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Tensile and flexural properties of polyester composites reinforced by iron filings

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Abstract

The effects of iron filings on the tensile and flexural properties of unsaturated polyester reinforced by iron filings have been studied. Particulate polyester composite reinforced by iron filings of different wt. % were synthesised and characterised. The mass percentage of the iron filings, varied from 0, 5, 10, 15, 20, 25 to 30 % were added to unsaturated polyester resin with 2 grams of methyl ethyl ketone peroxide catalyst and 0.5 grams of cobalt naphthalene accelerator to synthesise the composites. Tensile and flexural tests were carried out on the samples. The metallographic study was carried out using an optical microscope and scanning electron microscope. Results showed that tensile properties, including energy absorbed at fracture, percentage elongation, and tensile strength of the composite improved with increasing wt. % of filing particles up to 15 wt. %. This trend was also observed in the flexural strength results. The sample with 15 wt. % iron filings was observed to have the optimum reinforcement effect with a tensile strength of 34.91 MPa, a flexural strength of 111.06 MPa, and a modulus of elasticity of 1581.29 MPa.

1. Introduction

Composite materials are considered to be any multiphase materials that exhibit a significant proportion of the properties of both constituent phases such that a better combination of properties is realised. It, therefore, contains two or more physically distinct and mechanically separable materials [1] and can be made by dispersing one material, the reinforcement, in another material, the matrix, in a controlled way to achieve optimum properties [2].

Composite materials can be obtained from much cheaper components and possess significantly lower relative weight. Previous products whose manufacture requires expensive monolithic materials are being replaced with composite materials with alternative properties, which display better qualities and perform in a better way at a cheaper cost [3]. The global composite materials market size in 2011 was \$19.6 billion, and the same is estimated to reach approximately \$34.1 billion by 2018. This amounts to a compound annual growth rate (CAGR) of about 10.5 % [4].

Unsaturated polyester (UP), a thermosetting polymer resin, is found to be the most globally applied thermoset in the world [5]. More than 2 million tonnes of this material are used annually for structural products such as tanks and pipes, and vehicle parts such as car bodies, boat hulls and aircraft panels [6]. To improve its strength and stiffness, unsaturated polyester is reinforced with either organic or inorganic reinforcements. Recently, much focus has been on organic material reinforcements owing to their low cost and relative availability, with materials like animal bone and exo-skeletal shells, plant fibre and husks having been utilised as reinforcements [7-10]. However, organic reinforcements usually have poor interfacial adhesion with polymeric matrices owing to the presence of inherent organic detriments [11-13], which leads to poor performance and eventual delamination of the composite part [11].

Inorganic particulate reinforcements such as steelmaking slag have been investigated and shown to positively impact the flexural properties of unsaturated polyester [14]. In particle-reinforced composite materials, the particles act as a load-carrying medium and the matrix acts as a load-transporting medium [15]. There must be proper bonding for the transfer of load from the matrix to the reinforcement, which is critical to the strengthening of the composite. Delamination, a result of poor bonding, occurs at the matrix/reinforcement interface and is one of the major failure characteristics of polymer matrix composites [16].

In addition, it is inadequate for particulate reinforcement to form aggregates, as this will provide crack initiation sites or act to enhance crack propagation, causing premature failure of the composites under mechanical stresses [17]. Therefore, it is ideal that particles in composites are in a well-dispersed state. Hence, by achieving proper interfacial bonding and with a homogenous level of dispersion, the iron filings can be expected to have a positive strengthening effect on the unsaturated polyester material.

This research work investigated the impact of iron filings, a relatively cheap and strong inorganic phase on the tensile and flexural properties of unsaturated polyester.

2. Experimental details

2.1 Materials

The materials used are unsaturated polyester resin, methyl ethyl ketone peroxide (MEKP) catalyst, cobalt naphthalene accelerating agent, polyvinyl acetate as a mould-releasing agent, acetone as a solvent and iron filings. The iron filings were obtained by grinding a cast iron stock whose chemical composition is shown in Table 1.

Table 1. Cast iron chemical composition

Element	C	Si	Mn	Mg	S	P	Fe
wt. %	3.64	2.71	0.33	0.07	0.02	0.01	Balance

The particles were collected, followed by magnetic separation to remove inclusions and impurities [18]. Sieving was done by an Endecotts test sieve shaker, and particles in the sieve range of oversize of 125 µm, and undersize of 250 µm, which falls into the "fine sand" class under the Wentworth classification, were picked for reinforcement. Figure 1 shows the iron filings after sieving.

Figure 1. Iron filings after sieving at 125 – 250 µm

2.2 Sample preparation

The unsaturated polyester resin was measured on a digital weighing balance, starting with a 100 g sample with no reinforcement and ending with a 70 g sample with 30 g iron filings reinforcement. There were seven samples in all with the predetermined mass of iron filings at increments of 5 g per sample such that the polyester/iron filing ratios of each sample in grams are: 100/0, 95/5, 90/10, 85/15, 80/20, 75/25 and 70/30. To each sample formulation, 2 g of methyl ethyl ketone peroxide (MEKP) catalyst was added through a syringe followed by 0.5 g of cobalt naphthalene accelerator with a separate syringe on the balance; then the mixture was stirred for about a minute before being poured into prepared tensile and flexural mild steel moulds.

Each mould contained three machined test piece slots according to the standard sample dimensions. They were coated before the pouring was done with a releasing agent (polyvinyl acetate) to facilitate easier stripping. Methyl ethyl ketone peroxide functions, as a hardener, is to cure the liquid resin into solid, and cobalt naphthalene speeds up the curing process, allowing the solidification of the resin at room temperature.

The mixture was allowed to set and harden for a few hours before being carefully stripped and labelled. The process was then repeated for each weight percentage of iron filings. Unreinforced polyester reference samples were also cast. Both tensile and flexural samples were labelled according to the iron filing wt. % contained in each as: 0 %, 5 %, 10 %, 15 %, 20 %, 25 %, and 30 %, respectively. After stripping and labelling, the samples were left to properly cure for 3 weeks before any mechanical testing was done.

2.3 Mechanical characterisation

The tensile test was carried out on an Instron universal testing machine (UTM series 3369), with a 50 kN maximum load-bearing capacity and a crosshead speed of 5 mm/min. The dumbbell test samples were dimensioned 185 × 20 × 5 mm, according to ASTM D638 standard.

A three-point flexural test was also carried out using a 20 kN capacity Monsanto laboratory tensometer with 5 mm/min speed on the composite test samples dimensioned 125 × 20 × 5 mm, according to ASTM D790 standard.

Each of the tests was repeated thrice and the mean value was taken for the readings.

2.4 Metallographic analysis

Metallographic analysis was carried out on the cross-sectional surfaces of the composite samples. Preparation of selected samples for optical microscopy and scanning electron microscopy (SEM) was done by first degreasing them in ethanol and then drying them over a hot plate. A sample holder was used to transfer the optical microscope samples before mounting. The SEM samples were mounted on sample stubs of an Aspex 3020 scanning electron microscope and viewed. The surface morphology and composite phases were then examined and recorded.

3. Results and discussion

Results from the mechanical tests are shown in Figures 2 to 7, while pictures of the microstructural examination are shown in Figures 8 to 11.

3.1 Effects of iron filings on tensile properties

Figures 2, 3 and 4 illustrate the effect of iron filings on the tensile properties of unsaturated polyester composite reinforced by iron filings. The variations follow similar trends, and the average tensile strength (Fig. 4) increased steadily to a maximum value at 15 wt. % of particles, after which it decreased with increasing wt. % of particles. This may be a result of the particle agglomeration caused by higher surface energy as the reinforcement percentage increases [19].

This limits the load transfer from the matrix to the particles, causing cracks to initiate and propagate easily, resulting in reduced strength of the composite at higher wt. % [20].

The optimum tensile strength of 34.91 MPa was obtained at 15 wt. % of iron filings as compared to 16.59 MPa, given by the reference sample. A similar trend of decrease in tensile strength of composites with increasing wt. % of particles was reported by Durowaye et al. [21].

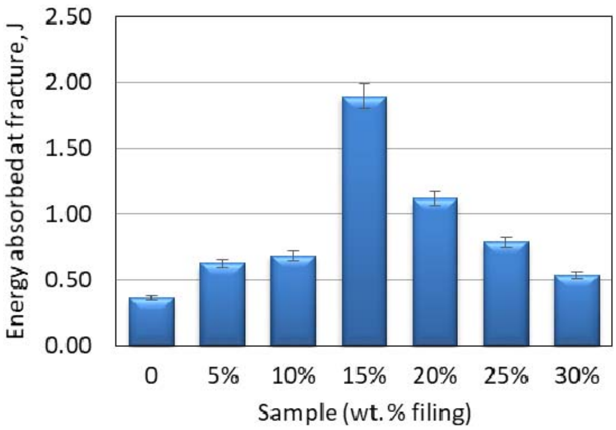

Figure 2. Variation of tensile energy absorbed at fracture with increasing wt. % of iron filings

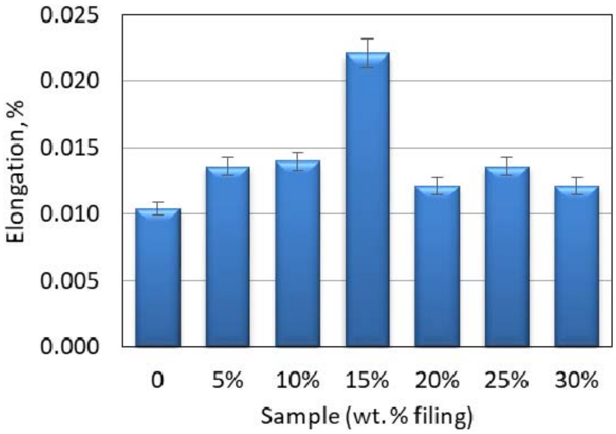

Figure 3. Variation of percentage elongation with increasing wt. % of iron filings

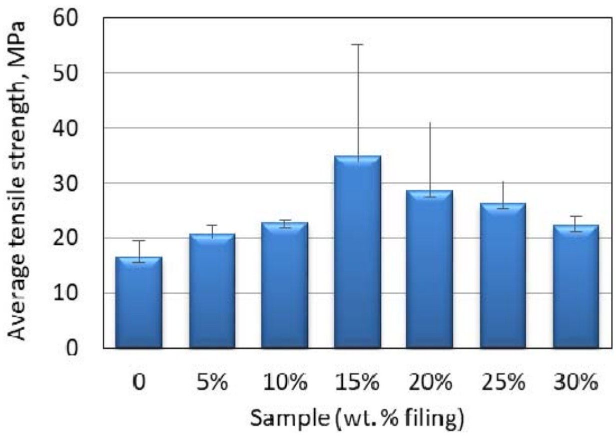

Figure 4. Variation of tensile strength with increasing wt. % of iron filings

Figure 5 shows the effect of iron filing particles on the tensile modulus (modulus of elasticity) of the composites, with the stress/strain curves of the samples shown in Figure 6. The figure shows that the modulus of elasticity of the reinforced

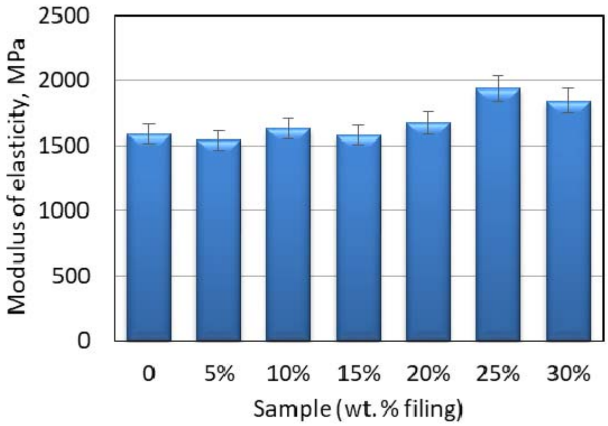

Figure 5. Variation of modulus of elasticity with increasing wt. % of iron filings

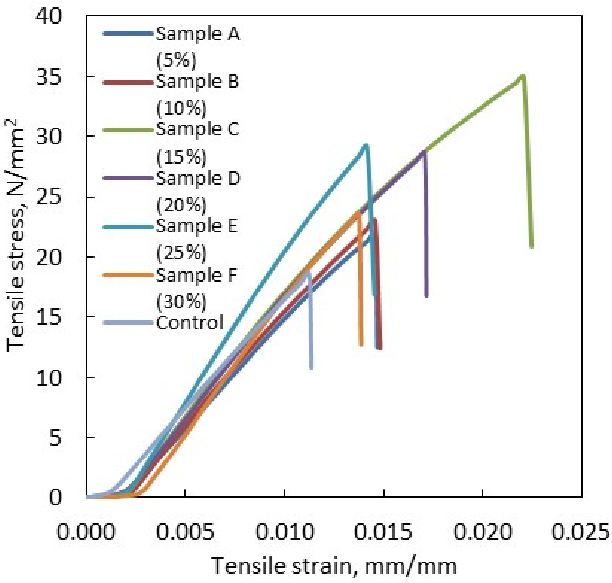

Figure 6. Stress/strain curves of the tested samples

composite of 1940.52 MPa at 25 wt. % is higher than for the reference sample (1592.24 MPa). This suggests that higher particle content increases the modulus of elasticity of the composites. This result conforms to the findings of Igwe and Onuegbu, who reported an increased tensile modulus of polypropylene with increased eggshell particles [22]. Sample 15 % shows a larger strain value at the highest applied tensile stress in the stress/strain curve (Fig. 6).

3.2 Effects of iron filings on flexural strength

Figure 7 shows the variation of flexural strength with increasing wt. % of iron filings. The flexural strength increased from 21.36 MPa in the reference sample to 111.06 MPa at 15 wt. % reinforcement; then it decreased to 39.58 MPa at 25 wt. %. The flexural strength variation also follows a similar trend as with the tensile results.

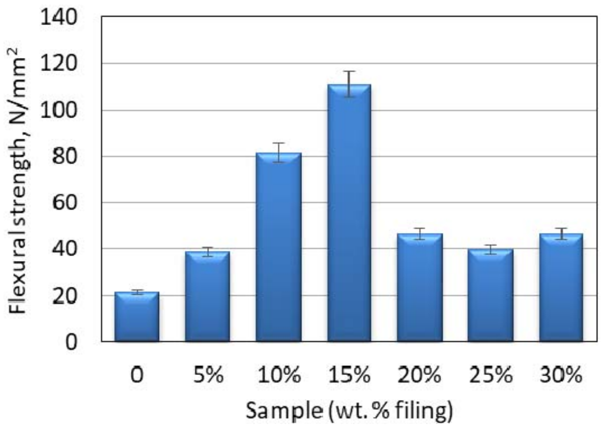

Figure 7. Variation of flexural strength with increasing wt. % of iron filings

3.3 Metallographic analysis

Optical micrographs of the 15 wt. %, 25 wt. % and 30 wt. % samples are shown in Figures 8, 9 and 10, respectively. The figures show increasing clusters of agglomerates (identified with an "A"), formed by the filing particles as the wt. % increases. This explains the decrease in tensile and flexural strength values beyond 15 wt. % of iron filings.

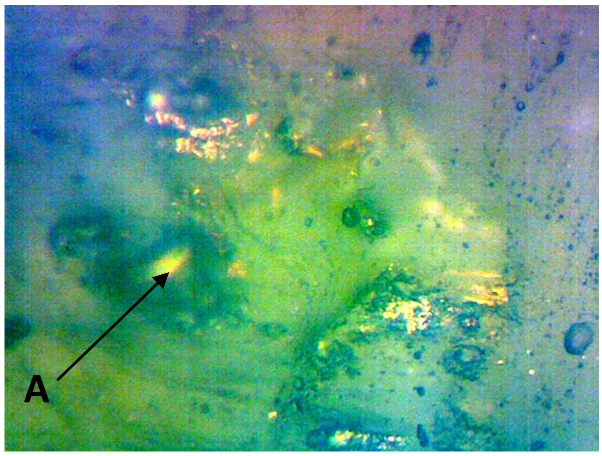

Figure 8. Optical micrograph of 15 wt. % sample at 400× magnification

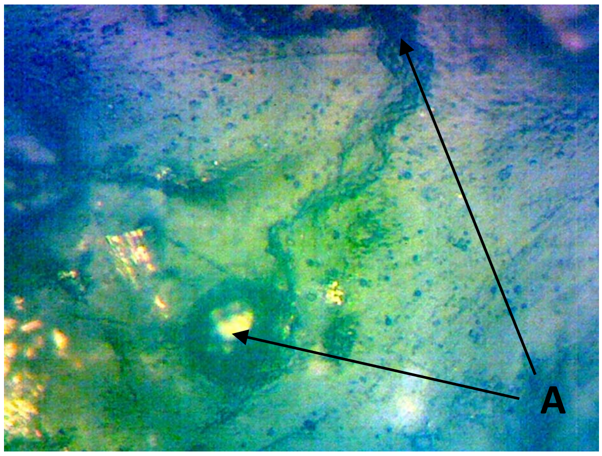

Figure 9. Optical micrograph of 25 wt. % sample at 400× magnification

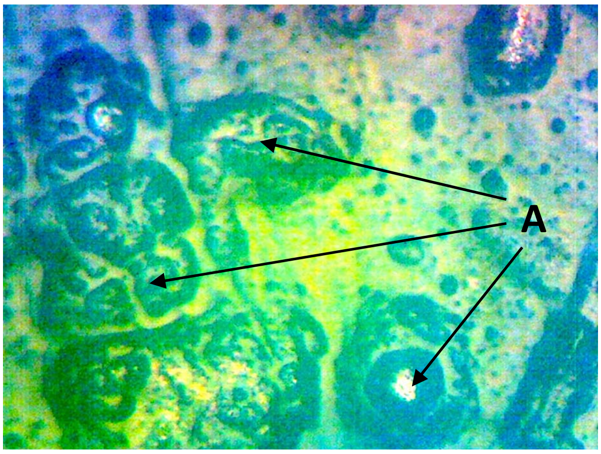

Figure 10. Optical micrograph of 30 wt. % sample at 400× magnification

SEM micrograph of the 15 wt. % sample (Fig. 11) shows proper bonding of filing particles (identified as "F") dispersed within the polyester matrix. This was also responsible for the improved tensile and flexural properties.

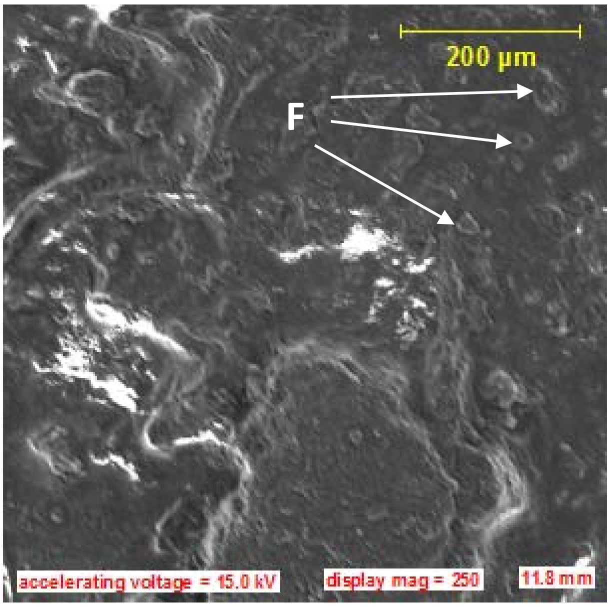

Figure 11. SEM micrograph of 15 wt. % sample showing surface morphology at 250× magnification

4. Conclusions

The following conclusions were made from the results and discussion.

- The work shows the successful development of polyester composites reinforced with iron filings.
- Tensile and flexural properties of the unsaturated polyester material are improved by the introduction of filing particles into the matrix up to 15 wt. %.
- The sample with 15 wt. % iron filings gave the optimum reinforcement values; optimum tensile strength (34.91 MPa), optimum flexural strength (111.06 MPa) and improved modulus of elasticity (1581.29 MPa). Further concentration of particles over 15 wt. % tends to form clusters which result in poor tensile and flexural properties.

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