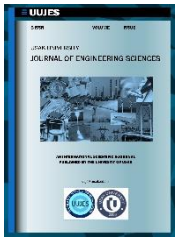

Usak University

Journal of Engineering Sciences

An international e-journal published by the University of Usak

Journal homepage: dergipark.gov.tr/uujes

Research article

EFFECTS OF SILICON CARBIDE, MILLSCALE, AND MAGNESIA PARTICULATES ON THE MECHANICAL PROPERTIES OF HYBRID UNSATURATED POLYESTER RESIN MATRIX COMPOSITES

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Received: 13 April 2018 Revised: 17 May 2018 Accepted: 28 May 2018 Online available: 27 June 2018
Handling Editor: Kemal Mazanoğlu

Abstract

The efficacy of reinforcement of polyester resin matrix composites with hard ceramic particles for optimal performance was studied. 5-25 wt. % of silicon carbide, millscale, and magnesia particles were applied in reinforcing unsaturated polyester resin matrix by mould casting and the microstructural and mechanical characteristics of the composites were evaluated. There was uniform distribution of silicon carbide, millscale, and magnesia particles in the polymer composites matrix from the scanning electron microscopy (SEM) result. The highest mechanical properties in terms of ultimate tensile strength (73.75 MPa), flexural strength (74.89 MPa), hardness (98.76 BHN), and impact energy (24.85 J) was exhibited by the hybrid composite at 15 wt. % reinforcement. This shows the efficacy of hybridisation and the high potential of the composite for wider applications.

Keywords: *Ceramic particles; polyester resin; hybridisation; mechanical properties.*

1. Introduction

Among the advantages of polymeric materials are their resistance to corrosive media, appreciable toughness, low density, shrinkage, flexibility, cost, and ease of casting. The preference for polymeric materials is also linked to their ease of processing and production [1, 2].

Despite these advantages, they do not possess high impact energy and other mechanical properties limiting their application in some areas. Polymeric composites have been produced using synthetic fillers in order to overcome these shortcomings. For example,

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using high strength fibres to reinforce polymers has greatly improved the mechanical properties of polymer matrix composites (PMCs) thereby making them to be suitable for an application in some areas. However, there are some drawbacks due to the high cost of synthetic fibres, difficulties in their processing, and their adverse environmental impact. This has increased the interest of replacing these synthetic fibres reinforced polymer matrix composites (PMCs) with readily available alternatives which can serve the same purpose of reinforcement.

Unsaturated polyester resin is a widely used thermoset resin. Annually, more than two million tons of unsaturated polyester resins are used worldwide for the production of a wide range of products which include sanitary-ware, pipes, tanks, gratings, components for marine and automotive industries. Generally, there is an increasing potential for the application of unsaturated polyester resin in many areas. The low cost, ease of use and weight advantage of polyester resin have made it preferable material for structural and decorative applications. Unsaturated polyester resin has also been used for making thermoset composites, especially with glass fibres. Natural fibres like jute, coir, sisal, sun hemp, straw, etc. are incorporated into the polyester matrix to make composites [3]. Furthermore, preparation of polyester composite is relatively easy in existing technology with a balanced set of properties as required. Researchers have found out that with some modifications, these materials can exhibit excellent performance especially in strength and stiffness [4]. Hence, the development and characterisation of polyester resin matrix composites reinforced with various fillers are needed for applications in many areas.

Reinforcement of polymers with particles enhances their mechanical characteristics for optimal performance and wider applications. The use of particles as fillers is being encouraged because they are economical, effective, and are good for modifying the properties of polymers. However, the degree of improvement of properties is often predicated on the type of reinforcement (either synthetic or natural), particles' size and shape, filler concentration, and surface treatment. Particles are widely used to enhance the mechanical, thermal, and tribological properties. They restrict dislocation movement in the matrix phase in the vicinity of each particle. A typical example is concrete being composed of cement (matrix), and sand and gravel (the particulates). To achieve effective reinforcement, the particle sizes should be small and uniformly dispersed in the matrix which carries the major load. Polymer matrix composites are usually strengthened and hardened as a result of the uniform dispersion of volume or weight fraction of fine particles of hard and inert materials in the polymer matrix. The dispersed phase could be metallic or non-metallic. For example, Agunsoye et al. [5] showed that the addition of cow bone particles to recycled low density polyethylene (LDPE) enhanced the mechanical properties of the LDPE polymer matrix. Also, Isiaka and Adewole [6] proved that reinforcing polyester resin matrix with cow bone particles resulted in improvement of the mechanical properties of the PMCs.

Hence, this study was undertaken to expand the application of PMCs by the development and characterisation of unsaturated polyester resin matrix composites reinforced with silicon carbide, millscale, magnesia particles, and the hybrid of these materials. These are ceramic materials which possess good mechanical, thermal, and tribological characteristics.

2. Materials and method

2.1. Materials and equipment

Silicon carbide, millscale, magnesia, unsaturated polyester resin, mould release agent, Cobalt Naphthanate (accelerator), and methyl ethyl ketone peroxide (catalyst) are the

materials used. Some of these materials are shown in Fig. 1 while the structure and composition of the unsaturated polyester resin are shown in Fig. 2 and Table 1 respectively.

(a) (b) (c)

Fig. 1 Photographs of the raw materials for (a) 150 μm silicon carbide particles, (b) 150 μm millscale particles, and (c) received 53 μm magnesia particles.

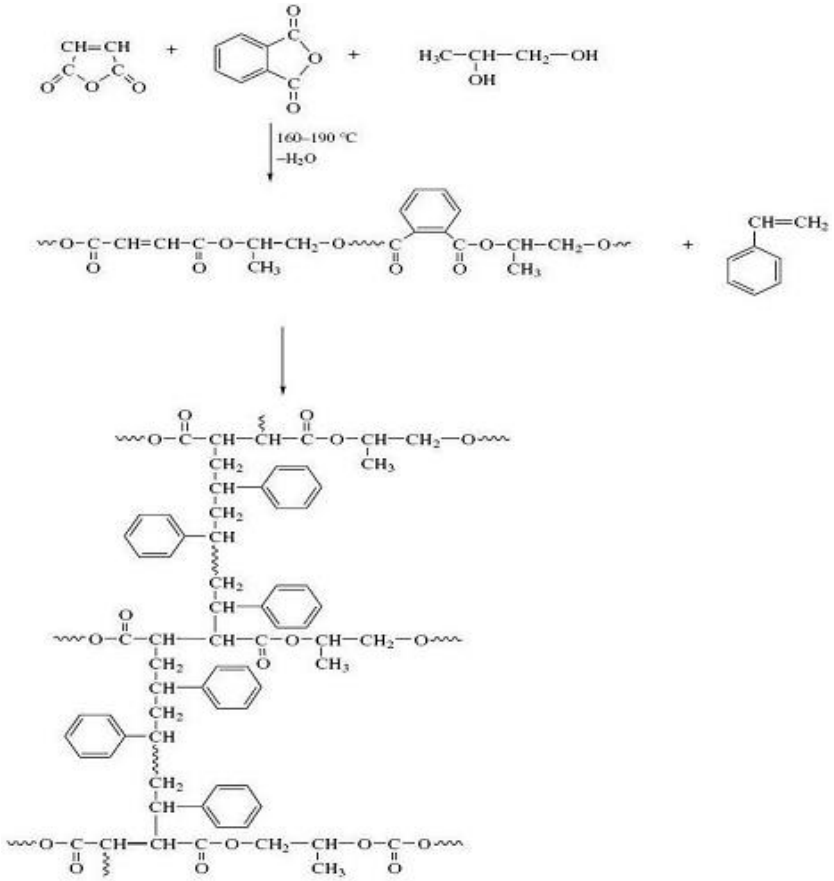

Fig. 2 Chemical structure of a typical unsaturated polyester resin linkage [7].

Table 1 Composition of unsaturated polyester resin.

Materials	Propylene glycol	Phythalic anhydride	Maleic anhydride	Styrene monomer	Additive/ Pigment paste
Weight (%)	23	21	16	38	2

2.2. Composite samples production

Each of the samples was prepared and weighed using an electronic weighing balance to give a total of 80 g. The proportion of the materials mixture presented in Table 2 is the weight fraction of 80 g for each of the samples. Desirable reinforcement quantities were added to the matrix (polyester resin) and stirred with a glass rod until a proper blend was obtained. 1 g of catalyst and 0.5 g of accelerator were added to each blend and was thoroughly stirred for proper blending. 80 g of each mixture was poured inside a paper tape coated wooden mould and allowed to solidify after which the samples were removed from the mould. The same process was adopted for all samples produced with changes in the weight fraction as shown in Table 2. The 1st batch is polyester resin reinforced with varied wt. % of silicon carbide particles. The 2nd batch is polyester resin reinforced with varied wt. % of millscale particles. The 3rd batch is polyester resin reinforced with varied wt. % of magnesia particles. 4th batch is the hybrid sample which is polyester resin reinforced with equal mixture of silicon carbide, millscale, and magnesia. 5 wt. % hybrid implies that 1.7 wt. % silicon carbide + 1.7 wt. % millscale + 1.6 wt. % magnesia particles were blended with 95 wt. % polyester resin matrix. 25 wt. % hybrid implies that 8.3 wt. % silicon carbide + 8.3 wt. % millscale + 8.4 wt. % magnesia particles were blended with 75 wt. % polyester resin as illustrated in Table 2.

2.3. Microstructural examination

The samples were etched using Keller's reagent (95 ml water, 2.5 ml HNO_3, 1.5 ml HCl, 1.0 ml HF) by swabbing for 15 secs at room temperature. Thereafter, an ASPEX 3020 model variable pressure scanning electron microscope was used to examine their microstructure.

2.4. Tensile strength determination

The tensile test specimens of dimension 120 mm x 80 mm x 50 mm were prepared using QualiLathe-210–CNC lathe machine and an Instron universal testing machine was used in accordance with the American Standard testing and measurement method D412 (ASTM D412 1983). The machine was operated at a cross head speed of 10 mm/min. Each specimen was positioned in the Instron universal tester and then subjected to tensile load. As the specimen stretched, the computer generated graph as well as all the desired parameters until it fractured. A graph of load versus extension was plotted automatically by the tester and various properties of the specimen determined are: tensile strength, tensile strain, modulus, and tensile strain at break.

2.5. Flexural strength determination

A three-point flexural test was conducted on the specimens of dimension 120 x 50 x 10 mm in accordance with ASTM D7264 using a testometric machine with serial number 25257 and capacity 25 KN with a cross-head speed of 20 mm/min while maintaining a span of 100 mm.

Table 2 Quantity of materials.

Matrix (wt. %)	Reinforcement (wt. %)				
Polyester resin	**SCP**	**MSP**	**MGP**	**Hybrid (SCP + MSP +MGP)**	**Total (wt. %)**
100 (control)	-	-	-		100
	1st Batch				
95	5	-	-	-	100
90	10	-	-	-	100
85	15	-	-	-	100
80	20	-	-	-	100
75	25	-	-		100
	2nd Batch				
95	-	5	-	-	100
90	-	10	-	-	100
85	-	15	-	-	100
80	-	20	-	-	100
75	-	25	-	-	100
	3rd Batch				
95	-	-	5	-	100
90	-	-	10	-	100
85	-	-	15	-	100
80	-	-	20	-	100
75	-	-	25	-	100
	4th Batch				
95	-	-	-	1.7 SCP + 1.7 MSP + 1.6 MGP	100
90	-	-	-	3.3 SCP + 3.3 MSP + 3.4 MGP	100
85	-	-	-	5 SCP + 5 MSP + 5 MGP	100
80	-	-	-	6.7 SCP + 6.7 MSP + 6.6 MGP	100
75	-	-	-	8.3 SCP + 8.3 MSP + 8.4 MGP	100

SCP = Silicon Carbide Particles (wt. %)
MSP = Millscale Particles (wt. %)
MGP = Magnesia Particles (wt. %)

2.6. Hardness determination

The hardness of the specimens of dimension 25 mm x 25 mm x 10 mm was determined in accordance with ASTM D 785 standard using a Brinell hardness machine with ball indenter of diameter 20 mm and maximum load of 4000 N. Each specimen was mounted on the machine and a load of 10 kg was applied for about 15 seconds and the diameter of indentation left on the specimen was measured with a low powered microscope. The hardness number was calculated by dividing the load applied by the surface area of the indentation using the expression below. Three hardness readings were taken for each specimen at different locations and the average was determined.

$$Hardness\ (HBN) = \frac{2P}{\pi D[D - \sqrt{D^2 - d^2}]}$$

where: P is load (kg), D is diameter of indenter (mm), d is the diameter of indentation (mm), $\pi = 3.142$

2.7. Impact energy determination

Test specimens of dimension 75 mm x 10 mm x 10 mm with a 2 mm deep V-notch at their centres were subjected to impact test using an Izod impact tester in accordance with ASTM D 256 standard. Each specimen was clamped vertically with the notch facing the striker and the striking pendulum was allowed to swing downwards from a height of about 1.5 m with a velocity of 5 ms^{-1} impacting the specimen. The energy absorbed to break each specimen was read from the dynamometer.

3. Results and discussion

3.1. Microstructure of samples

As illustrated in Figs. 3a to 3d, the gray portions in the microstructure of the specimens indicate the presence of polyester resin matrix phase. Formation of pores is more pronounced in Figs. 3a and 3b which had adverse effect on the mechanical and wear properties of the unreinforced and reinforced samples. Fig. 3b shows a fairly uniform dispersion of MgO particles in the unsaturated resin. In Fig. 3c, the micrograph shows a uniform dispersion of millscale particles in the resin matrix with little formation of pores. This improved the mechanical and wear properties of the composites compared to the unreinforced polyester resin and MgO particles reinforced samples with much pores in their microstructures. In Fig. 3d, uniform dispersion of the hybrid reinforcing particles is observed in the microstructure. There is also strong adhesion of particles – polyester resin interphase thereby preventing particles pulling out. These are the two major factors that led to the improvement in mechanical and wear properties of the hybrid specimens compared with others.

3.2. Ultimate tensile strength

As shown in Fig. 4, the ultimate tensile strength (UTS) of the reinforced samples are greater than the control sample which was not reinforced. At 15 wt. %, the hybrid sample demonstrated the greatest ultimate tensile strength value of 73.75 MPa. This shows the ability of the blend of particles of magnesia, millscale, and silicon carbide in enhancing the UTS. The uniform dispersion of the hybrid reinforcing particles as observed in the microstructure and strong adhesion of particles – polyester resin interphase must have contributed to the improvement of the UTS. The greatest tensile strength value of the hybrid composite sample falls within the range of values stated by Patel and Gohil [8]. A reduction in UTS is observed beyond 15 wt. % which could be weak adhesion which adversely affected load distribution.

3.3. Flexural strength

As illustrated in Fig. 5, there is a progressive increase in flexural strength of reinforced specimens with increasing reinforcement up to 15 wt. %. It is an indication of improving characteristics of the reinforced specimen to resist deformation under bending stress. At 15 wt. %, the hybrid specimen exhibited the greatest flexural strength value of 74.89 MPa. Uniform dispersion of the hybrid reinforcing particles in the microstructure and strong

adhesion of particles – polyester resin interphase must have contributed to the improvement of the flexural strength. A reduction in the flexural strength of the reinforced samples is observed above 15 wt. % reinforcement which may be due to the controlled mobility of polyester matrix by particles as amount of reinforcement increased. Hence, a decrease in the total surface area available for particles-matrix interaction in the specimens.

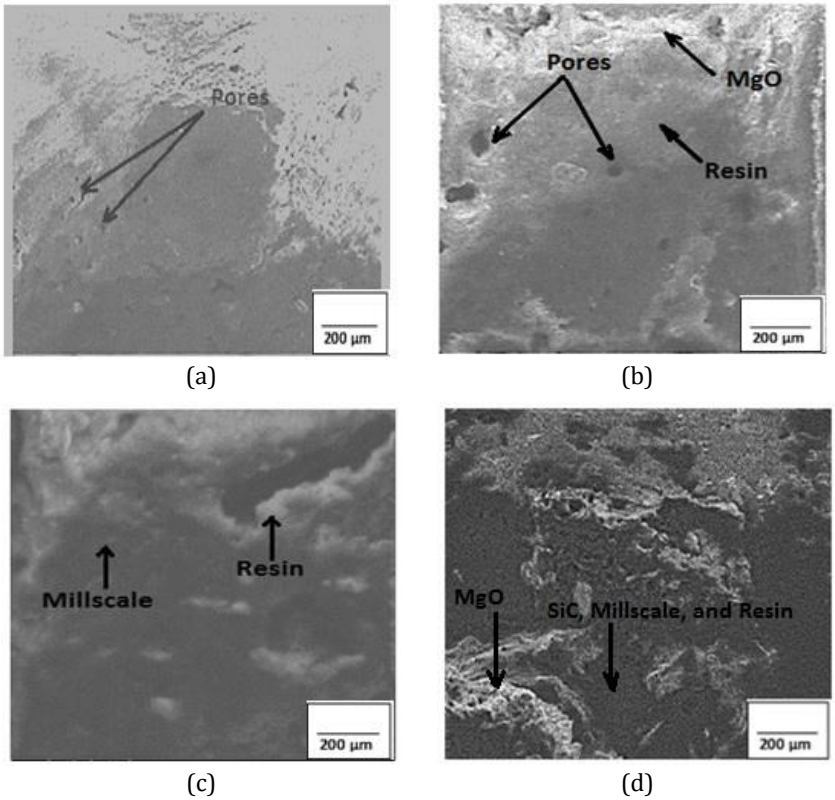

Fig. 3 Microstructure of the samples for (a) unreinforced unsaturated resin matrix, (b) 15 wt. % MgO particles reinforced, (c) 15 wt. % Mill-scale particles reinforced, and (d) 15 wt. % hybrid composites.

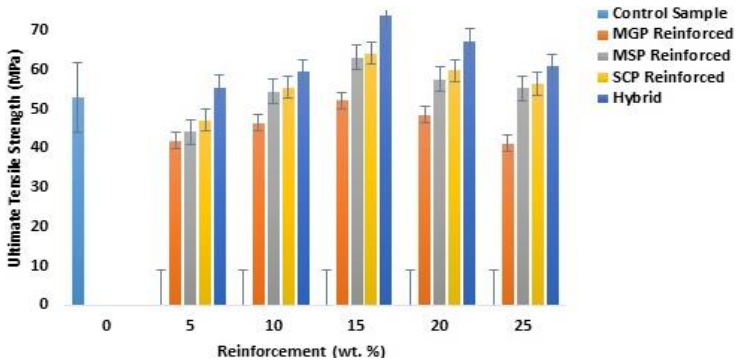

Fig. 4 Graph of ultimate tensile strength against wt. % reinforcement of the composites.

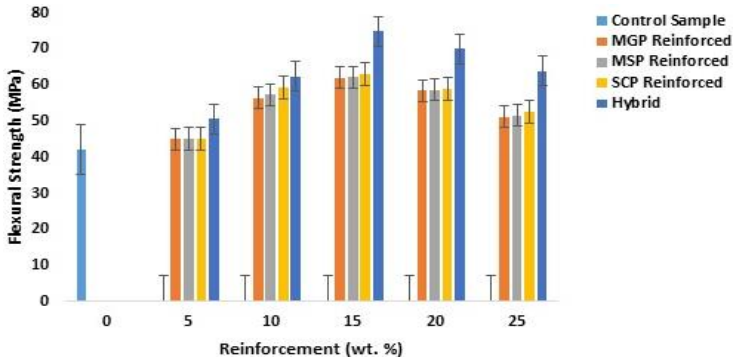

Fig. 5 Graph of flexural strength against wt. % reinforcement of the composites.

3.4. Hardness

The hardness value of the unreinforced sample is 80.16 BHN. The reinforced samples exhibited higher hardness than the unreinforced sample as shown in Fig. 6. The hybrid composite exhibited the highest hardness of value of 98.76 BHN at 15 wt. % reinforcement. This indicates the ability of the blend of particles of magnesia, millscale, and silicon carbide in enhancing the hardness of the specimen. The uniform dispersion of the hybrid reinforcing particles as observed in the microstructure and strong adhesion of particles – polyester resin interphase must have also contributed to the improvement of the hardness. The reduction observed in hardness above 15 wt.% reinforcement may be due to weak adhesion of particles and polyester resin.

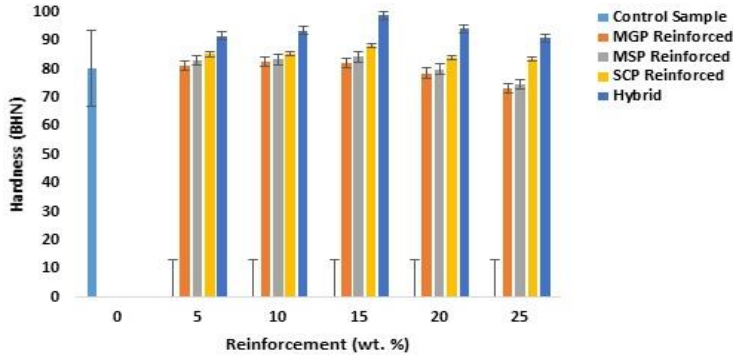

Fig. 6 Graph of hardness against wt. % reinforcement of the composites.

3.5. Impact energy

As illustrated in Fig. 7, there is a progressive increase in impact energy of the reinforced specimens up to 15 wt. % reinforcement. Generally, the reinforced specimens exhibited greater impact energy than the unreinforced with the hybrid specimen exhibiting the greatest impact energy value as of 24.85 J at 15 wt. % reinforcement. Uniform dispersion of the hybrid reinforcing particles as observed in the microstructure and strong adhesion of particles – polyester resin interphase must have also contributed to the improvement of the impact energy. Reduction observed in impact energy above 15 wt.% reinforcement may be due to weak adhesion of particles and polyester. This may also be due to agglomeration of particles which enhanced pores formation resulting into formation and propagation of cracks.

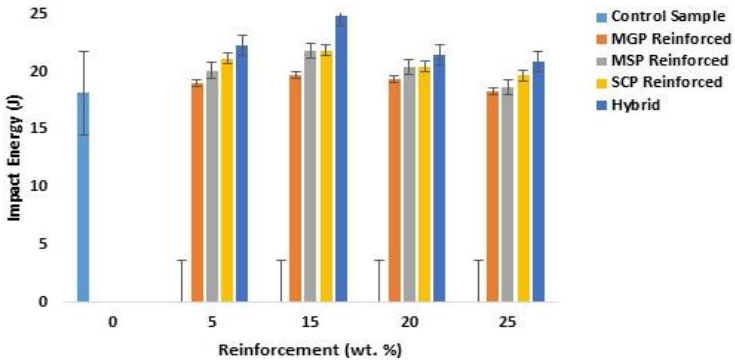

Fig. 7 Graph of impact energy against wt. % reinforcement of the composites.

4. Conclusions

In this study, polyester resin matrix composites reinforced with particles of magnesia, millscale, silicon carbide, were developed and characterised.

- Hybrid sample demonstrated the highest mechanical characteristics with respect to UTS (73.75 MPa), flexural strength (74.89 MPa), hardness (98.76 BHN), and impact energy (24.85 J) at 15 wt. % particles addition.
- The positive effects of particles reinforcement on the mechanical properties of the PMCs have been demonstrated.
- The hybrid composite at 15 wt. % reinforcement meets the structural and surface conditions necessary for biomedical application.

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