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Physical-mechanical properties of palm kernel activated carbon reinforced polymeric composite: Potential as a self-lubricating material

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KEYWORDS

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ABSTRACT

Palm kernel activated carbon is one of the potential self-lubricating materials. Therefore, in this study the effect of palm kernel activated carbon composition on the physical-mechanical properties of palm kernel activated carbon reinforced polymeric composite was investigated. The polymer resin was reinforced with 65%, 70% and 75% by weight of the activated carbon and compacted into a die at 70 °C with 20-ton pressure for 15 minutes by using compaction technique. The specimens were prepared for conducting of tensile, hardness, porosity, density and water absorption tests. The 65% sample had the most excellent properties in term of hardness and had the lowest density, but not in terms of tensile test as compared with the other two compositions' samples. This sample also had proven its superiority in terms of hardness and density compared with that of other synthetic-natural reinforced polymeric composites.

1.0 INTRODUCTION

Malaysia has lots of agricultural waste products which can be utilized by researchers as low-cost materials which are in demand especially in developing countries (Abdullah et l., 2011).

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The use of agricultural wastes in activated carbon industries would be favoured as it is economical and environmentally friendly. Huge amounts of palm kernel and coconut shells are produced as agricultural wastes in Malaysia. The utilization of these wastes as carbon precursor is very promising. Activated carbon as formaldehyde absorbent has been studied by various experts, for use as a bio-scavenger for decreasing formaldehyde emission from melamine formaldehyde resin (Kim and Kim, 2006). The activated carbon acts by absorbing release formaldehyde from the wood panel (Darmawan, 2010). Today's advanced technology can simulate test models in the design process for technical insight in order to reduce weight and material cost (Hubalovsky, 2013).

These wastes can also be used to produce fibre reinforced polymeric composites for commercial use, especially in automotive and packaging materials, benefitting from agricultural wastes by being renewable resources and having marketing appeal as another important economic resource.

Furthermore, increasing global awareness about the environment and social concern, depletion of petroleum resources and new environmental regulations have prompted scientific researchers to look for new alternatives to replace traditional polymeric composites with ''Eco composites'' or ''green composites'' substitutes which have lower environmental impact, low cost, outweigh strength requirements, lightweight, non-toxic, non-abrasive and have low density. Polymeric materials have also been known widely to have impressive adhesion to different types of substrates, high chemical and electrical resistance, and can endure high or low temperatures (Uygunoglu et al., 2015). Other benefits of polymeric composites which can replace metals are higher fatigue strength and good corrosion resistance (Banakar et al., 2012).

In general, polymer materials have weak physical-mechanical properties compared with metals or ceramic materials. Therefore, polymer resins are reinforced by natural fillers (fibres, particles or powders) by plant sources (Shuhimi et al., 2016). The properties can be modified by using activated carbon particles to suit high strength/high modulus requirements (La Mantia and Morreale, 2011).

These composite materials can also fail easily due to mechanical damage which relate to tension, flexural and compression. Thus, using material with higher damage tolerance and sufficient mechanical evaluation is very crucial to reducing the problems (Banakar et al., 2012). Cracking, low toughness and low tensile strength have caused poor durability, and this results in increased maintenance cost of the composite material (Yang et al., 2017).

The composition of engineering material and surface modification have resulted in a big contribution in improving mechanical properties performance of composites (Abdullah et al., 2011; Mushtaq and Wani, 2017). Most engineering composite materials made up of carbon reinforcement in thermosetting epoxy polymer which were required in applications have had a huge upgrade in recent days (Banakar et al., 2012).

In addition, polymeric composites usually use epoxy resin as thermoset material because it has good chemical and insulation properties, as well as good bonding strength with other materials (Uygunoglu et al., 2015). According to some researchers, the combination of graphite or carbon with other materials can produce great potential in producing composites useful in reducing wear and friction. The production of activated carbon of palm kernel with high porosity as reinforcement in polymer matrix to function as self-lubricated material has been tested by Chua et al. (2014); and is available at affordable costs. The uses of palm kernel activated carbon reinforced polymeric composite has potential in replacing the current high-cost commercial self-lubricated material because it has a low friction coefficient value (Tahir et al., 2016).

Furthermore, the enhancement of the tribological performance of this new solid lubricant material can contribute tremendously to reducing production costs as well as improving machining process efficiency (Shankar et al., 2017).

Palm kernel activated carbon reinforced polymeric composite is a novel composite which has good tribological properties with high resistance to friction and low wear rate at different temperatures and loads (Tahir et al., 2016). However, no previous studies in literature have focused on the physical-mechanical properties of activated carbon from palm kernel as reinforcement in polymer matrix materials. The absence of physical-mechanical properties reduces the chances of use in other applications. Thus, it is necessary to study the influence of reinforcement content on physical-mechanical properties to suit high strength/high modulus requirements, with a probability of employment in other diverse applications.

2.0 METHODOLOGY

2.1 Material preparation

The palm kernel waste in the form of activated carbon was crushed and sieved into 300μm in size and was mixed with a binder known as high-density epoxy [West system 105 epoxy resin (105-B) and West system 206 slow hardener (206-B)]. A sample was formed in 15 minutes of heating by using compression technique, 10 minutes of cooling and 3 days of curing process. Then, the sample could proceed to be tested. This study was concerned with three percentages of polymeric composite, which were 65-35%, 70-30% and 75-25% of palm kernel activated carbon and epoxy. These samples were validated according to the Taguchi method.

2.2 Physical-mechanical testing

2.2.1 Tensile test

Tensile test of polymeric composite samples is usually carried out according to the ASTM D3039 / D3039M-17 standard. In this test, the tensile strength, Young's modulus and strain of palm kernel activated carbon reinforced polymeric composite were determined. In order to do so, an Instron universal testing machine was utilized for tension, compression, bending and component testing, with 250 kN capacity, 0.001-500 mm/min speed range, 1256 mm x 575 mm test area and controlled by Bluehill 3 software with reference to the standard mentioned above. The specimens' sizes were classified with dimensions of 250 mm length, 25 mm width, and 2.5 mm thickness. The speed of testing was according to the standard strain rate of 1 mm/mm during the test.

2.2.2 Hardness test

Hardness property of palm kernel activated carbon reinforced polymeric composites was determined using a digital shore scale "D" with reference to the ASTM D2240-15e1 standard.

The test measured the penetration of a specified indenter into the material under specified conditions of force and time. Readings were taken immediately after application and could be switched from those taken after the weight had been controlled for an extended period, due to creep in.

2.2.3 Density test

In this test, the density of palm kernel activated carbon reinforced polymeric composites was determined, by measuring each of specific gravity and the total volume of the samples using an electronic densitometer. The electronic Densimeter gives very precise calculations on the specific gravity of an object of any shape whatsoever.

2.2.4 Porosity test

The porosity test of the palm kernel activated carbon reinforced polymeric composite was performed using an electronic densitometer and the porosity calculations of the specimens were calculated based on Archimedes' principle.

2.2.5 Water absorption test

Water absorption properties of the palm kernel activated carbon reinforced polymeric composites (65-35%), (70-30%), and (75-25%) had been analysed according to the ASTM D570-98(2010)e1 standard. The initial weight of each specimen was taken before immersing into the water by electronic balance, which is capable of reading to an accuracy of 0.0001 g. Samples were then immersed in the sterile water maintained at a temperature of 23 ± 1°C for a certain period to determine the specific weight.

In this test, the dimensions of the specimens (rectangular bar) for the water absorption test were 76.2 mm in length, 25.4 mm in width and 3.2 mm in thickness. All the samples were dried in an oven for 1 hour at 105 °C to remove moisture content before immersing in sterile water. The specimens were then taken out at different intervals during the total period of each specimen's immersion (528 hours), and then wiped off with a dry cloth.

3.0 RESULTS AND DISCUSSION

3.1 Tensile strength

The results of the tensile test were as shown in Figures 1 and 2. From the tensile test, the elastic modulus has been determined for the different compositions. In Figure 1, the increase of activated carbon percentage formed a stronger bonding from 65% to 70%. Based on Arash et al. (2015), the weight percentage or ratio can increase the elastic modulus of a composite. Unfortunately, after the addition of another 5% of activated carbon, the value of elastic modulus decreased immediately. This may have been due to the weak interfacial bonding between the particles. According to Uygunoglu et al. (2015), elastic modulus is mainly affected by the interfacial adhesive bond. Besides this, it could also have been caused by high distribution of voids due to low amounts of epoxy resin used to hold the activated carbon particle.

Figure 2 illustrates the ultimate tensile stresses of the composites with different ratios of palm kernel activated carbon (65%, 70%, and 75%) with the polymer epoxy. It was observed from Figure 2 that there was little difference between the ultimate tensile stress values of 65-35% and 70-30%. However, it was apparent that there was a big difference in the ultimate tensile stress value with a proportion of 75% activated carbon, as a result of poor dispersion and weak bonding of the carbon with the resin matrix of this composite. The 75% samples appeared to be more brittle material since some of the specimens of 75% failed in the elasticity region. Although the ultimate tensile strength of 75% was not much different compared to 65%, the composition of

70% could withstand the maximum load of 1306N which was the highest load among the compositions.

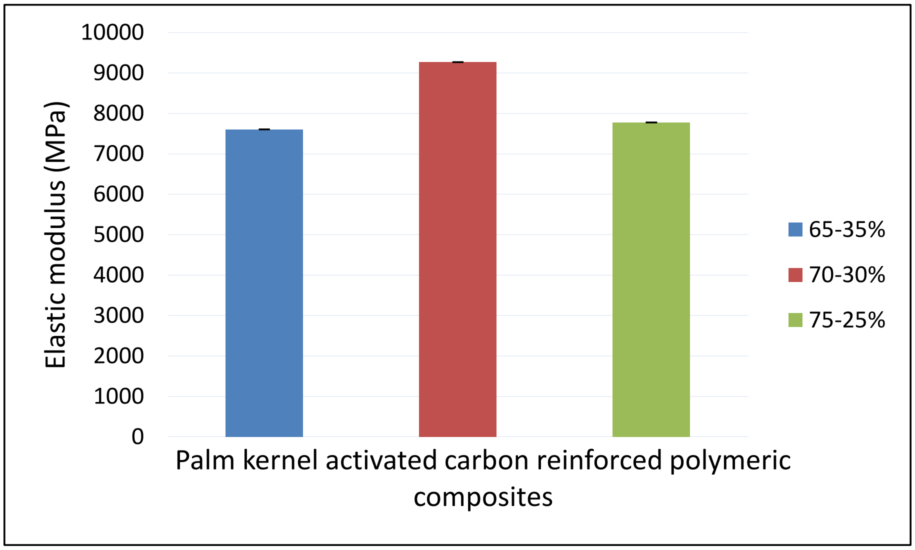


Figure 1: Average elastic modulus of palm kernel activated carbon reinforced polymeric composite at different compositions.

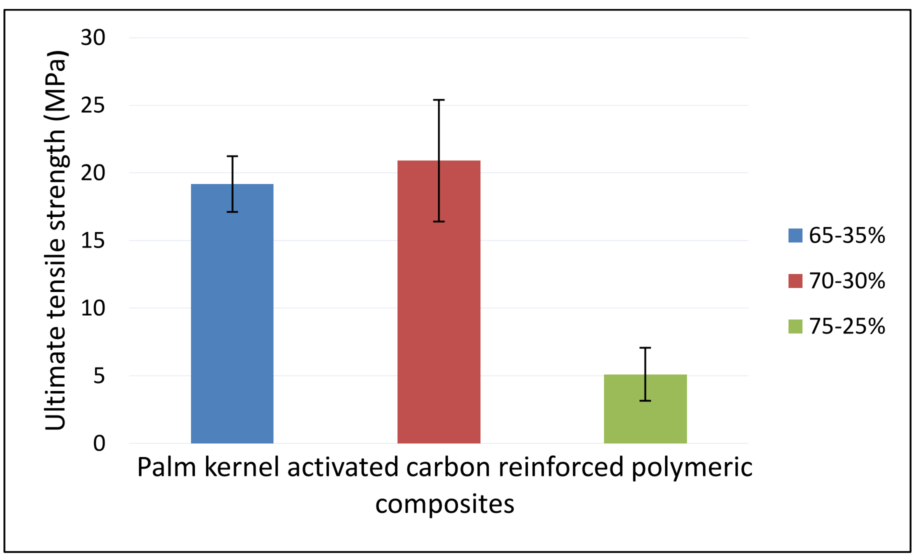


Figure 2: Average ultimate tensile strength of palm kernel activated carbon reinforced polymeric composite at different compositions.

The mechanical properties of the palm kernel activated carbon reinforced polymeric composite samples differed in terms of being solid or flexible, depending on the molecular mass of the final grouping. The unsaturated epoxy of higher carbon contents (> 75%) gave films with lower rubber-like elasticity compared with those of lower carbon content with the acceptable ratio of 65% carbon. For this reason, the molecular weight between crosslinks increased with the increase of the carbon content between 65 and 70%. Therefore, the tensile strength and the hardness of composite depended on the molecular mass of the final cured material. High molecular mass presents higher hardness and tensile strength; but with lower molecular weight, the mechanical properties will be poor (Kuang and Cantwell, 2002). The reduction in tensile strength may be attributed to the poor dispersion of the activated carbon with matrix due to manual mixing technique during the preparation of the samples and the curing period. As a consequence, the palm kernel activated carbon dramatically affected the mechanical properties of the resin and composite.

In other words, the tensile strength increased when increasing the epoxy resin concentration ratio between 65-70% of activated carbon, because the epoxy strengthened the interface of the carbon material but began to deteriorate in the 75% sample and beyond. Sapuan et al. (2003), studied the mechanical properties of composites with filler epoxy/coconut particle. The tensile strength of the composites was reported to have increased by increasing the filler content as coconut filler particles strengthened the interface with the resin matrix and filler materials. The composite with 15% filler showed the highest tensile strength of 35.48 MPa when compared to two other combinations (5% and 10%). Meanwhile, Sapuan et al. (2006), studied the mechanical properties of unsaturated polyester composites reinforced with different weight percentages of kenaf fibre. The results showed that tensile strength increased as the fibre content was increased.

Table 1 shows photographs of the three specimens from each of the palm kernel activated carbon reinforced polymeric composites after failure. It was observed that the failures of specimens occurred in the gauge zone, close to the centre of specimens, which clearly proves that the samples' manufacturing process was correct. The shape of the fracture which appeared in the samples was brittle and fractured. The high brittleness which appeared in these sections of specimens reduced the internal stresses as a result of shrinkage which occurred with higher degrees of crosslinking in the specimens. Thus, the activated carbon increased the brittleness in the composite.

In conclusion, it was observed that the stress property of the palm kernel activated carbon reinforced polymeric composite increased by increasing the carbon concentration from 65% to 70% in the composite, and began to reduce after this percentage. This may have been due to the better bonding strength between the matrix and reinforcement by this mixing ratio of the composite.

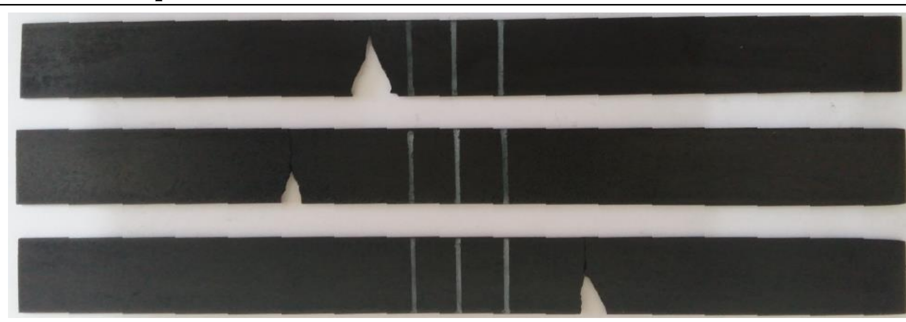
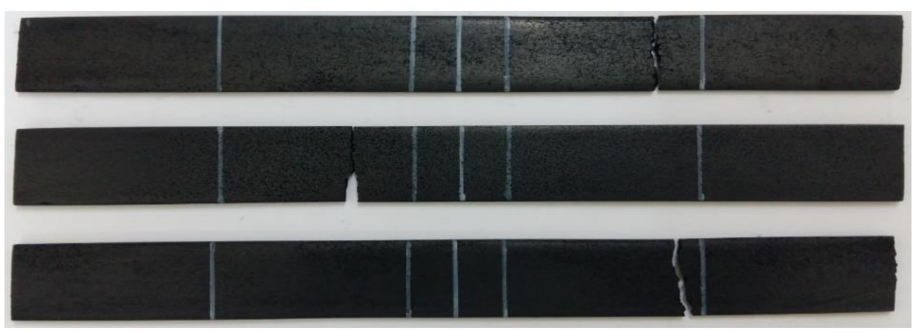
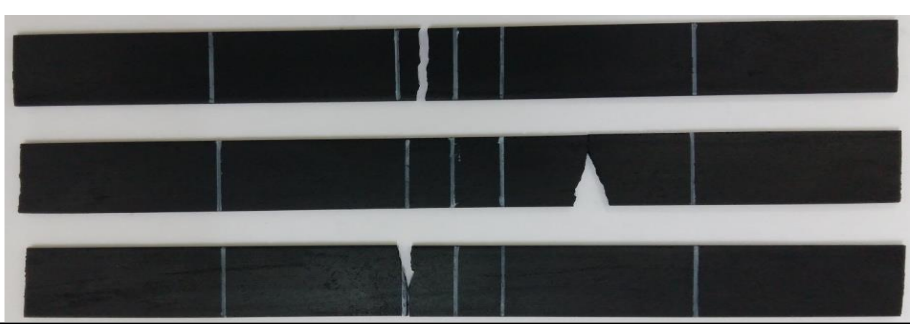
3.2 Hardness

The graph in Figure 3 shows the average value of composite hardness at room temperature and at high temperature of 90°C. It was observed that the hardness values at room temperature increased from 89.5 (75-25 % sample) to 95.1 (70-30 % sample) and thereafter increased until a maximum of 96 (65-35 % sample). Meanwhile, a little difference in hardness values was obtained, although with temperature of 90°C with the same procedures to perform the hardness test. The hardness values at 90°C increased from 86.3 (75-25 % sample) to 93.1 (70-30% sample), and thereafter increased until a maximum of 94 (65-35 % sample). The average values of hardness test of palm kernel activated carbon reinforced polymeric composites proved that the hardness of the composites began to decrease from room temperature to the high temperature of 90°C. This result was supported by the study by Brostow et al. (2010), who found that temperature had a direct impact on the polymeric composites. As the temperature increased, material hardness also decreased, which was also in good agreement with the previous study by Nayani et al. (2013).

The reason for these phenomena is that high molecular mass will give higher hardness of the final cured material. Goud and Rao, 2012, found a considerable increase in the tensile, flexural, impact and hardness properties of glass fibre hybrid composites with the increase in glass fibre molecular mass.

In addition, from the results, it is believed that as temperature rose, there was an activation process between palm kernel activated carbon and epoxy in the composite. The activation process between both materials occurred owing to the degradation of epoxy in the composite, which also decreased the hardness in the composite. A trend was observed, where the greater the epoxy ratio in the composite, the greater the hardness value of the final composite formed. Therefore, the increase in the hardness was due to the improvement in the bonding strength between the carbon particles and the matrix. This is in agreement with the work done by Nayani et al. (2013).

Table 1: Photographs of the composite failures after tensile test.

Composition	**Tested samples**
65-35%	
70-30%	
75-25%	

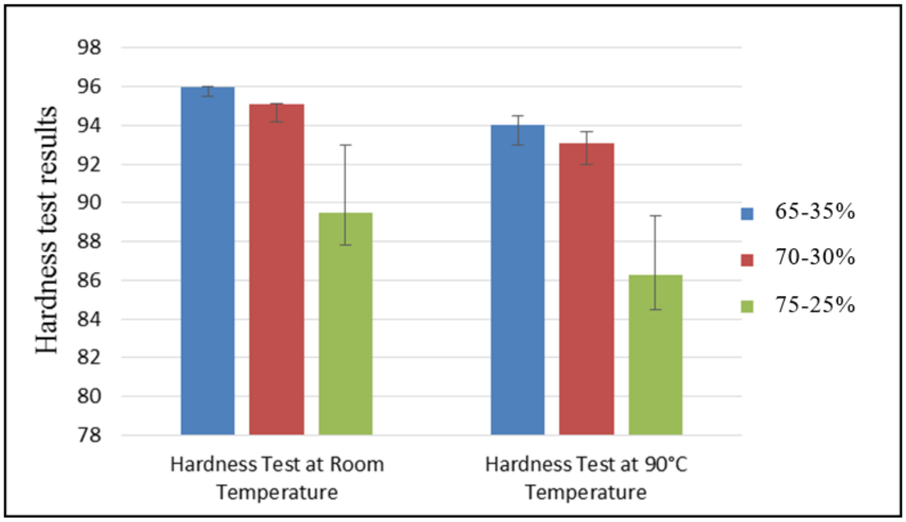


Figure 3: Hardness of palm kernel activated carbon reinforced polymeric composite at room temperature and at 90°C.

3.3 Density

The reinforcement of this activated carbon was affected by the adhesion and the density of epoxy resin in the polymeric composites. In fact, increase of the carbon concentration influenced the wettability between the particles and epoxy resin.

Figure 4 shows the density test results of the composite with different ratios of palm kernel activated carbon mixed with polymer epoxy. It was observed that the addition of an epoxy matrix led to the increase of the density to a certain ratio of the carbon, which was 70%, and then the density began to decrease after this ratio of the carbon content due to the low interfacial bonding between carbon particles and epoxy at 75% composition. The increase of carbon to 70% exhibited high adhesion forces between the molecules of the composite. The reason was the presence of a better interfacial bonding with epoxy, as well as to reduce the micro-voids by increasing the density of this composite. Therefore, the density decreased while increasing the carbon content up to 70%, which proves that higher density could be obtained using 70% of the carbon with 30% epoxy.

In addition, the polymeric composites had a density lower than other synthetic-natural fibres based polymeric composites, such as Kevlar fibre polymeric composite and coconut fibre polymeric composite. These materials are used for manufacturing in automotive and homemade applications because these materials have high strength and stiffness, combined with low density. Therefore, this composite perhaps will be more attractive in the future in applications requiring low density and high strength and stiffness.

Synthetic fibres are the most widely used to reinforce plastics due to their low-cost and good mechanical properties. However, these fibres have drawbacks, such as having high density, being non-renewable, being non-biodegradable and requiring high-energy consumption. Therefore, it is possible to make lighter constructive elements from this composite, as long as the design stiffness is controlled.

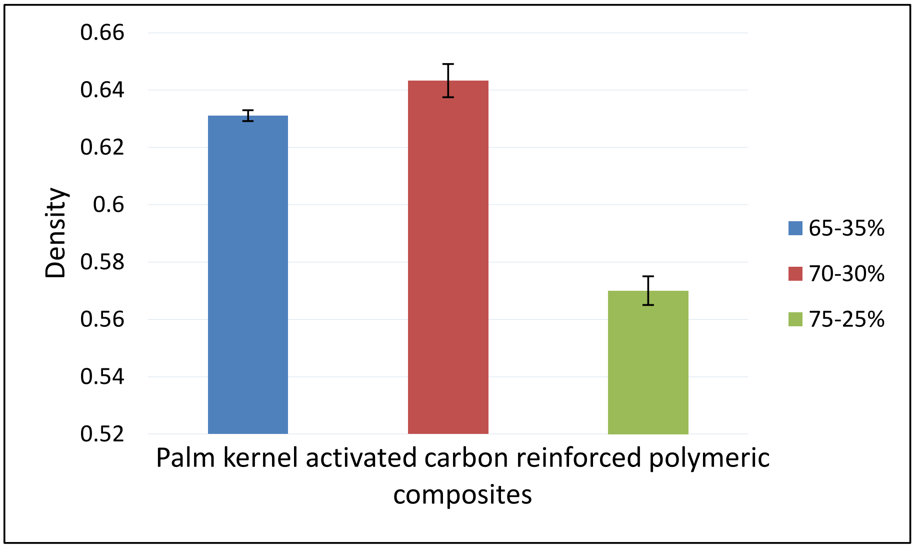


Figure 4: Density of palm kernel activated carbon reinforced polymeric composite at different compositions.

3.4 Porosity

Figure 5 shows the porosity test values obtained from different ratios of palm kernel activated carbon reinforced polymeric composites having 65%, 70% and 75% composition.

It was observed that the high degree of porosity (14.6%) calculated in the surface area was by this composite (75-25%). Meanwhile, the lowest porosity (10.7%) was calculated for the (65-35%) sample which confirmed that the internal bonding between the particles and the epoxy was the best compared to the other two composites. The good interfacial bonding of the (65-35%) sample meant the reduction of voids which would allow water to enter inside the samples. If the porosity of a polymeric composite increased, the water molecules could enter into the composite structure.

There was a variation in the porosity ratio for each composition of palm kernel activated carbon reinforced polymeric composite. The increasing rate in the porosity was largely related to the reinforcement content for each of them, meaning that the porosity increased proportionally with the increase of the amount of activated carbon in the composite until reaching the highest level with the 75-25% composite. The reason for this was due to the saturation state of carbon with the epoxy resin and the formation of bonds between them. The lack of epoxy led to the formation of undesirable voids in the composite.

Defects formation is a common problem in manufacturing polymeric composites. Some defects are resin-rich areas, outside inclusions, distortion of fibres, and voids. The most serious problem among these defects is the voids due to the difficulty in getting rid of them in the manufacturing of polymeric materials, especially at the corners and surfaces of the polymer components. They also have a damaging effect on the mechanical properties of the composites.

Voids are formed by bubbles from volatile byproducts produced through curing reaction of polymer resin with high-viscosity, combined with tightly packed fibres which are not fully wetted by the resin, resulting in air retention within the materials system.

Dhakal et al. (2007), stated in their study that the composite materials porosity is affected by fibres alignment. Long fibres with unidirectional orientation in a composite produce higher mechanical properties compared to random orientation of the fibres. The random orientation of the fibres can create rich areas rich in resin and other areas with poor resin. This entanglement can play a significant role in the formation of pores and voids in the composite material. In addition, high porosity and internal de-bonds are also undesirable. Therefore, high degree of perfection and high-quality adhesive bonding procedures are needed to ensure the stability of composite dimensions.

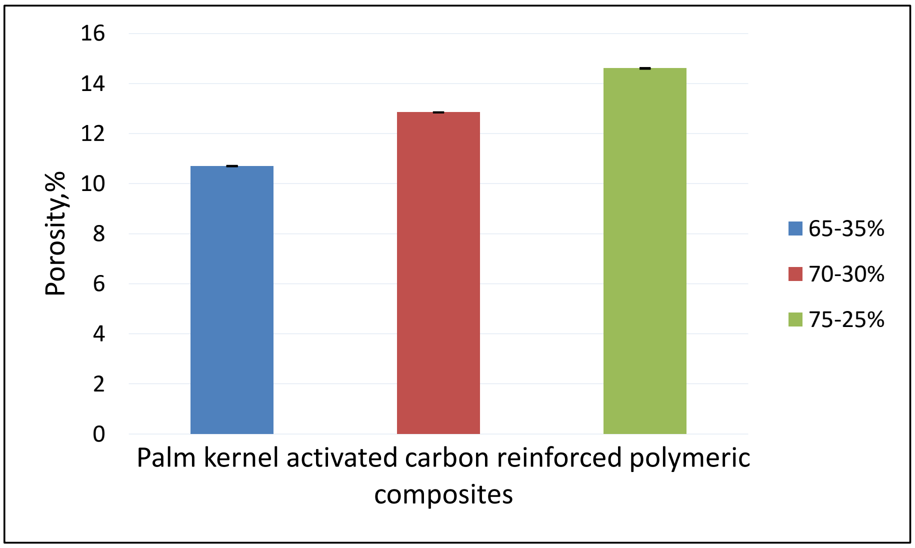


Figure 5: Porosity of palm kernel activated carbon reinforced polymeric composite at different compositions.

3.5 Water absorption

The mechanical properties and dimensional stability of polymeric composites can be affected by the poor resistance of reinforcement fillers to water absorption.

Figure 6 shows the percentage of weight gained in the specimens, in which absorption equilibrium of each specimen reached its highest value in a three-week period. From this test, it was observed that the water absorption rate in 75-25% composite was 29.9%, which was the highest percentage when compared to 65-35% and 70-30%, with 11.8%, and 14.8% respectively, which resulted in a high-water absorption level.

Dhakal et al. (2007), found that hemp fibre reinforced polyester corresponded to 0, 0.15, 0.21 and 0.26 fibre volume fractions during immersion at room temperature for 888 h, which were 0.879, 5.63, 8.16 and 10.97% water absorption, respectively. Similar results had also been observed in this study, in which with longer fibre, the water absorption became higher. Hence, the water molecules could actively be attracted to the interface, which in turn resulted in the de-bonding of filler and matrix. For instance, carbon, Kevlar, and glass give their best performance in a matrix. They must be kept in position by the matrix, usually epoxy. Both carbon and glass have no trouble sticking to epoxy. However, the aramid-epoxy bond is not as strong. Aramid tends to absorb water.

This, combined with non-ideal adhesion to epoxy, means that if the surface of an aramid composite is damaged, water can get in. Then, it is possible that the aramid will absorb water along the fibres and weaken the composite. Thus, the chemical treatment will increase the mechanical properties of the composites. Generally, the rate of water absorption is greatly affected by the composite's density and voids content. Therefore, the water absorption rate gradually increased with the increase of activated carbon content in the composite and decrease of the epoxy resin and could be attributed to the formation of voids inside the composite which led to the formation of internal microchannels inside the specimens.

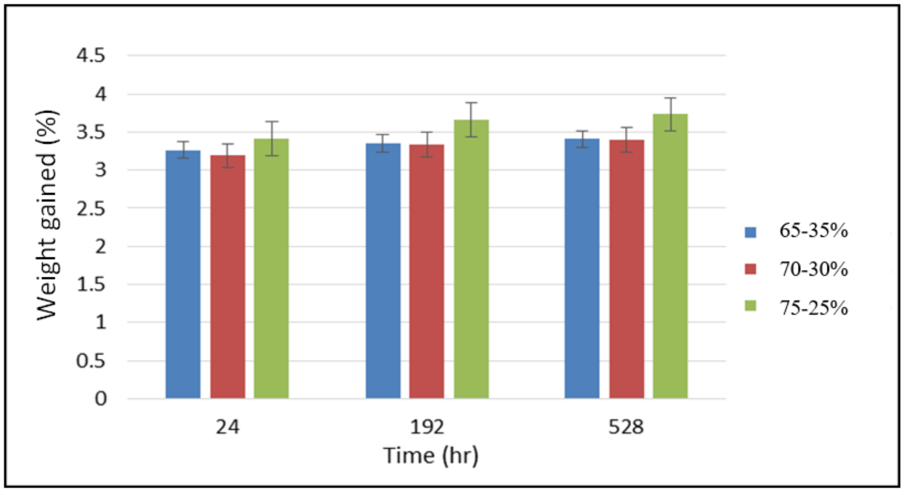


Figure 6: Weight gained by palm kernel activated carbon reinforced polymeric composite during water absorption tests.

3.6 Comparison with other polymeric composites

In this study, one of the main objectives was to compare the most superior test results of palm kernel activated carbon reinforced polymeric composites with synthetic and other natural reinforcement-based polymeric composites. The comparison of the physical-mechanical properties of these composites would be necessary to find out the features of this composite compared to other polymeric composites, as well as to find out the desired properties to enable this composite to replace other conventional synthetic composites in the future, such as carbon, aramid, glass, and other natural reinforcement-based polymeric composites.

Six laboratory tests had been conducted to determine the physical-mechanical properties as mentioned above. The obtained results from these tests refer to the best compositions of 65% and 70% samples chosen for the comparison purposes as in Tables 2 and 3.

Table 2 illustrates some of the physical-mechanical properties, such as tensile strength, hardness and density of an agricultural waste based polymeric composites for comparison purposes. The collected data with the current data of composites are presented in Figure 7.

Table 3 illustrates some of the physical-mechanical properties such as tensile strength, hardness, and density of synthetic fillers based polymeric composites for comparison purposes with the current data of palm kernel activated carbon reinforced polymeric composites. The collected data with the current data of composites are presented in Figure 8.

Table 2: Comparison of tensile strength, hardness and density values between palm kernel activated carbon reinforced polymeric composites and other natural reinforcement-based polymeric composites.

Composite material	Tensile strength (MPa)	Hardness (room temp.)	Density (g/cm^3)	References
Banana fibre-epoxy	45.5	79	1.35	Maleque et al. (2007)
Hemp fibre-epoxy	165	65	1.5	Islam et al. (2011)
Sisal fibre-epoxy	183	70	1.3	Mishra et al. (2000)
Kenaf (random)-pp	46	45-66	1.4	Hamma et al. (2014)
Palm Fibre/Epoxy	30-47	84.2	0.7-1.5	Aljami and Shalwan (2015)
*PKAC-E 65-35%	19.17	96	0.63	This study
*PKAC-E 70-30%	20.9	95.1	0.64	This study

*Palm kernel activated carbon reinforced polymeric composite.

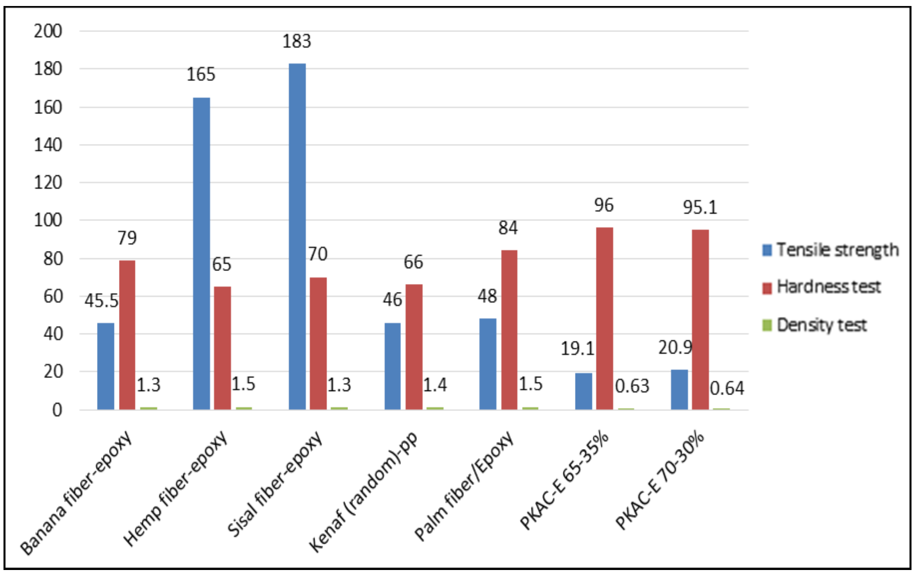


Figure 7: Comparison of the tensile strength, hardness and density values between palm kernel activated carbon reinforced polymeric composites and other natural reinforcement-based polymeric composites.

Table 3: Comparison of tensile strength, hardness and density values between palm kernel activated carbon reinforced polymeric composites and synthetic-reinforcement polymeric composites.

Composite material	Tensile strength (MPa)	Hardness (room temp)	Density (g/cm^3)	References
E-glass-polyester	1000-3500	85	2.5	Islam et al. (2011)
Carbon-polymer	4000	95	1.4	Bijwe et al. (2004)
Aramid-polymer	3000-3150	90	1.4	Bijwe et al. (2004)
Neat Epoxy	130	82.2	1.1	Yousif and Chin (2012)
*PKAC-E 65-35%	19.17	96	0.63	This study
*PKAC-E 70-30%	20.9	95.1	0.64	This study

*Palm kernel activated carbon reinforced polymeric composite.

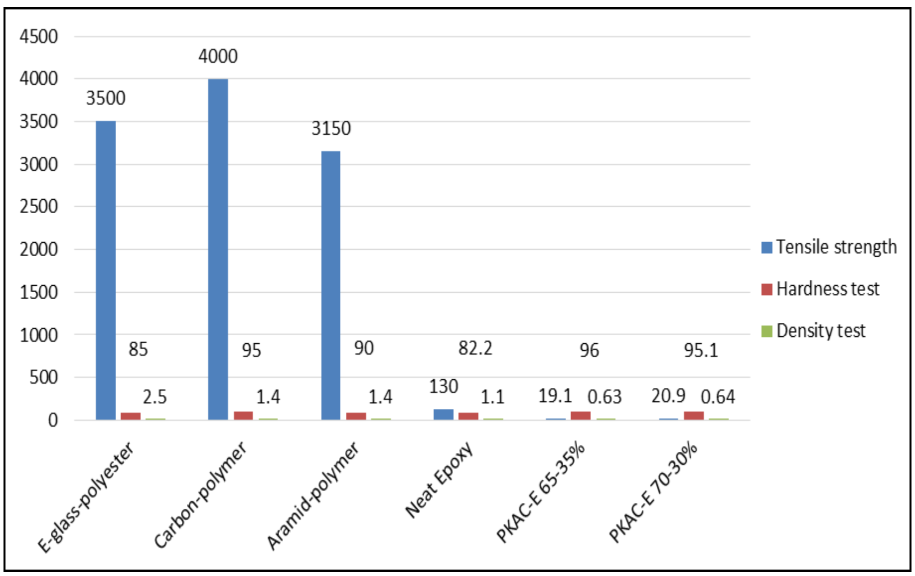


Figure 8: Comparison of tensile strength, hardness and density values between palm kernel activated carbon reinforced polymeric composites and synthetic-reinforcement polymeric composites.

From the above comparisons, the highest value of the hardness presented in the 65-35% was 96, with low density value of 0.63 g/cm3. This confirms the superiority of this composite over other synthetic-natural fibers reinforced polymeric composites in terms of physical-mechanical properties. In addition, they usually have very desirable and favorable properties such as high hardness, lightweight, and are usually also low-cost materials. Therefore, this composite has potential to work in operational conditions which need a high hardness and light weight such as aircraft and spacecraft. However, palm kernel activated carbon reinforced polymeric composite with composition of 65-35% showed very weak tensile strength as a result of the high brittle nature of this composite.

4.0 CONCLUSIONS

In summary, it was observed that the composition of 65-35% palm kernel activated carbon reinforced polymeric composite was the best composition of composite in term of physical-mechanical properties, while 70-30% composite was slightly better in terms of tensile strength properties. Comparing results of these composites with with other properties of synthetic and natural filler-based reinforcement polymeric composites showed that the highest value of the hardness presented by the 65-35% sample was with 95.6 hardness, with low density value of 0.63 g/cm^3. This confirmed the superiority of this composite over other synthetic-natural fibres reinforced polymeric composites in terms of physical-mechanical properties of high hardness, lightweight, and as a low-cost composite.

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