is to expel any entrapped air from the composite, during the setting period. After 12 hours, the composite produced was stripped off from the mould and cured at ambient room temperature for one week.This procedure was repeated for other specimen as shown in Table 1 with changes in the weight percentages of the carbonized snail shells powder and carbon black.

Mechanical Testing

Tensile test

The tensile properties of the composite were determined by using the Universal Testing Machine (Testometric model), according to ASTM D 3039 (2017) standards. The machine was pre-set at a loading speed of 1 mm/min. During the test, the sample was clamped between the two jaws of the machine, and pulled slowly (at the speed of 1 mm/min) until the rupture point (Figure 1). As the tension continued, a force-deformation curve was plotted by the machine, and displayed on the screen attached to the machine. From the curve, the tensile strength and percentage elongation were mined automatically, by the microprocessor attached to the machine. The tensile strength and tensile elongation were calculated using equation 1 and 2, as described by Abdullah-Al-Kafi*et al*. (2006).

$$Tensile\ Strength\ (\sigma) = \frac{F_{Max}}{Area} \quad (1)$$

$$Tensile\ Elongation = \frac{\Delta L_b}{L_o} \times 100 \quad (2)$$

Where:

F_{max}= Maximum force absolved by the sample at rupture point

$d\sigma$ = Stress at rupture point;

$d\varepsilon$ = Strain at rupture point;

ΔL_b = Extension at rupture point;

L_o = Original length of the sample..

Figure 1: The composite undergoing tensile test

Electrical Testing

Determination of Electrical Resistivity of the composite

The electrical resistivity of the composite was measured by using the Digital Insulation Tester, in accordance with ASTM B193 (2020) approved procedure. The composite sample was cut into a rectangular shape of 100 mm x 10 mm x 5 mm, with a 2.5 mm^2 copper cable (length = 10 mm) placed at each end of the composite sample. After the circuit had been secured, the resistance of the composite was read from the screen of the insulation tester, the electrical resistivity was calculated using the expression in Equation 3 (Omah *et al*., 2018).

$$\text{Electrical resistivity} = \frac{R \times A}{L} \quad (3)$$

Where:
R = Resistance (Ω),
A = Cross-sectional area (m^2),
L = Length ofthe composite sample

Determination of Electrical Conductivity of the composite

Electrical conductivity is expressed as a percentage of the conductivity of the sample. The electrical conductivity of the composite samples was measured according the procedures approved by ASTM D6343 – 14(2018), for composites and insulating materials. Then the electrical conductivity values of the composites were calculated using the equation 4.

$$Electrical\ conductivity\ (s/mm) = \frac{1}{R} = \frac{L}{rA} \quad (4)$$

Where:
R = resistivity of the composite (Ωm),
r = resistance of the composite (Ω),
A = cross-section area of the composite (m^2),
L = length of the composite (m)
All the tests were conducted at ambient laboratory temperature of 28±4^{0}C with relative humidity of 85±5%.

RESULTS AND DISCUSSION

Tensile Properties of the Composite

The results showed that the hybridization of carbon black and carbonized snail shell powder had significant effect on the tensile properties of the epoxy composite.

Tensile Strength

The results of the tensile strength, of the carbon black and carbonized snail shell powder reinforced epoxy composite, are presented in Figure 2. As revealed by the results, the tensile strength of the composite increased non-linearly, as the filler volume increased from 2 w% to 10 wt%. According to the study results (Figure 2), the lowest tensile strength (28.5MPa) was recorded at2 wt% fillers loading; while the highest tensile strength (58.4MPa) was recorded at 8wt% filler loading. Similarly, at 4wt%, 4 wt%, 6wt% and 10wt% fillers loading, the composites developed tensile strength of 39.2 MPa, 51.8 MPa and 52.9MPa, respectively. This revealed that after 8 wt% fillers loading, the compressive strength of the composite started to decline. The decline in the compressive strength of the composite after 8 wt% fillers loading, can be attributed to the non-intercalation of the carbon black power with the matrix (epoxy). According to Bera *et al.* (2018), high volume of carbon black in epoxy matrix can prevent the easy interaction of the carbon black filler with the matrix; hence, leading to the formation of weaker bonding and poorer interface of the epoxy and fillers, which reduces the tensile strength of the composite produced. These results revealed that the combination of carbon black and carbonized snail shell powder can be used to improve the tensile strength of composite samples. This study results were similar to those previously obtained by Imoisili *et al*. (2013) for rice husk/carbon black hybrid natural rubber composite. In addition, Uddin and Sun (2008) as observed that the incorporation of nano silica in epoxy resin increased the tensile strength and elastic modulus in the polymeric composite produced.

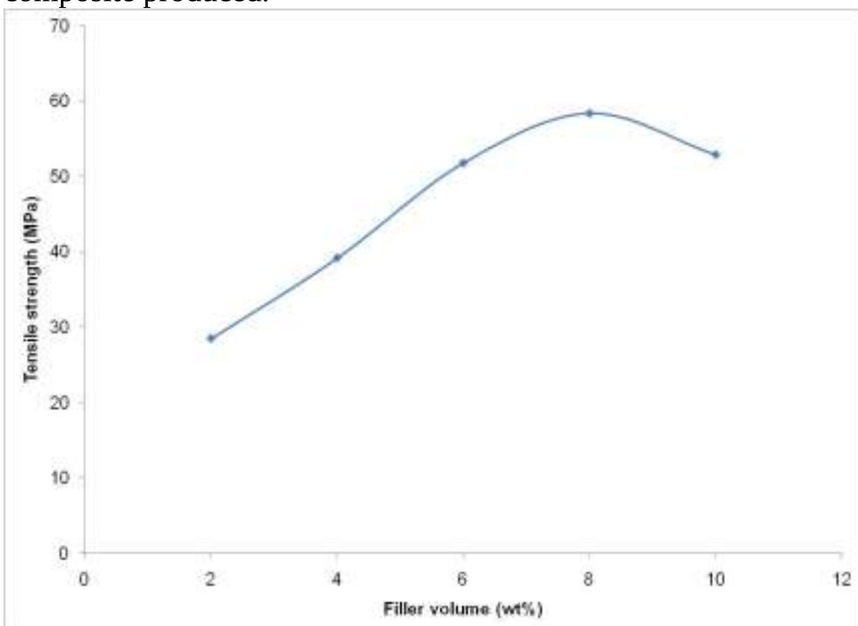

Figure 2: Relationship between filler volume and the tensile strength of epoxy composite

Tensile Elongation

The relationship between the fillers volume and the tensile elongation of the epoxy composite is given in Figure 3. Figure 3 clarified that the volume of the carbon black and carbonized snail shells powder had effect on the tensile elongation of the hybridized epoxy composite. The tensile elongation values composite increased linearly, as the fillers volume increased from 2 wt% to 6wt%; then it stated to decrease linearly, as the fillers volume increased from 6wt% to 10 wt%. As revealed by the results (Figure 3), the highest tensile elongation (40.1%) was recorded at 6wt% fillers loading; while the lowest tensile elongation (34.9%) was recorded at 10wt% filler loading. According to the results, as the fillers volume increased from 2 wt% to 6wt%, the tensile elongation increased from 35.3% to 40.1%.While as the fillers volume increased from 6wt% to 10 wt%, the tensile elongation decreased from 40.1% to 34.9%. This revealed that the addition of the fillers enhances the ductility of the composite up to a point (6wt%); after which, the ductility of the composite stated to decline, as the fillers volume increases from 6wt% upwards. Radzuan *et al*. (2017) reported that high volume of carbon-based materials in a composite after a certain level; usually lead the deterioration of the mechanical properties of the composite board.

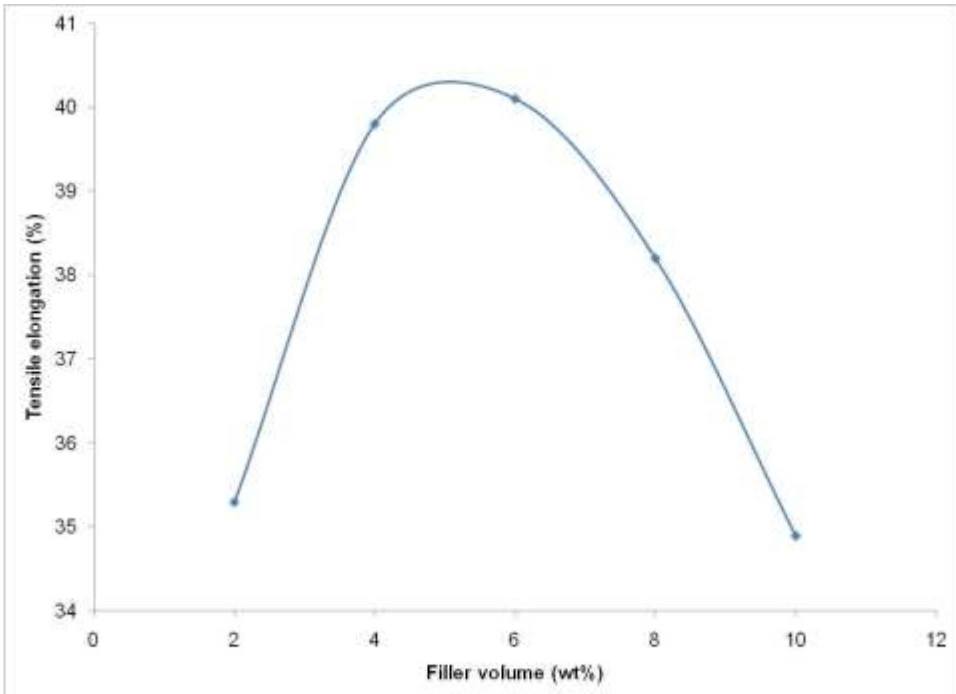

Figure 3: Relationship between filler volume and the tensile elongation of epoxy composite

Electrical Properties of the Composite

Electrical resistivity

The electrical resistivity of the various composite samples is presented in Figure 4. As shown in Figure 4, the electrical resistivity of the composite samples decreased linearly, as the carbonized snail shells powder and carbon black volume increased from 2 wt% to 6 wt%, before it increased sharply up to 10 wt%. The results revealed that at hybrid volume of 6 wt%, the composite produced developed the lowest electrical resistivity of 425000Ωm; while at 10 wt%, the composite had the highest electrical resistivity of 492000Ωm. It was observed from the results that the electrical resistivity of the composite samples, reinforced with 2wt%, 4wt% and 8wt%had electrical resistivity of 454000 Ωm, 450000Ωm and 452500Ωm, respectively. These results clearly revealed that, by increasing the volume of the carbonized snail shells powder in the composite sample, the electrical resistance of sample of decreases down to a point (6 wt%), before the resistance of the composite stated to increased. A low resistivity indicates a material that readily allows electric current. Similar results were obtained by Melnyk (2017) for carbon nanotubes reinforced epoxy composite, as the resistances decreases as the carbon nanotubes volume increased from 0% to 2.5%. According to Omah *et al*. (2018) the electrical resistivity of cattle bone fillers reinforced epoxy composite decreased from 7800 x 10^6Ωmmto 6200 x 10^6Ωmm as the cattle bone fillers volume in the composite increased from 40% to 60%. Zhou *et al*. (2009) reported that increasing the volume of the non-conductive fillers in a composite, will resulted to a decline in the dielectric constant, as the electrical system becomes more heterogeneous. Electrical resistivity of a composite depends on: the average size of the composite, the concentration of the active centers on the surface of the reinforcing material(s), concentration of non-conductive reinforcing material(s), temperature and humidity of the prevailing environment, etc. (Melnyk, 2017).

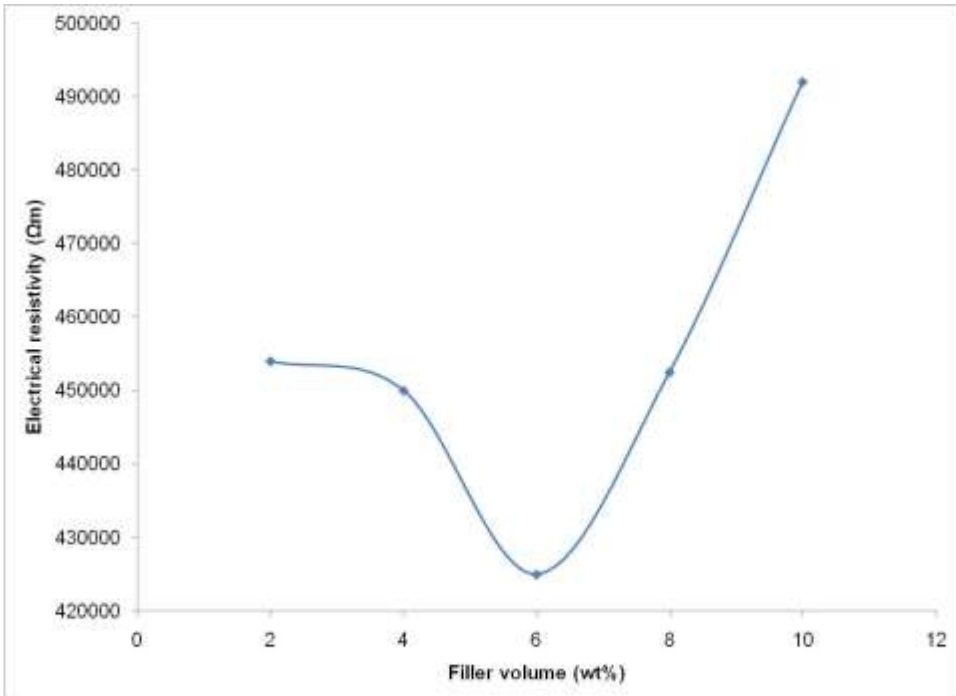

Figure 4: Effect of snail shells powder volume on the electrical resistivity of epoxy composite

Electrical conductivity

The results of the electrical conductivity of the composite are presented in Figure 5. As shown in figure 5, the electrical conductivity of the composite increased sharply, as the fillers concentration increased from 2 vwt% to 6 wt%; and dropped abruptly as the fillers volume increased from 6 wt% to 10 wt%. It was observed from the results that, the reinforcement of the epoxy matrix, with combination of the carbon black and the carbonized snail shell powder above 6wt%, resulted in a decline in the electrical conductivity of the composite. The decline observed in the electrical conductivity of the composite samples, after 6 wt% powder loading can be attributed to the higher amount of voids created in the composites, due to the weak interaction between the matrix and the fillers. According to Mehta and Cooper (2003), the presence of large volume of fillers in composite, can lead to greater mixture viscosity, which will cause formation of voids within the composite. This is more obvious, when the filler(s) volume surpassed the bonding capacity of the matrix. As seen in the results, the composite containing the 6 wt% carbon black and carbonized snail shell powder, exhibited the best balance of electrical properties. Similar results were obtained by Lee *et al*. (2009), when the carbon fillers loading of 5 vol% was critical loading concentration. According to Dhakate *et al*. (2009), increasing the amount of carbon black in a polymer composite above the critical point (7.5 vol%), can led to decline in the electrical conductivity of the composite as the wetting of the filler became poorer. Taherian *et al.* (2013) stated that in order for a composite material to be electrically conductive, the concentration of the conducting phase must be above the percolation threshold (Suherman *et al*., 2013; Radzuan *et al.*, 2017). These results clearly revealed that, by carbonized snail shell powder can be used as a substitute for carbon black during the production of conductive polymer composite. According to Lee *et al*. (2009), reinforcing polymer composite with hybrid fillers, usually resulted to increase in their electrical and mechanical performances mostly, in bipolar plate applications.

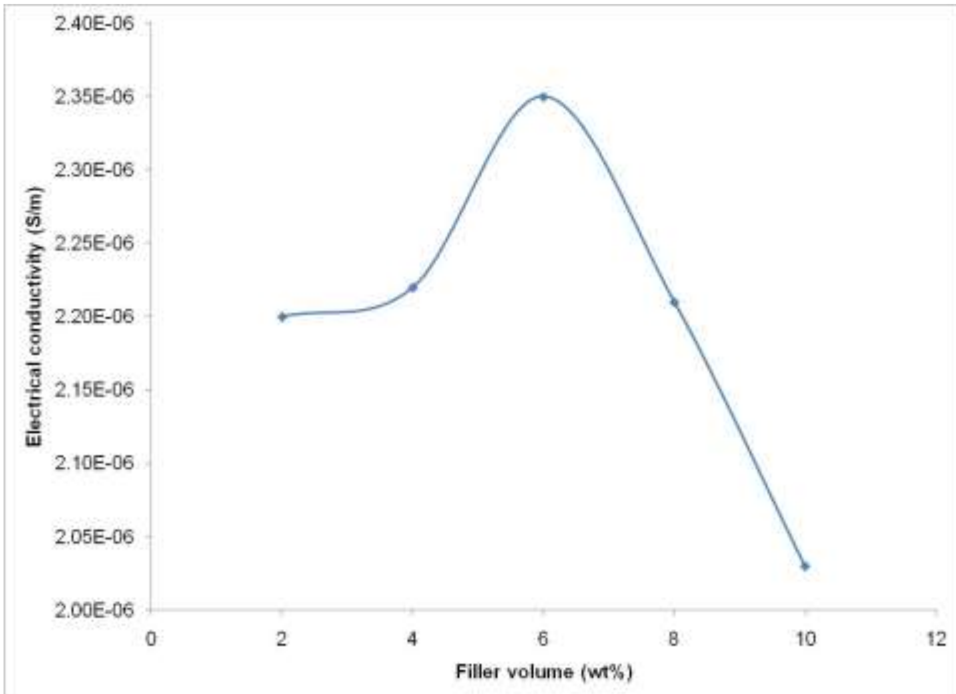

Figure 5: Relationship between filler volume and the electrical conductivity of epoxy composite

CONCLUSION

Some mechanical and electrical properties of epoxy resin reinforced with difference volume of carbon black and carbonized snail shells powder were investigated in this research work. Composite samples were produced with primary reinforcement fillers (carbon black and carbonized snail shells powder), at a volume proportions of: 2 wt%, 4 wt%, 6 wt%, 8 wt%, and 10 wt%. The tensile, electrical resistivity and electrical conductivity properties of the produced composite samples were determined according to ASTM D 3039, ASTM B193 and ASTM D6343 – 14 recommended procedures. Results obtained from the laboratory tests revealed that the mechanical properties, such as the tensile strength of the composite samples reinforced with the fillers, was enhanced up to 8 wt% loading, before it started to decline. The incorporation of 6 wt% of the fillers into the epoxy matrix gave the best electrical resistivity of the composite samples produced. Similarly, the results showed that incorporating of 6 wt% of the fillers into the epoxy matrix gave the maximum electrical conductivity; while incorporating of 10wt% of the fillers into the epoxy matrix gave the minimum electrical conductivity. This study results had revealed that, if the fillers volume in a composite was controlled, then the mechanical and electrical properties of composite samples can be controlled. This research results had shown that the utilization of snail shell in the production of conductive composite, can add value to agricultural wastes; hence help in waste management.

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