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[1.] I.O. OLADELE, [2.] O.O. DARAMOLA, [3.] E.O. OGUNDIJI

FLEXURAL PROPERTIES OF STEELMAKING SLAG REINFORCED POLYESTER COMPOSITES

[1-3.] Department of Metallurgical & Materials Engineering, Federal University of Technology, Akure, NIGERIA
[1.] African Materials Science and Engineering Network (AMSEN): A Carnegie-IAS (RISE) Network

Abstract: This work was carried out to investigate the influence of steelmaking slag on the flexural property of reinforced polyester matrix composites. Steelmaking slag was obtained from an indigenous steel production plant and prepared by crushing and pulverizing with Denver laboratory ball mill. This was followed by sieving with sieve shaker 16155 Model into 106 μm sieve sizes. XRD was carried out with FLUXANA-HD ELEKTRONIK VULCAN Fusion Technology and varied masses of the particles were used to develop the composites by reinforcing the polyester with the steelmaking slag particles. The homogeneous mixtures were poured into the flexural test mould and allowed to cure before being stripped from the mould. The samples were further allowed to cure for 30 days before carrying out the flexural test. The results showed that the composites produced have indeed gained increment in flexural properties compared to the unreinforced polyester material. Flexural properties were observed to decrease as the filler content increases. However,2 wt% reinforcement from the steelmaking slag gave the optimum results.
Keywords: Steelmaking slag, reinforcement, composites, flexural properties

1. INTRODUCTION

The term composite in material science refers to a material made up of a matrix containing reinforcing agents. Reinforcement is the part of the composite that provides strength, stiffness, and the ability to carry a load. Wood is a natural composite of cellulose fibers in a matrix of lignin. The reinforcement is embedded into the matrix. Common matrixes include mud (wattle and daub), cement (concrete), polymers (fiber reinforced plastics), metals and ceramics. The most common polymer-based composite materials include fiberglass, carbon fiber and kevlar. Fiberglass is probably one of the most familiar reinforcing composite materials that were introduced in 1940, consisting of glass fiber reinforcement of unsaturated polyester matrix, [1-2]. This glass fiber had numerous drawbacks that led to search for alternate substitute as reinforcement. Fiber as reinforcement to the composite had outstanding physio-chemico-thermo-mechanical performance, durability and eco-friendly nature that highlighted and promoted its scope.

The beginning of composite materials may have been the bricks fashioned by the ancient Egyptians from mud and straw. The ancient brick-making process can still be seen on Egyptian tomb paintings in the Metropolitan Museum of Art. Commercialization of the composites could be traced to early century when the cellulose fibers were used to reinforce phenolics, urea and melamine resins. Composites in the world of today have wide range of applications, wherever high strength-to-weight ratio remains and important consideration for use. Its principal use is found in automotive, marine and construction industries. In majority of cases, requiring high performance in the automotive and aerospace industries, the discontinuous phase or filler is in the form of a fiber. In most cases, composite matrices are the thermosets having carbon and ceramics for high temperature applications. Thermosets (epoxy, polysulfones) and thermoplastics (polyetherether ketone, polyimide) due to high strength and performance are pioneer for research and industrial applications.

The use of natural fiber as reinforcement in composite was a challenging task , improved the fatigue strength by using hybrid fiber composites with a polypropylene hemp layer adjacent to the bond interface which was expected to produce more uniform stress in transient regions[3]. Eucalyptus urograndis pulp used as the reinforcement for thermoplastic starch showed an increase of 100% in tensile strength and more than 50% in modulus with respect to non-reinforced thermoplastic starch, [4]. Fiber reinforced composite materials offered a combination of strength and modulus that are either comparable to or better than many traditional metallic materials. Increase in the flax and jute fiber content in polyurethane based composites increased the shear modulus and impact strength. However, increasing the micro void content in the matrix decreased its strength [5]. In wood fiber waste based plastic composites the tensile strength does not generally change with fiber content [6]. In the development of Natural Rubber (NR)-Polypropylene (PP) composites by increasing the amount of NR in PP by 5-20% increase in its composition, inter-laminar fracture properties as well as the resistance of material to delaminate crack propagation; with increase in NR amount of this inter-laminar fracture the toughness of composite material decreased[7]. In the study of the resistance of bamboo fiber-PP hybrid composites to hygrothermal aging and their fatigue behavior under cyclic tensile load, The use of maleic anhydride polypropylene as a coupling agent suppressed the moisture absorption and degradation in such composites [8]. The fiber matrix adhesion has been reported to promote the fiber surface modification on alkaline treatment and matrix pre-impregnation e.g. use of silane as coupling agent in case of henequen fiber-HDPE composite[9]. The increase in mechanical strength was found to be raised between 3–43% for longitudinal tensile and flexural properties whereas in transverse direction, the increase was greater than 50% with respect to the properties of composites made of untreated fiber. Increase in stiffness was approximately 80% of the calculated values.

There are, however, several studies that show toughness increase with introduction of rigid particles in polypropylene and polyethylene [10]. Impressively, enhanced impact toughness has been reported for polyethylene filled with calcium carbonate particles [11-12] . Enhancement of impact properties of some pseudo-ductile polymers by the introduction of inorganic particles has also been achieved [12].

Having noticed that particulate fibres can be used to fill and enhanced the properties of polymers, this research was carried out in order to investigate the effect of particulate steelmaking slag on the flexural properties polyester matrix. This was done with the aim of turning waste to wealth by using slag for engineering applications.

2. MATERIALS AND METHODS

This research was carried out with the following materials; Unsaturated polyester resin, Ethyl Ethyl Ketone Peroxide (MEKP), Cobalt 2% in solution, polyvinyl acetate and ethanol. The steelmaking slag that was a waste product of electric arc furnace was sourced from universal steel, Ikeja, Lagos, Nigeria. XRD was carried out to examine the composition of the slag and it was as shown below in Table I.

Table I: XRD analysis for the steelmaking slag

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	NaO	LOI	LSF	SR	AR	Mn	Ti
36.79	10.55	21.05	5.79	2.58	0.06	0.4	1.39	0.01	5.73	1.01	0.4	11.01	2.26

2.1. Material Preparation

The steelmaking slag that was obtained in lumps form was crushed with hammer and finally pulverized using Denver laboratory ball mill. The particle from the process was sieved with sieve shaker 16155 Model into 106 μm sieve sizes. XRD was carried out with FLUXANA-HD ELEKTRONIK VULCAN Fusion Technology.

2.2. Production of Composites

To develop the composites, 1.5 g each of catalyst and accelerator was added to 120 g of the polyester resin while the steelmaking slag particulate was varied in a predetermined proportion of: 2, 4, 6, and 8 wt%. After proper stirring, the homogenous slurry is poured into the mould and allowed to cure at room temperature before it is removed. Flexural mould of 150 x 50 x 3 mm was used for the production of the flexural samples. The cured sample is left for 3 weeks before the flexural test was carried out.

3. FLEXURAL TESTS AND METALLOGRAPHIC EXAMINATION OF THE COMPOSITES

Cured composite samples were prepared for flexural test after which Scanning Electron Microscope (SEM) was used to investigate the miscibility between the filler and matrix at the fractured surfaces. These tests were carried out as follows;

3.1. Determination of the flexural property of the materials

Flexural test was carried out by using Testometric Universal Testing Machine in accordance with ASTM D790. To carry out the test, the grip for the test was fixed on the machine and the sample that has been cut into the test piece dimension of 150 mm x 50 mm x 3 mm, was hooked on the grip and the test commenced. As the specimen is stretched the computer generates the required data and graphs. The Flexural Test was performed at the speed of 100 mm/min.

3.2. SEM Observation

SEM of the composites was observed using Zeiss SEM: Zeiss Ultra Plus 55 FECSEM, Zeiss, Oberkochen Germany. Before the examination, the samples were prepared by cutting with bench vice and hacksaw followed by gluing on sample holder and finally coated with carbon using Carbon Coater: EMITECH K950X, EM Technologies, Kent England.

4. RESULTS AND DISCUSSIONS

The mechanical properties of particulate–polymer composites depend strongly on the particle size, particle–matrix interface adhesion and particle loading. The strength of particulate composites is determined not only by particle size and particle/matrix interfacial adhesion but also by particle loading. Various trends of the effect of particle loading on composite strength have been observed due to the interplay between these three factors, which cannot always be separated, Shao-Yun et al, (2008). Flexural properties are some of the significant mechanical properties of materials that need to be understood for proper use of the material. Therefore, the flexural properties results are shown in Figures 1-3 while the SEM micrograph is shown in Figure 4.

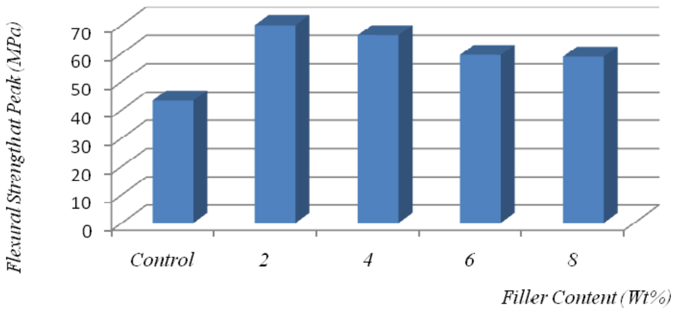

Figure 1: Variation of flexural strength at peak with filler content for the varied steel making slag particles

Figures 1-3 show the result of flexural strength at peak from where it was observed that, the reinforcement brings about enhancement in flexural properties of the composites compared to the unreinforced polyester material for all the filler content used. The results revealed that, flexural property was highly improved with the 106 μm particle sizes addition and that, the property decreases as the filler content increases from 2-8 wt%. However, 2 wt% filler content sample gave the best result with a value of 69.91 MPa compared to the unreinforced polyester matrix with a value of 43.25 MPa. This result shows that the flexural strength at peak was better enhanced with low filler content. The result is in agreement with the findings of [13] for oil palm reinforced epoxy composites, who reported that flexural strength showed a decreasing trend as volume fraction of the fibre was increased. It has been reported that the decrease in the flexural properties at high fibre content implied poor fibre-matrix adhesion which promotes micro crack at the interface and the non-uniform stress transfer due to fibre agglomeration within the matrix [14]. Similar report was also made for jute fibre reinforced polyester matrix [15].

The result of the flexural modulus from Figure 2 show similar trend to that of flexural strength at peak (Figure 1). Here, the flexural modulus result revealed that only 2 wt% filler content sample

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gave a better result than the unreinforced polyester matrix. The values are 11957 and 7451.8 MPa for the 2 wt% sample and the unreinforced sample respectively. Young's modulus is the stiffness (the ratio between stress and strain) of a material at the elastic stage of a fluxural test. It is markedly improved by adding micro- and nano-particles to a polymer matrix since hard particles have much higher stiffness values than the matrix.

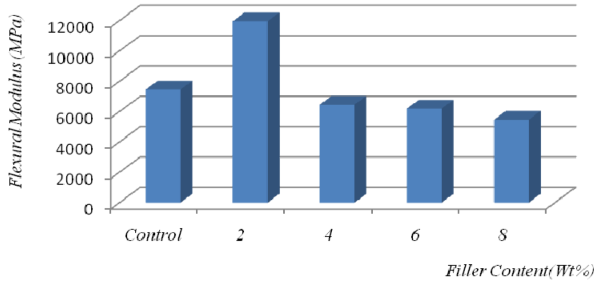

Figure 2: Variation of flexural modulus with filler content for the varied steel making slag particles

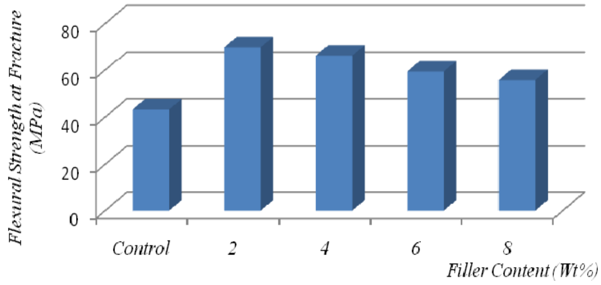

Figure 3: Variation of flexural strength at fracture with filler content for the varied steelmaking slag particles

The strength of the composites at the point of fracture is referred to as the flexural strength at fracture when subjected to bending load. Figure 3 revealed the result of the test which was similar to that of the flexural strength at peak where, 2 wt% filler content sample gave the best result with a value of 69.91 MPa compared to the unreinforced polyester matrix with a value of 43.25 MPa. It was noticed that all the samples except 8 wt% filler content sample fractured at the same point as their peak strength value.

The improvement of the composites flexural strength at peak, modulus and strength at fracture is because the crystallinity of semi-crystalline polyester, and hence the composite flexural properties are affected by the filler [16]. Unsaturated polyester matrix is a thermosetting material that exhibit brittle fracture property which is catastrophic in nature and there is therefore, need to improve on its strength to avoid this in service. Flexural test is a mechanical test that is carried out in order to determine the bending properties of a material. The result provides information on the flexural strength-at-peak, flexural modulus and flexural strength-at-fracture which show better performance when compared to the unreinforced polyester matrix.

Figure 4 revealed fractured surface for the steelmaking slag filled polyester composite. The micrograph revealed that there is a proper bonding between the steelmaking slag particles (white part) and the polyester matrix (dark part) which was responsible for the good flexural properties that was obtained from the flexural test results. As a result of the good wettability between the slag and the polyester matrix as well as adequate particle dispersal in the polyester matrix, better enhancement of properties was obtained for the composites in flexural properties compared to the unreinforced polyester matrix.

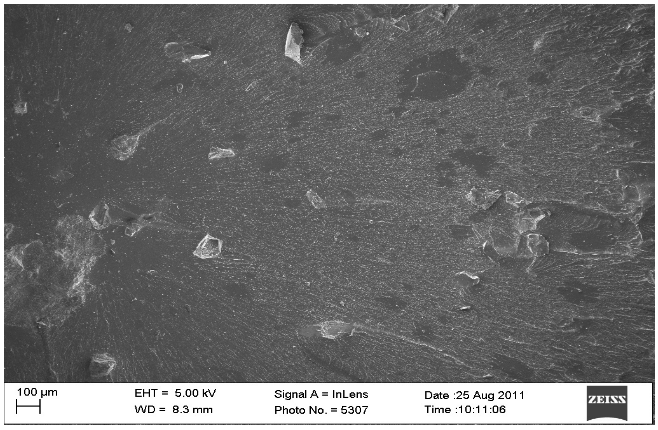

Figure 4: SEM micrograph of fractured surface of 2 wt% steelmaking slag filled polyester Composites

5. CONCLUSION

The desire to ensure that there is proper utilization of materials and the drive for zero waste have motivate the use of steelmaking slag as a filler in polyester matrix in order to enhanced the flexural properties of the material. The mechanical properties of polymers are not as enhanced as that of metal and since polymers are now competing with metal in almost all areas of applications, there is therefore, need to develop polymer based composites for different areas such as automobile and structural applications. As a result of the capability of particulate materials to reinforced and bring enhancement in polymer properties, this research has shown that steelmaking slag is also suitable for use as a filler and reinforcement in polyester material.

From this work, it was observed that;

- ✓ There is a similar trend for all the flexural properties examined where there is decrease in the flexural properties as the filler content increases.
- ✓ The flexural properties were highly enhanced by the addition of 106 μm particle sizes of the steelmaking slag with 2 wt% filler content sample emerging as the best in all the flexural properties. This was due to proper bonding and wetting that occurred between the steelmaking slag filler and the polyester matrix.

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