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An experimental investigation on mechanical properties of SiC particle and sisal fibre reinforced epoxy matrix composites

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Abstract. In the present work, the effect of SiC particle addition on mechanical behaviour of sisal fibre/epoxy composites was investigated. The epoxy composites were prepared by using hand layup technique. During the processing of composites, the fixed amount of sisal fibre and different amounts of SiC Particles ranging from 2 to 10 wt% were used as reinforcements. The produced composites were subjected to mechanical characterization (tensile, bending and impact tests). As per ASTM standards the test specimens were prepared to perform the mechanical testing. The findings revealed that the tensile strength and elongation at failure was reduced when the SiC particles content was increased. The increases in wt % of SiC up to 10 % drastically reduced the ultimate strength and elongation to 10.94 MPa and 0.729 % respectively, which was 39.2 % and 38.84 % lower than that of sisal fibre/epoxy composite. The flexural strength of sisal fibre/epoxy composite was increased to 74 MPa when the SiC particles increased up to 5 wt % and then reduced to 65 MPa with further increment in weight fraction of SiC particle. The impact strength was increased from 2 to 4 J/mm² when the SiC particles content was increased up to 10 wt %. Scanning electron microscope was used to observe the fracture mechanism of the tensile test specimen. The brittle mode of failure was observed from the fractographs of the tensile test specimen.

Keywords: Epoxy, SiC particle, Sisal fibre, Mechanical properties

1. Introduction

Epoxy is a widely used thermosetting polymer matrix to produce the fibre reinforced composites because of their excellent resistance to the chemical environment, low level of shrinkage and simple procedure of processing. Hence, its usage is restricted in certain applications due to their low toughness and strength. These properties can be improved when it is reinforced with inorganic fibres and particles, which led to the development of polymer matrix composites. The epoxy matrix composites are advanced materials, which offer a combination of strength and modulus that are



comparable to the conventional metals [1-4]. These composites play a major role in various industries like automotive, aerospace, marine, defence and sporting because of their superior mechanical behaviour. The mechanical behaviour of the fibre and/or particle reinforced epoxy composites have been investigated by many researchers. Osman Asi [5] analysed the influence of Al_2O_3 particles on mechanical behaviour of GFRP composite. The experimental results revealed that the tensile strength and shear strength of the composites declined and flexural strength improved with an increase in weight fractions of Al_2O_3 particles. Srivastava and Anshul Verma [6] examined the effect of copper and aluminium particles as a filler material on the mechanical behaviour of epoxy resins. Their findings showed that the increase in weight fractions of copper and aluminium particles reduced the tensile strength and wear loss but increased the hardness, compressive strength and coefficient of friction.

Singha and Vijaykumarthakur [7] studied the mechanical properties of polymer matrix composites containing urea-formaldehyde and Hibiscus sabdariffa. It is observed that the wear resistance, compressive strength and tensile strength etc of the urea-formaldehyde resin increased when it is incorporated with the Hibiscus sabdariffa. Ary Subagia and Yonjig Kim [8] analysed the performances of carbon-basalt/epoxy hybrid composites by flexural testing. The authors noted that the flexural property of composites depends on the arrangement of basalt fabric and carbon. Higher bending strength and modulus was observed on the outermost layers of hybrid composites compared to the innermost layer. From the fractured surfaces, delamination and fiber pull-out were observed for hybrid laminates. Manoj Singla and Vikas Chawla [9] investigated the mechanical performance of fly ash filled GFRP composites. From the observations, they concluded that the compressive behaviour of epoxy resin is increased and impact strength is reduced when it is reinforced with fly ash. Further, the addition of glass fibre with fly ash/epoxy composites enhanced the compressive and impact strength.

Akindapo Jacob Olaitan et al. [10] examined the mechanical performance of rice husks and groundnut shell blended epoxy resin. The composites containing epoxy and groundnut shell showed superior performance compared to composites of epoxy and rice husk. Satnam Singh et al. [11] investigated the mechanical performance of GFRP composites fabricated by using hand layup process. They recorded that there was an improvement in the bending and tensile behaviour of GFRP composites compared to pure epoxy. Hence, they noted the low impact strength due to more brittleness of the composites. Sivasaravanan et al. [12] studied the mechanical performance of epoxy/clay nanocomposites prepared by hand layup technique. The toughness of epoxy is improved when it is reinforced with nano clay up to 5 wt%. Also, it is observed that the composite preparation is very difficult when the content of nano clay is greater than 5 wt%.

Mishra and Biswas [13] analysed the influence of reinforcement variation on mechanical performance of composites containing jute and epoxy. The addition of jute fiber reduced the void content in the composite. The superior inter-laminar shear and bending strength is reported for the composite containing 48 wt% of jute fiber due to less void content. Romli et al. [14] investigated the influence of the fibre loading and curing time of composite on the mechanical performance of coir/epoxy composites. The fiber loading and curing period had an effect on the tensile properties and no adverse effect on compressive properties. Bernd Wetzel et al. [15] studied the influence of micro and nano particles content on mechanical and wear behaviour of epoxy composites. Their results indicated that flexural strength and modulus increased and impact strength decreased when the reinforcement content increased. From the literature, it has been noted that not enough research work is attempted on hybrid epoxy composites containing sisal fibre and SiC particle. So, it is decided to study the influence of SiC particle on mechanical behaviour of sisal fibre/epoxy composites.

2. Experimental procedures

2.1 Materials

In the current study, the epoxy resin (LY 556) and hardener (HY 951) was selected as a matrix materials and sisal fibre was used as a reinforcement material. Silicon carbide (SiC) with a size of 50 μm was chosen as filler material to improve properties of the epoxy. The photographic image of the SiC particles and sisal fibre are shown in Figure1.

2.2 Processing of composites

The epoxy resin and SiC particles were preheated to 65°C for 1 hour to improve their wettability and then the filler material was mixed with matrix by using mechanical stirring. Different weight fractions of SiC particles, ranging from 2 to 10% were added with epoxy resin. After the addition of SiC particles with the epoxy resin, the stirring was extended for 10 minutes to obtain the homogeneous mixing. The hardener (HY 951) was mixed with the epoxy and SiC particles in the ratio 1:10 by weight. The mould with the dimensions 300 mm length, 300 mm breadth and 10 mm thick was designed to produce the composites. Teflon coated glass fabric separator was spread over the mould surface, which facilitate the easy removal of composites from the mould. Initially, the sisal fibres were aligned at an angle 0° and then the mixture of epoxy and SiC particles poured over the surface of the fibres. Similarly, the fibres were aligned at an angle 45° and 90° and then the mixture of epoxy and SiC particles poured over the surface of the fibres to get the required thickness of composite. Finally, the composite mixture was allowed to curing for approximately 24 hours and then it was taken out from the mould.



Figure1. Reinforcements (a) SiC particle (b) Sisal fibre.

2.3 Mechanical testing

As per standard procedures, all the test specimens for performing mechanical testing were prepared from the produced composites. The tensile test was conducted as per the standard ASTM D3039 in the universal tensile testing machine. The tensile test needed specimens with a length of 250 mm, breadth of 25 mm and thickness of 5 mm, which were machined and prepared from the composite. The test specimen and machine is shown in Figure 2.



Figure 2. Tensile testing (a) Test specimen and (b) Failed specimen.

The 3 point bending test was performed according to the ASTM D790 in the universal testing machine at room temperature. The bending test specimen was cut from the composite with 100 mm long, 15 mm breadth and 5 mm thickness. The spacing between the supports was fixed as 60 mm to perform the bend test. The test specimen and machine is shown in Figure 3. The charpy impact test was conducted as per the standard ASTM D256 to determine the impact behaviour of the composite. The test samples were prepared with a length of 55 mm, breadth of 10 mm and thickness of 10 mm with a V-notch. The test specimen and machine is shown in Figure 4. For all the testing, three trials of experiments were conducted and the average values were reported. Scanning electron microscope was used to observe the fracture mechanism of the tensile test specimen.

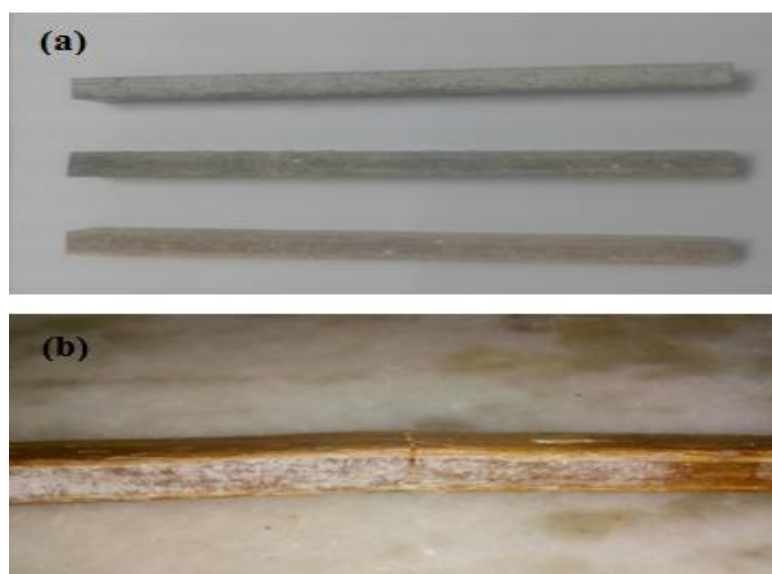


Figure 3. Bend testing (a) Test specimen and (b) Failed specimen.

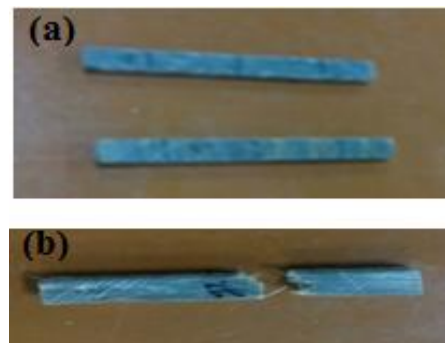


Figure 4. Impact testing (a) Test specimen and (b) Failed specimen.

3. Results and discussion

3.1 Mechanical properties

The variation in ultimate tensile strength and percent elongation of sisal fibre/epoxy composites with SiC particle content is presented in Figure 5. The addition of SiC particles into sisal fibre/epoxy composites reduced the percent elongation and ultimate tensile strength. Further, the percent elongation and ultimate tensile strength of composites are reduced when the SiC content is increased. The ultimate strength and elongation of 2 wt % SiC reinforced sisal fibre/epoxy composite are 17.25 MPa and 1.192 % respectively, which is 4.167 % and 21.89 % lower than that of sisal fibre/epoxy composite. Further, the increases in wt % of SiC up to 10 % drastically reduced the ultimate strength and elongation to 10.94 MPa and 0.729 % respectively, which is 39.2 % and 38.84 % lower than that of sisal fibre/epoxy composite. This is because of agglomeration of SiC particles and presence of voids in the composites. At higher wt % of SiC particles weak adhesion and large agglomeration are observed, which resulted in lower percent elongation and ultimate tensile strength.

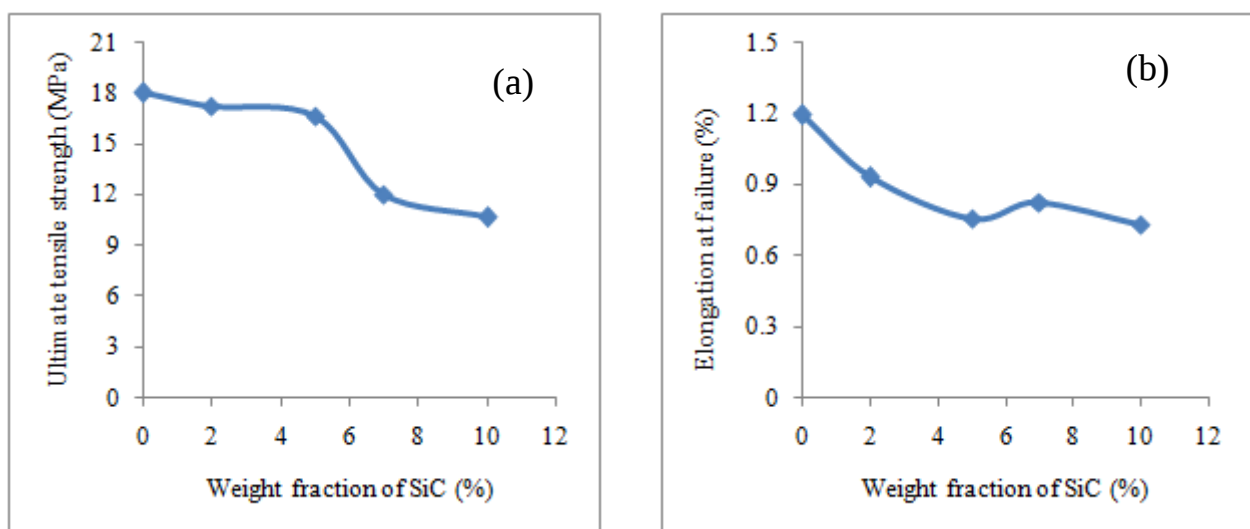


Figure 5. Variation of (a) Ultimate tensile strength and (b) elongation at failure of sisal fibre/epoxy composites with SiC particle content.

The variation in flexural strength and impact strength of sisal fibre/epoxy composites with SiC particle content is presented in Figure 6. The flexural strength of sisal fibre/epoxy composites are

increased when the SiC particles increased up to 5 wt % and then reduced with further increment in weight fraction of SiC particle. The flexural strength of 5 wt % SiC reinforced sisal fibre/epoxy composite is 74 MPa, which is 64.4 % greater than that of sisal fibre/epoxy composite.

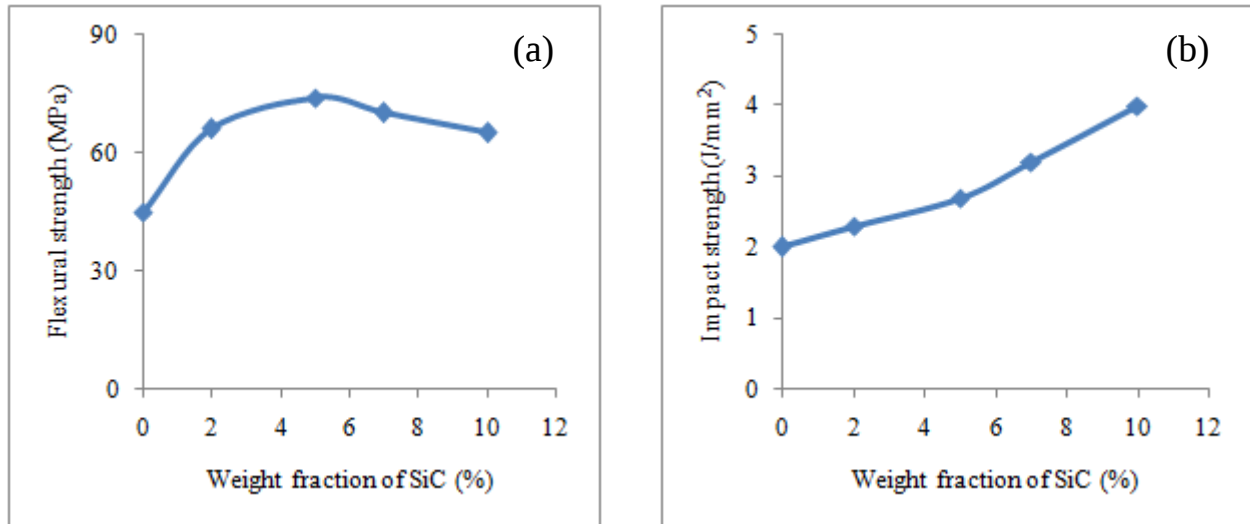


Figure 6. Variation of (a) Flexural strength and (b) Impact strength of sisal fibre/epoxy composites with SiC particle content.

Hence, the flexural strength is reduced to 65 MPa when the wt % of SiC is increased from 5 to 10 %, which is 12.16 % lower than that of 5 wt % SiC reinforced sisal fibre/epoxy composite. This is because of strong adhesion at the SiC/epoxy interface. Large agglomeration is observed at higher wt % of SiC particles, which leads to lower flexural strength. The impact strength of sisal fibre reinforced epoxy composites are linearly increased when the SiC content is increased. The impact strength of 2 wt % SiC reinforced sisal fibre/epoxy composite is 2.3 J/mm², which is 15 % greater than that of sisal fibre/epoxy composite. Further, the increases in wt % of SiC up to 10 % increased the impact strength to 4 J/mm², which is 48.15 % greater than that of 5 wt % SiC reinforced sisal fibre/epoxy composite. This is because of strong adhesion at the SiC/epoxy interface.

3.2 Fractograph

The tensile fracture surface of sisal fibre/epoxy composites with SiC particle content is presented in Figure 7. The lower magnification of tensile fractograph of 2 and 5 wt% SiC reinforced sisal fibre reinforced epoxy composites is shown in Figure 7 (a) and (b). These fractograph portraits the fibre fracture, voids and fibre pull out. The higher magnification of tensile fractograph of 7 and 10 wt% SiC reinforced sisal fibre reinforced epoxy composites is shown in Figure 7 (c) and (d).

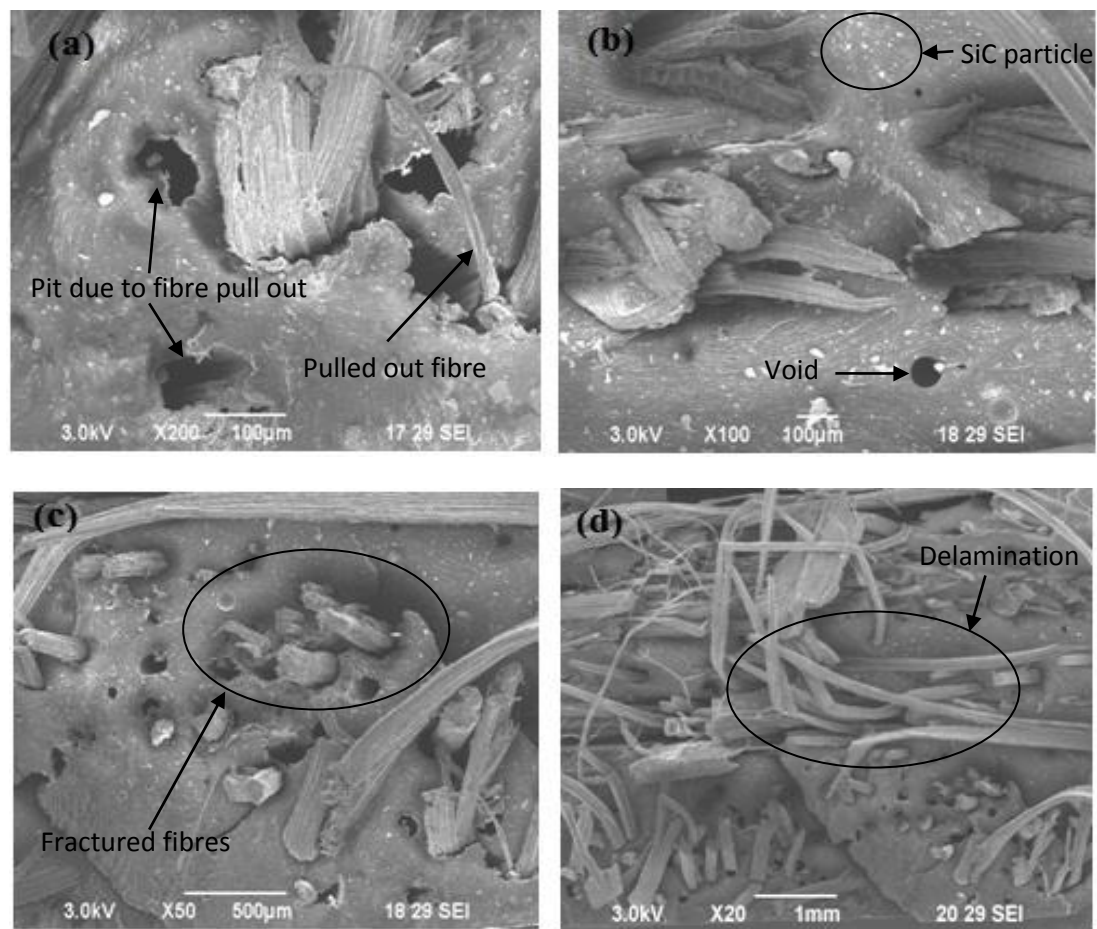


Figure 7. Tensile fracture surface of sisal fibre reinforced epoxy composites with (a) 2 wt% of SiC, (b) 5 wt% of SiC, (c) 7 wt% of SiC and (d) 10 wt% of SiC particles.

The higher magnification fractograph clearly indicates the fibre fracture, fibre pull out, delamination and voids. From the fractographs, the pulled out SiC particles were also observed. As the bonding between the epoxy and sisal fibre is not enough strong, the fibres are fractured and pulled out from the interface of the composite. The brittle mode of failure was observed from the fractographs of the tensile test specimen.

4. Conclusion

The epoxy composites reinforced with SiC particle and sisal fibre were prepared by hand layup process. The mechanical performance of the produced composites was investigated when the composites were subjected to mechanical testing. The following conclusions have been arrived from this study.

1. The addition of SiC particles into sisal fibre/epoxy composite reduced the ultimate tensile strength and percent elongation. When the wt % of SiC was increased up to 10 %, the ultimate tensile strength and elongation was reduced from 18 MPa and 1.192 % to 10.94 MPa and 0.729 % respectively.

2. The flexural strength of sisal fibre/epoxy composite was increased from 45 to 74 MPa when the SiC particles increased up to 5 wt % and then reduced to 65 MPa with further increment in weight fraction of SiC particle.
3. The impact strength of sisal fibre/epoxy composite was increased from 2 to 4 J/mm² when the SiC particles content was increased up to 10 wt %.
4. The composites failed in a brittle manner, which was observed from the SEM image of tensile test samples.

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