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Mechanical characteristics of polyester filled with palm fibers and ash particles

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ABSTRACT

This study investigated the mechanical properties of polyester matrix reinforced with surface-modified fibers derived from oil palms and surface-modified ceramic fly ash particles obtained from a coal-fired power plant. Two different composite materials were made: the first composite was made with only an increased percentage of fibers, and the second composite contained both a constant amount of fly ash and the different fiber content. The investigation of the mechanical properties included hardness, tensile strength, impact strength and corresponding fractographic analysis of the composites. It has been shown that the composites containing fly ash are superior in hardness and tensile strength, but lower in toughness. Factorography and image processing further demonstrated and explained the behavior of palm oil fibers and fly ash particles within the polyester matrix.

Keywords: Polyester composites, fly ash particles, palm oil fibers, mechanical properties, fractorography, image processing

1. Introduction

The oil palm, or scientifically known as *Elaeis guineensis*, is the most productive edible oilseed in the world. Palm trees are grown in more than forty countries on more than ten million hectares around the world. Currently, 55 tons of dry matters per year are produced from oil palm plantations in the form of fibrous biomass and 5.5 tons of oil [1]. The palm oil fibers are very similar to sawdust [2] obtained from wood dust. Palm oil fibers, extracted from the empty fruit clusters, can be considered as one of the main waste products from processing palm oil trees, which are stored under uncontrolled conditions and can be an important factor in environmental pollution. But at the same time, it can be one of the main sources of biomass for the production of solid fuels for heat production in a centralized system and in cogeneration plants, as well as in a decentralized system for domestic use in classical boilers for the production of thermal energy. The conversion of biomass from oil fibers has a beneficial effect. However, as with any energy source, emissions of pollutants adversely affect the environment and biological systems. The resulting pollutants, as a result of the conversion of fiber into wood briquettes, and then into thermal energy, are air pollutants and ash released through flue gases. The fibers are complex structures consisting of a continuous or intermittent fibrous material embedded in an organic matrix that can act as an adhesive. This is a piece of wood that contains glucose monomers and an organic lignin polymer. The oil palm fiber has established itself as a good raw material for bio-composites, since its cellulose content is in the range of 43% to 65%, and the lignin content is in the range of 13% to 25% [3]. Old methods of using these fibers are still insufficient. From a scientific point of view, fiber is currently an excellent improvement in wear resistance.

Fly ash is a fine residue formed by the combustion of pulverized coal in thermal power plants [4]. The residual fly ash is a microhard ball that is released from burnt coal. This is a raw material consisting of alumina-silica spheres based minor ceramic particles. This raw material consisted of two parts, crystalline ad glass phases. The glass phase is the largest and consists of SiO_2, as well as the network formers Al_2O_3, Fe_2O_3, TiO_2, and the network modifiers CaO, MgO, MnO, Na_2O and K_2O. Detailed chemical-physical properties were published in a previous publication [5]. The development of these coal-fired power plants causes growing concern about pollution caused by fly ash, which has led to global interest in its use in various polymer matrices, Portland cement, as adsorption and block structures [6-13]. An extremely large amount of fly ash is currently being disposed of at landfills. Many workers in ash dust processing plants have significantly higher levels of DNA damage [14-15]. From a medical point of view, it is known that small particles cause inhalation of metal for the human body and, finally, damage its DNA. The use of fly ash as a soil correction for growing plants can lead to the accumulation of some toxic microelements and, as a result, to the suppression of plant growth along with the deterioration of soil properties.

Reusing fly ash as an additive to the soil can lead to soil pollution. For building materials containing fly ash, body tissues and cells suffer from prolonged radiation attacks. This leads to damage to the structure of DNA and RNA molecules through electrophoresis, which affects the information transmitted to them, cell reproduction and, finally, causes a mutation of chromosomes. This can ultimately lead to lung cancer. The current use of fly ash is still inadequate and new application possibilities need to be explored. A very interesting solution to these problems is the use in the polymer industry [16]. Plastics are currently overused in many industries. From a commercial point of view, this solution can be useful after increasing the mechanical strength of polymer matrices.

Hybrid non-woven oil palm mats were reported, which included empty fruit bundles reinforced polyester composites [17]. In addition, considerable efforts have been made, such as surface treatment of the fibers with various chemical solutions, such as sodium hydroxide, to further improve the properties of the fibers. Detailed studies of the extensibility properties of single empty palm bunch of palm oil were published elsewhere [18-19]. On the other hand, several polymer matrices were reinforced using fly ash particles, such as epoxy composites [20]. However, limited studies on fly ash-reinforced polyesters are still underway [21]. The polyester composite is a matrix of polyester resin that can be reinforced with available fillers and additives. The difference between the filler and the additive is that the filler has little effect on the properties, but makes it cheaper, while the additive can significantly modify the properties. Efforts have focused on improving mechanical strength, which has shown some improvements. In addition, limited or no studies are being conducted to study the mechanical characteristics of hybrid composites, which consist of natural fibres and powder fillers or additives. This study focuses on the mechanical properties of polyester reinforced with palm fiber and polyester reinforced with both fly ash powder and palm fibre fillers. This should give a scientific start after following this new combination.

2. Experimental study

Unsaturated orthophthalic polyester resin (Polymal 8225PT) was purchased from a company. Empty palm fruit fibers were obtained from the oil palm factory in Malaysia. Class F fly ash was collected from a coal-fired power plant located in Malaysia. The detailed procedures for preparing oil palm fiber are as follows. First, the collected fibers were sorted, and long and thick fibers were selected, and impurities such as dirt, grease, and other substances were removed manually. Secondly, the fibers were soaked in raw water for 16 hours at ambient temperature (27°C) in order to remove the oil content from the fiber surface. Thirdly, the fibers were washed and dried at room temperature for 24 hours. Then the chosen fibers were cut to a short length of 5 mm. In general, intermittent (short) fibers have a length of at least 3 mm and not more than about 21 mm, and their orientation is directed in the direction of flow of the matrix resin. The prepared fibers were soaked in a 5% solution of NaOH at room temperature for 24 hours. The treated fibers were then washed several times with water to ensure that there were no substances containing sodium hydroxides on the surface of the fibers before drying at room temperature for 12 hours. Later, the prepared fibers were kept in an oven at 50 ° C for 1 hour to remove excess moisture content. In the processing of fly ash, 20 g of as-received fly ash was mixed with 20 ml of ethanol and 10 ml of distilled water. The mixture was stirred evenly using a hot plate mixer at 700 ° C for about 30 minutes. The treated fly ash was then dried in an oven at 110 ° C for one hour.

To prepare and test the polyester and the composites, a mold for various samples was made on an aluminum block. For the fiber-polyester composites, three layers of polyester resin mixed with 1% hardener were placed between two layers of palm fiber for each sample in accordance with a fixed weight ratio. The samples were left to cure for 1 hour at room temperature before being removed from the mold. Then, the samples were cured at room temperature for 24 hours, and then cured in an oven at 90 ° C for 1 hour. For the fly ash-fiber-polyester composites, 10% wt. fly ash was homogeneously mixed together with polyester and hardener. The remaining fabrication procedures were the same as for the first composites, as mentioned above. The hardness test was conducted on a Mitutoyo Microwizhard HM-211/221 Series 810-Micro instrument. An average hardness of 20 readings was taken for each sample. The tensile test was performed on a Shimadzu Autograph (AG-I) 100 kN universal computer-controlled testing machine in accordance with ASTM 638-I, which determine the tensile properties of unreinforced and reinforced plastics. Five tensile tests were recorded on average. The Charpy impact test was performed using Charpy impact strength of 7.5 J in accordance with ASTM D6110. Five Charpy test readings were taken as average. Fracture was observed using scanning electron microscopy (SEM-ZEISS EVO 50), and image properties were obtained using Matlab software.

3. Results and discussion

Figure 1 shows the fibrous material from palm oil and Figure 2 shows ash particles. Figure 3 shows the microhardness of fiber-polyester composites and fiber-ash-polyester composites, as well as pure polyester. It also shows a comparison of hardness measurements in which fly ash particles played an important role in increasing hardness. The fly ash components increased the hardness of all composites. The increase in hardness can be explained by an increase in the number of particles of different phases that are the crystalline ad glass components. This is alumina-silica major phase, which is dispersed in the polyester matrix. In this regard, it can be said that fiber-ash-polyester composites had greater hardness than fiber-polyester composites. The reduction in the 15% composites can be due to the polyester matrix, which consists of crystalline and amorphous forms and which affects the distribution of the fiber after curing. Most structural materials are anisotropic, which means that their mechanical properties change depending on the orientation. In addition, the change in properties can be associated with changes in the microstructure of the filler/fiber and matrix reinforcement [22].

Figure 1. As-received oil palm fibers

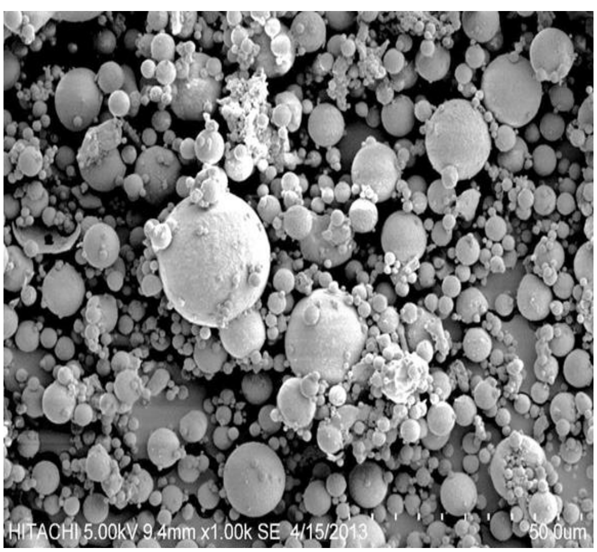

Figure 2. Fly ash spherical particles

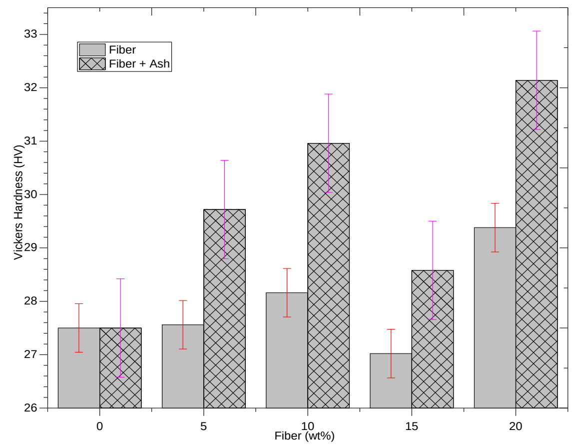

Figure 3. Hardness of the composites

Figure 4 shows two typical stress-strain curves for ash/polyester composites, from which three main regional behaviors can be distinguished. Point 1 indicates proportional limits, the slope of which is equal to the modulus of elasticity. Point 2 represents the elastic limit, a small strain peak that must be defined as the approximate yield strength, which is similar to a stress displacement of 0.2%. Then, the plastic deformation reaches a maximum at point 3, indicating a tensile strength of more than 20 MPa. Thus, this behavior could contribute to the global mechanical behavior of the composites. It has been found that increasing the fly ash content can reduce the deformation of complex plastics and lead to reduced stress. Figure 5 shows the average strength of fiber/polyester composites and fiber/ ash/ polyester composites. Fly ash increased mechanical strength. Reinforcement fibers were found to have lower tensile strength compared to pure polyester, as shown in a previous study [19].

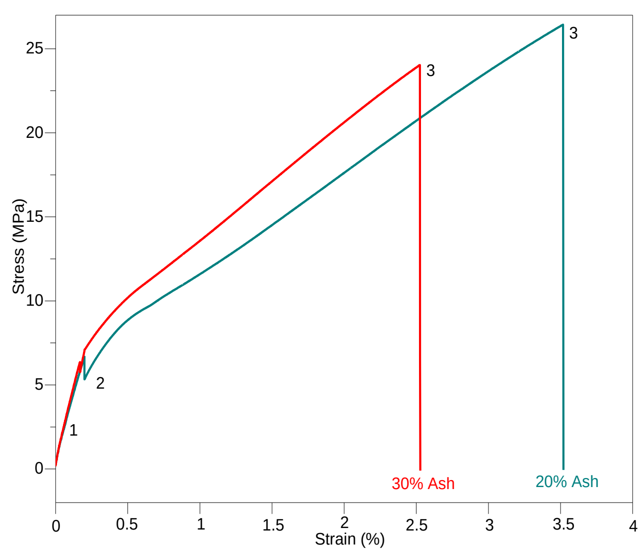

Figure 4. stress-strain curves of ash-polyester composites

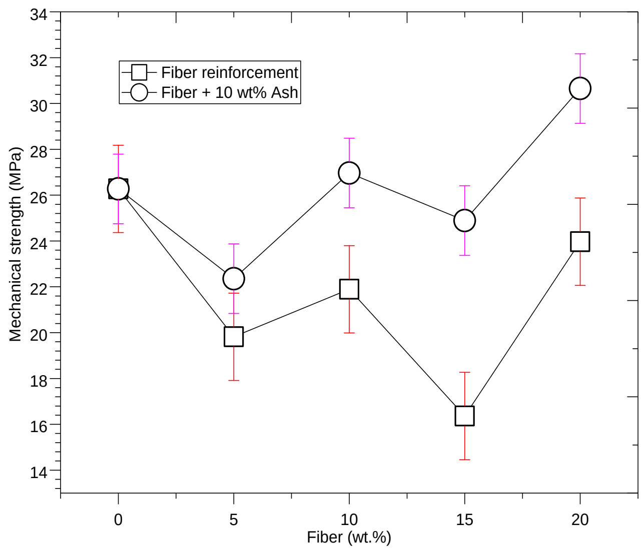

Figure 5. mechanical strength of the composites

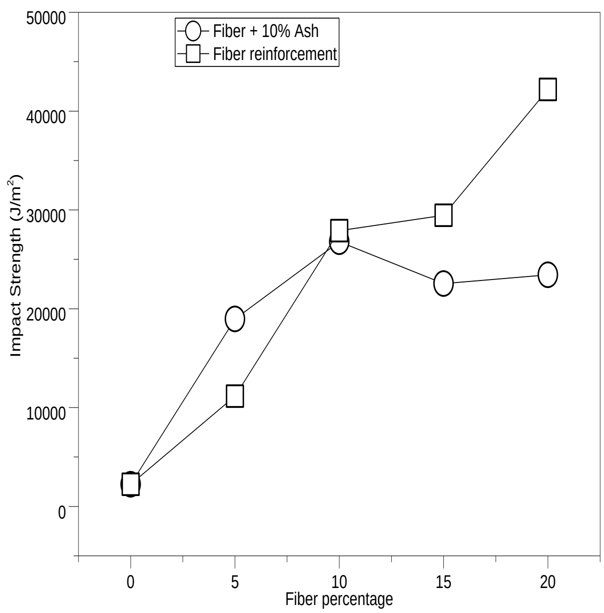

Figure 6. Impact strength of the composites

Figure 6 shows the toughness determined by the Charpy impact strength test of the fiber-polyester composites and fiber-ash-polyester composites. It is noteworthy that the toughness of the fiber-polyester composites is quite higher after their percentage exceeded the percentage of fly ash. This means that in order to obtain a higher impact of the fiber-ash-polyester composites, it is necessary to increase the number of fly ash particles with a decrease in the percentage of fiber. The reason can be the need to increase the overall adhesion between the reinforcement and the matrix by increasing the specific quantity of unique reinforcement since the impact resistance is the ability of a material to resist breaking under a shock loading. On the other hand, since it is also defined as the ability to resist the fracture under stress applied at a high speed, the reason can be explained by the interface since the weak interface of the fiber-only composite is better suited for impact testing because cracks tend to pass between interfaces. A detailed study of impact strength, mechanical strength and hardness of the polyester-xFA composite (x = 0-50 wt.%) was published in a previous publication [23], where FA refers to fly ash.

Figure 7 shows fractography obtained from Charpy impact testing of 5% fiber, 10% ash and polyester composites. This showed that the polyester matrix was filled with both fly ash particles and fibers. As previously shown, at the 5 percent level, the strength of fly ash composites was higher, and this was due to the high ability to withstand fracture upon application of a load. Consequently, the fly ash particles were distributed evenly and did not aggregate in the matrix, which created mechanical adhesion to the fiber-polyester composites, which improved the overall adhesion between the fiber and the matrix, acting as pins at the interface. Also, as previously shown, the composites containing only 10 percent fiber had slightly higher toughness, which means the fiber is better for increasing toughness. Deformations along the fiber boundary are shown, since there were cracks in these areas. Meanwhile, fibrillation of the fibers was observed due to the concentration of stress at the ends of the fibers. Fibrillation is the destruction of the fiber structure and splitting of the fiber bundle into final fibrils, which contributes to increased strength. This proved a weak physical bond between fiber and matrix. Figure 8 shows the negative image obtained by image processing. The images show the small and large ash particles as well as deformations and fibrillation of the fiber. Figure 9 shows the histogram obtained by image processing. The histogram indicates that polyester rich phase is dominenet since the amount of reinforcement is small.

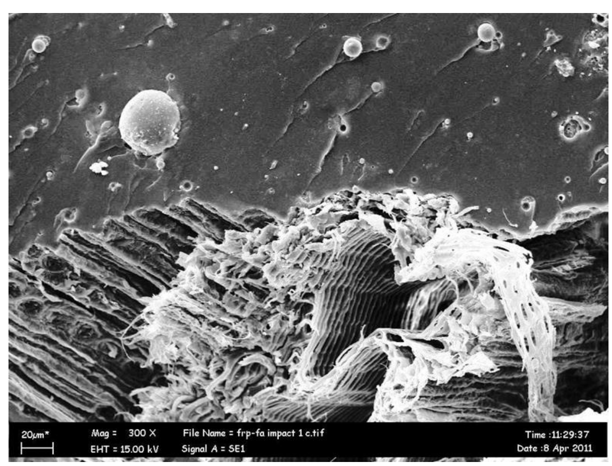

Figure 7. Fractography of fiber-ash-polyester composite

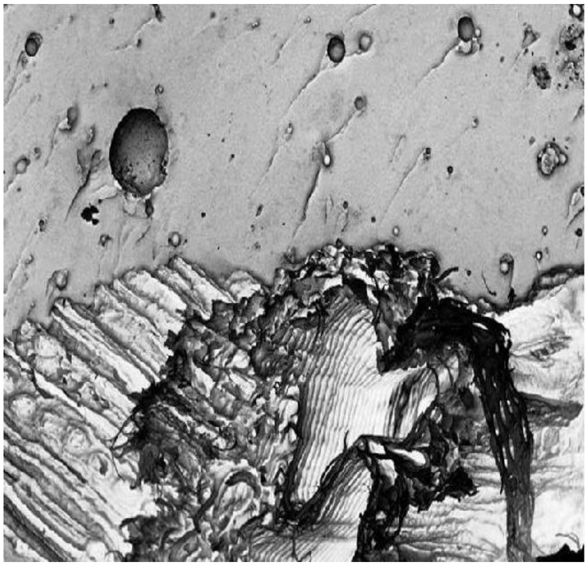

Figure 8. The negative image of the fiber-ash-polyester composite

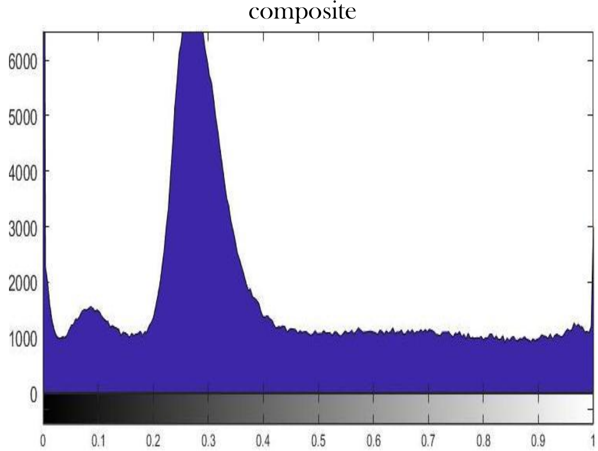

Figure 9. The histogram of the fiber-ash-polyester composite

4. Conclusion

In this work, the unsaturated polyester matrix was promoted by the addition of two major industrial residues available in Algeria and Malaysia. The composites have been tested using a variety of mechanical analyzes including hardness, strength, toughness, morphology, and imaging studies. The study led to the following conclusions: (1) fly ash particles, composed of several components added to the fiber, can increase the hardness, strength and toughness of the composites; (2) Single-component palm oil fibers can only increase the toughness of the composites; (3) adhesion between the various components was achieved by considering fly ash particles acting as pins at the fiber / polyester interfaces, and (4) both morphological and image properties well confirmed the constituent parts of the composite.

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