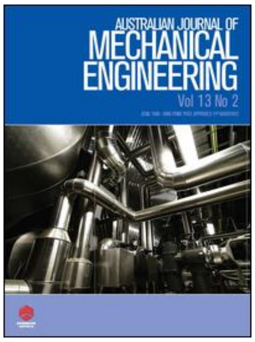

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ARTICLE

Enhanced mechanical properties of glass fibre-reinforced polymer composites with addition of AL_2O_3

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ABSTRACT

This paper depicts the mechanical behaviour of new class of multi-phase composites consisting of glass fibre-reinforced polyester composite filled with Al_2O_3 particles, Glass fibre-reinforced polyester composites was prepared by incorporating alumina particle at three different filler contents viz. 1 3 and 6%, and the mechanical properties of these composites are evaluated. The mechanical properties such as impact energy and hardness of the glass fibre-reinforced polyester composite was improved by adding alumina particles but increasing the percentage of filler content could be seen that there was reduction of impact energy, but increasing of hardness value. The macroscopic fracture surfaces of tensile specimens of all types of composites are studied briefly, However, the tensile strength and modulus of the Al_2O_3-filled glass fibre polyester composite was slightly lower than that of bare glass fibre-reinforced polyester composite, because of the tensile properties are more sensitive for how particles presented as network in the matrix.

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KEYWORDS
Particulate-reinforced polyester composites; mechanical properties; hybrid composite material; Al_2O_3

1. Introduction

Fibre-reinforced composite materials consist of fibres of high strength and modulus surrounded in or bonded to a matrix with different interfaces between them. In this manner, the both fibres and matrix retain their physical and chemical characteristics, but still they produce a combination of properties, which cannot be obtained with either of it element acting separately. In fibre composites, the load carrying and load transfer elements are fibres and matrix, respectively. The reinforced fibre carries the applied load to its ultimate strength whereas the matrix transfers the load through interface to all reinforcement fibres. Moreover, this matrix provides desired orientation and location to fibres, it also protects that from environment damages due to elevated temperature, erosion, corrosion and humidity (Mallick 2007). Since a few decades, the research and developments on the fibre-reinforced polymer composites has not been just limited to the structural applications but thermal, electrical, aerospace and automobile, and marine applications, because their different characteristics such as low density, high rigidity, eminent strength, greater specific modulus and ability to be tailored for specific purposes. Though these are the advantages, but the impact behaviour of composite is unpredictable, which strongly depends on residual load bearing capacity. In addition, the damage to the composite structures resulted from accidental impacts were classified according to low/high impact velocity (Navaneethakrishnan and Athijayamani 2017). Similarly, during assembly and maintenance the operational life was affected by dynamic and impact loading whereas mechanical arms, aircraft wings were affected by bending stress, which limits the use of composite materials (Morozov, Morozov, and Selvarajalu 2003).

To overcome these limitations, the desired properties of the fibre composites have generally been achieved by two common methods with either fibre modification or matrix modification technique. As the name itself describes that fibre modification is a change on the sphysical structure of fibre surface for better impregnate into polymer matrix whereas the matrix modification states that polymer matrix filled with inorganic/organic particles or blends. However, the present work focused only on matrix modification technique where polymer matrix can be modified with ceramic or oxide particles such as carbon nanotubes, nanosilica, clay, alumina, silicon carbides and titanium oxides. Although there were difficulties observed for improving of particular mechanical properties of such nanopolymer through this method, due to agglomeration and phase separation between matrix and fillers with high loading of reinforcement particles, there have been several researches evident to improved mechanical properties of fibre-reinforced polymer composite at optimum loading of fillers in polymer matrix (Das and Biswas 2016; Kiran et al. 2018;

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Godara et al. 2010; Wichmann et al. 2006; Navaneethakrishnan and Athijayamani 2015).

Additionally, the mechanical properties of silk hybrid bio composite were optimised with inclusion of 6% silicon carbide particles (Akash, Avinash, and Ramachandra 2018). The tensile strength, flexural strength and hardness of the respective composite were 41.4 Mpa, 53 Mpa and 88 RBHN, respectively. According to Agarwal et al (Navaneethakrishnan and Athijayamani 2016), For 10 wt% loading of SiC, The tensile strength, flexural strength, hardness, interlaminar shear strength and impact strength of the short glass fibre-reinforced glass composite were improved from 185 MPa, 55 MPa, 88 HV, 35 MPa and 0.32 J to 290 MPa, 85 MPa, 96 HV and 0.63 J, respectively. Gull et al. (2015) studied that inclusion of various percentages of ZnO particles in glass fibre polyester composite and observed that flexural strength was improved by 188% for 3% ZnO content, beyond that negative effect was also observed. In addition to that, impact strength and hardness were improved by 68 and 68.37% for 5% of ZnO content, respectively. Another instance (Asi 2009) that the ultimate tensile strength was decreased and tensile modulus was increased with increasing loading of Al_2O_3 content in glass fibre-reinforced epoxy composite, but Flexural strength and modulus were increased to 10wt % of alumina loading and beyond this limit, negative effect. Moreover, the shear strength was decreased gradually with inclusion of alumina particles. Kaundal, Patnaik, and Satapathy (2018) studied the mechanical properties of Al_2O_3-filled Glass fibre-reinforced polymer composite and reported that, the micro-hardness and impact strength of the composite were increased with increasing of filler content, however tensile strength and flexture strength were decreased. But, tensile modulus and flexural modulus were increased comparatively with loading of Al_2O_3. Mohanty and Srivastava (2015) also reported that inclusion of Al2O3 in polymers increased the flexural strength and modulus, and impact energy, due to enhancement of stress transfer between fibre and matrix.

The above-presented review showed that the excellent improvement of mechanical properties of glass fibre-reinforced polymer composite were achieved using different fillers addition to the matrix. In this paper, the authors have investigated the effect of inclusion of Al_2O_3 particles to the matrix on mechanical properties of glass fibre-reinforced polyester composite. The composite panels were fabricated by hand lay-up process. The nanoparticles were dispersed in polymer by direct mechanical shear method. Mechanical testing of the composite such as tensile, impact and hardness were performed as per ASTM standards. Also, the macroscopic study was performed on the fracture surface of tensile specimens.

2. Experiments

2.1. Materials

The primary reinforcement and matrix materials used in this work werebidirectional (0°/90°) woven glass fabric(The average filament diameter of the glass fibres were about 14–18 μm) and cobalt naphthenate accelerator (at 1 wt%) pre-mixed isothalic polyester resin with methyl ethyl ketone peroxide (MEKP) as hardener, respectively, purchased from Sri Lakshmi Fiber Glass, Chithode. The mixing ratio of the resin and hardener was 100:1 by weight. Commercially available Al_2O_3active neutral powder (PH: 6.5–7.5 and Wt: 0.9 g/ml) also called as alumina of particle size 70–230 mesh obtained from Bangalore Fine Chem., Bangalore, was used as secondary reinforcement as particulate fillers. The woven glass fabric and particulate fillers both were used as chemically untreated nature.

2.2. Composite panel fabrication

The composite panels were prepared by using conventional hand lay-up manufacturing process as shown in Figure 1. The glass fabric was cut to the dimensions of 250 × 200 mm and its edges were wrapped with salfan tape to avoid splitting of tow of fibres during processing. Then, a pair of ceramic tiles covered with O-HP sheet (as release agent) in the active region used as work table as shown in Figure 1(c), wherein isothalic polyester resin mixed with hardener was poured onto woven glass fabric and squeezed with roller to infiltrate into the tow of fibres uniformly, and to remove the entrapped air from it. Similarly, the process was continued to the next 5 layers stack so as to obtain final composite panel's (Figure 1(d)) dimension to 250 × 200 mm with 3 mm thickness. After that, the composite panel was closed with top cover tile, and it was subjected to uniform pressure by placing weight stone of 10 Kg on it. The curing of composite was held at room temperature (28°C) for 48 h. In this work, without inclusion of Al_2O_3fillers in the glass fibre-reinforced polyester composite is referred as 'Bare'. To study the effects of fillers, the composites were prepared additionally by blending resin with Al_2O_3 particles in the weight percentages of 1% (C1), 3% (C2) and 6% (C3) to the fraction of total weight of matrix, thus maintaining same fibre/matrix ratio to 60:40 (Fibre volume fraction = 0.60) for all types of composite panels.

To preparation of nano-polymer, the Al_2O_3particulate filler sand isothalic polyester resin were initially mixed by hand held glass stirrer for 10 mts without formation major air bubbles. Then, this pre-mixture was further dispersed by direct mechanical shear method using ultrasonic water bath at the maximum sonic frequency of 15 KHz, as shown in Figure 1(b).

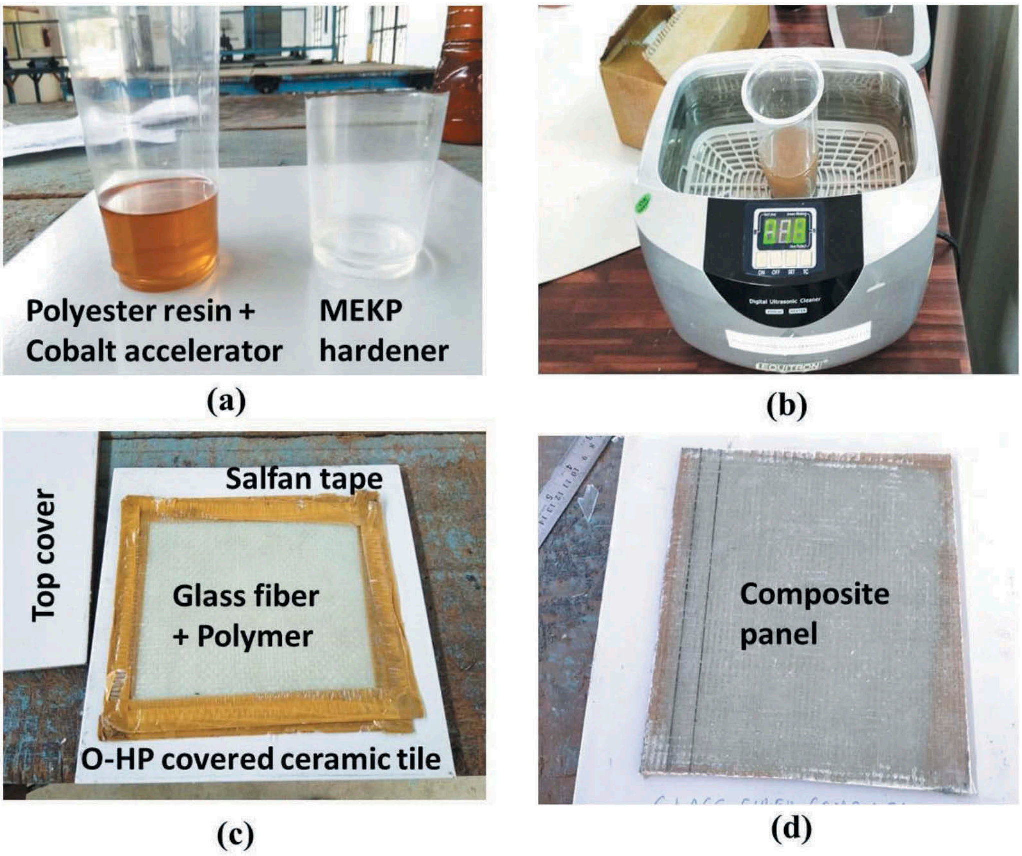


Figure 1. The materials and processes of fibre-particulate-reinforced polymer composite (a) polyester resin and hardener, (b) ultrasonic dispersion, (c) fabrication method and (d) composite panel.

The mixture contained beaker was placed inside the bath at room temperature (28°C) continuously for 1 h time. Finally, the MEKP hardener was added to the mixture and casted out Al_2O_3 particles-filled glass fibre-reinforced polyester composites with various percentages of filler contents as mentioned earlier.

2.3. Mechanical testing

The as-prepared composite panels were examined with various mechanical testing such as tensile, impact and hardness to study the effects of mechanical and physical properties of the glass fibre-reinforced polyester composite with addition of varying percentage of alumina content.

2.3.1. Tensile test

The specimens were prepared in rectangular shape of dimensions 250 × 13 × 3 mm as shown in Figure 2(a) for the tensile testing as per ASTM D638. The both ends of the specimen were tapped with SiC card board to avoid slippery and stress concentration during

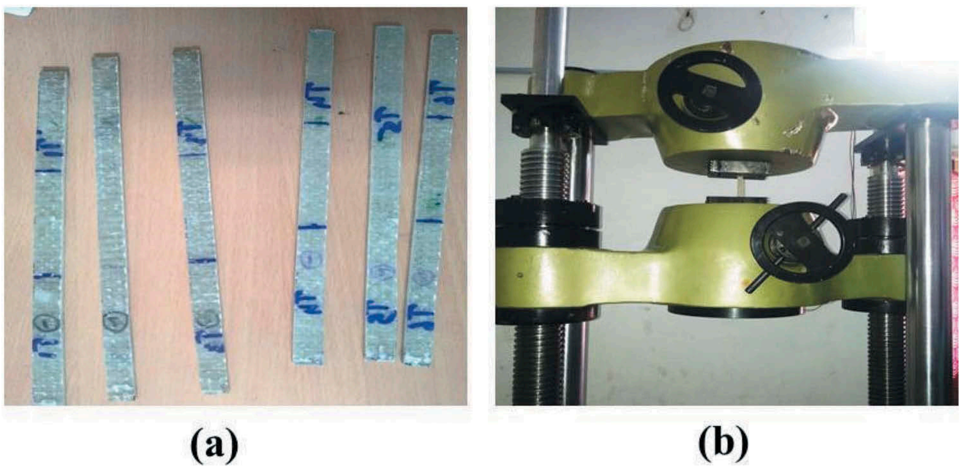


Figure 2. Tensile testing (a) composite specimens and (b) UTM with specimen loading.

testing. The load was applied equal and opposite direction to the specimen at crosshead speed of 1.5 mm/min in computerised Universal Testing Machine (Make: YAMA mode 1, UTM E 60) with 600 KN load cell, as shown in Figure 2(b). The total of 5 samples was tested in each category of composite panel types namely bare, C1, C2 and C3 glass fibre-reinforced polyester composites.

2.3.2. Impact test

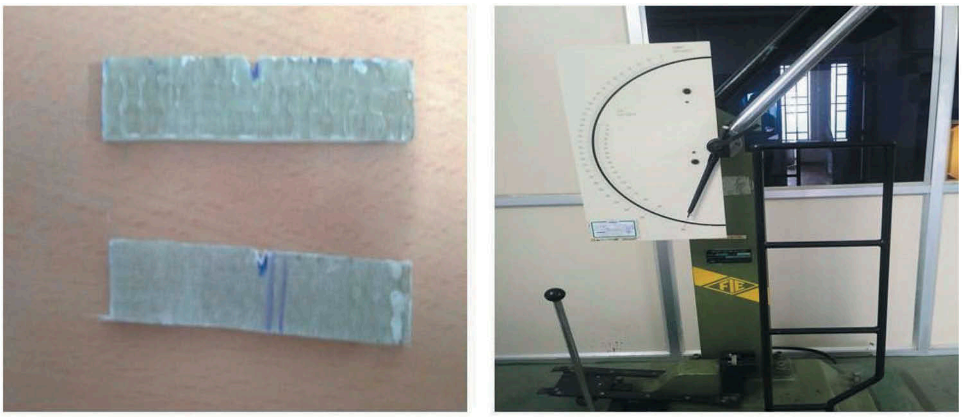
The impact test was conducted on the composite panels to study its energy absorption capacity before it failure. Charpy V notch impact test samples were prepared to the dimensions of 64 × 13 × 3.2 mm as per the ASTM D 256 (1997). The V notch was formed on one face of the specimen at perfectly centre to the depth of 2 mm as shown in Figure 3(a). The specimen was fixed on the impact tester (Figure 3(b)) such that the notch facing opposite direction to the striking end of the hammer. The total of five samples was tested in each category of composite panels. The impact energy (E) is calculated using the Eq. (1) given by,

$$E = \frac{\Delta E}{w * t} \tag{1}$$

Where, E- Impact Energy (J/mm^2), ΔE – Absorbed energy during impact loading (Joules), w- Width of the sepecimen at notch (mm), t- Thickness of the specimen (mm).

2.3.3. Hardness test

As shown in Figure 4, the hardness of all types of composite panels were tested as per ASTM D2583 with the specimen dimensions of 40 × 15 × 3 mm by barcol hardness tester (Model: VBH 2) having ball indenter of 10 mm base diameter. The specimen was placed under the indenter of barcol hardness tester and a uniform pressure was applied to the specimen until the dial gauge reaches a maximum value, hence the barcol hardness tester does not require waiting, pre-loading or other separate measurements. Then, the depth of penetration was converted into Absolute Barcol Numbers (ABN).The measurement was taken on five different surfaces in a specimen of each category of composite panels.



(a) (b)

Figure 3. Impact testing (a) V-notch samples and (b) Charpy impact tester.

(a) (b)

Figure 4. Hardness testing (a) composite specimens and (b) barcol harness tester.

3. Results and discussion

3.1. Tensile test

The tensile properties of the glass fibre-reinforced polyester composite with and without of Al_2O_3 particulate fillers are presented as Table 1. It was seen that the tensile strength of all types of composites was poor with increasing the percentage of inclusion of Al_2O_3particulate fillers in matrix. The ultimate tensile strength of bare composite specimen was 348.20 MPa. This experimental value has been observed similar for such authors (Patnaik et al. 2009; SaiSravani, Ram Gopal Reddy, and Mohammed 2017). However, the ultimate tensile strength of composite specimen types C1, C2 and C3 was about 305.14, 293.76 and 281.90 MPa, respectively. Thus, incorporation Al_2O_3particulate fillers decreasing those from bare composite specimen by 12.3, 15.6 and 19%, respectively. This is due to the fact that increasing of incorporation of fillers to matrix has two major contributions, one towards increasing the surface fracture energy, size of voids and agglomeration of particles and another one, irregular and randomly oriented particles may initiates crack along the void growth area, because of stress concentration (Parvaiz et al. 2010; Landel and Nielsen 1993).

In Table 1, the young's modulus of all types of composite specimen obtained via stress-strain plot is also presented. The typical stress-strain plot of all types of composite specimens was plotted by obtaining the average value of load vs displacement from tensile test, which is shown in Figure 5. For bare, C1, C2 and C3 types of composite specimens, the young's modulus was about 7.03, 6.42, 6.37 and 6.19 GPa, respectively. This was obvious that there were 8.62, 9.38 and 11.94% of decreases in modulus for C1, C2 and C3 types of composite specimens, respectively. According to the authors (Biswas and Satapathy 2010; Mohanty, Srivastava, and Sastry 2014), the density and void fraction of filled and unfilled alumina particle glass fibre epoxy composite have been observed and resulted as increasedwith increasing the fillers contents. Thereby, they obtained as decreased tensile strength and modulus for Al_2O_3-filled glass fibercomposite, which was also attributed to poor interfacial bonding between fibre and matrix.

However, the present author also studied the macroscopic fracture surfaces of tensile specimens of all types of composites, as shown Figure 6. For bare composite specimen (Figure 6(a)), the failure was held on the plane at right angle to the plane of cross section due to normal stress, which was attributed to the fact as perfect brittle and high stiffness. However, the failure mode of C1 type of composite specimen was same as bare composite specimen type, it had left along with short fibrous facture at the end, as shown in Figure 6(b). Alternatively, For C2 (Figure 6(c)) and C3 (Figure 6(d)) type of composite specimens, due to the failure was occurred on the plane angled to the plane of cross section due to shear stress, resulting that long damage length along with lengthy fibrous fracture at the end. This phenomenon was also observed by the other author (Alavi and Ashrafi 2012), wherein the mode of failure changes with addition of filler alumina contents in glass fibre-reinforced polyester composite from brittle to shear for 0.2 and 1 wt%, respectively. He had also observed transverse failure and cracks parallel to tensile direction for increasing alumina contents. In view of this, the present author did not observe any transverse failure for composite of bare and C1 types, but with minor delamination at the

Table 1. Tensile properties of all types of glass fibre-reinforced polyester composites.

S.No	Composite Specimen Types	Tensile Strength (MPa)	Failure Strain (%)	Young's Modulus (GPa)
1	Bare	348.20 ± 13.45	5.1 ± 1.2	7.03 ± 0.98
2	C1	305.14 ± 12.62	4.8 ± 1.6	6.42 ± 1.19
3	C2	293.76 ± 18.54	4.6 ± 2.1	6.37 ± 1.04
4	C3	281.90 ± 17.62	4.5 ± 1.9	6.19 ± 1.23

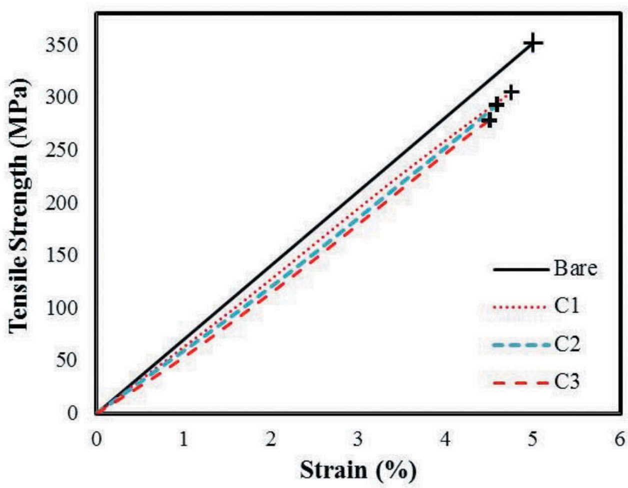


Figure 5. Typical stress–strain curve of all types of glass fibre-reinforced polyester composite.

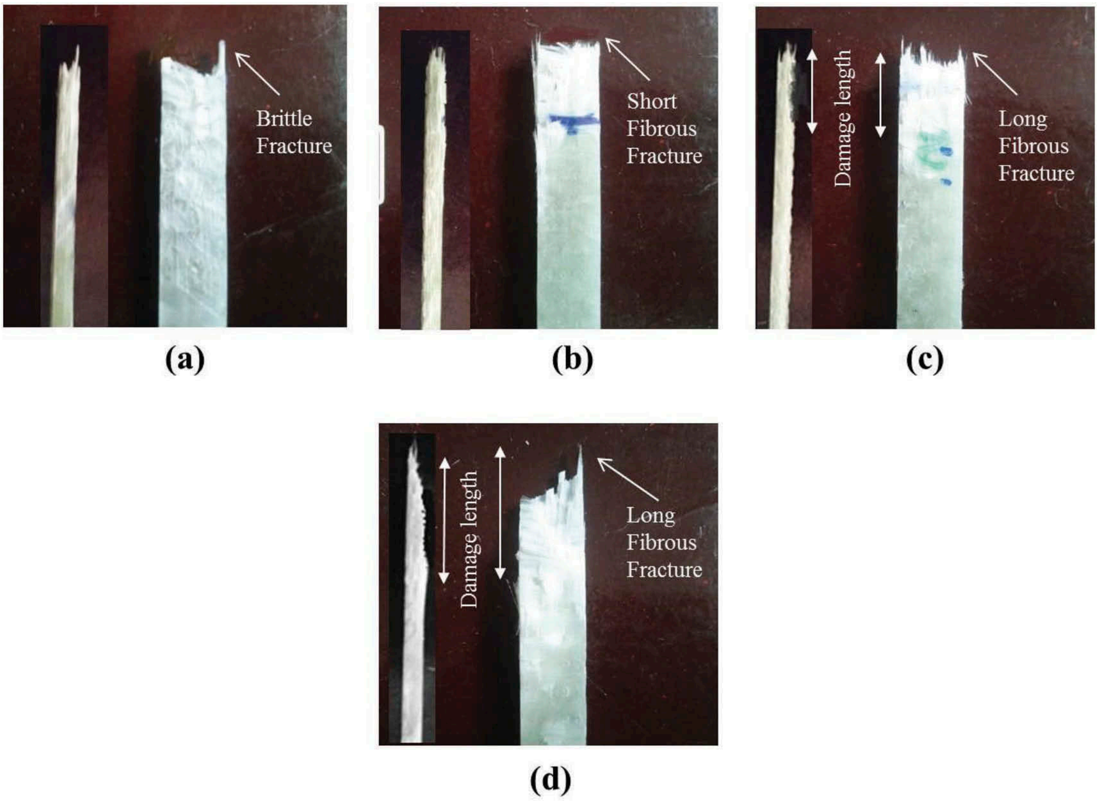


Figure 6. Macroscopic fracture surface of tensile specimens of (a) bare, (b) C1, (c) C2 and (d) C3 glass fibre-reinforced polyester composite.

lateral side of the specimens near fracture for C2 and C3 types, as evident from Figure 6(c, d).

3.2. Impact test

The impact test was conducted such that the blade on the free-hanging pendulum just barely contacts the specimen(zero position). Because there are practically no losses due tobearing friction, etc. (<0.3%), the testing conditions may be regarded as ideal. The respective value of the absorbed energy of the specimen was obtained on the dial guage when the blade strikes on. The Figure 6 shows the calculated impact energy of the bare, C1, C2 and C3 glass fibre-reinforced polymer composite. The impact energy of C1 type composite specimen was 0. 571 J/mm^2, which was about higher than bare composite specimen by 10%. In addition, the impact energy of C2 and C3 composite specimen types were lower than that of bare by 4.8 and 29.8%, respectively.

The fracture behaviour was also observed visually during the impact testing that the fracture for bare and C1 composite specimen was like brittle and the specimen broke into two pieces when the blade striking,whereas for the case of C2 and C3 specimens were like semi brittle which left the specimen broke upto 80% and not into two pieces, which was more likely to be fibrous at failure region. This was expected due to fact that the resin infusion was more sensitive to the amount of filler content, and how it was formed as network in the matrix. As evident from Kaundal, Patnaik, and Satapathy (2018) that, with increasing alumina content in short glass fibre-reinforced polymer composite having decreased tensile strength and increased modulus had increased impact energy. Though the several mechanisms are involved in toughening of polymer, there are atleast three factors concerned on toughening of polymers while fillers as inorganic particles; they are inherent ductility of matrix, interface bonding of filler and matrix, and interparticle distance (Kinloch 2013). In the present work, C1 glass fibre-reinforced polyester composite having good interfacial bonding and ductility of matrix caused appropriate toughening of composite, which resulted in high impact energy. However, the increasing of fillers content (for C2 and C3 composite specimen) a weak interface between the filler/matrix and close inter-particle distance caused low-impact energy. In addition, the present author also observed that the reduction of impact energy was high with increasing of filler contents, as evidence form test results of C2 and C3 type composites, unlike tensile properties.

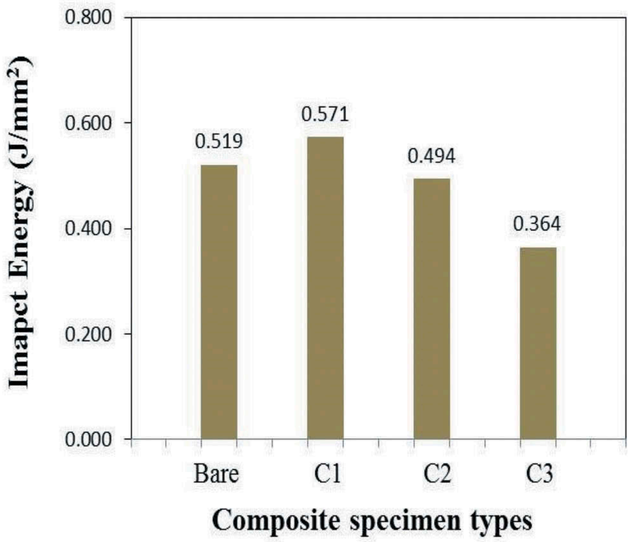


Figure 7. Impact energy of (a) bare, (b) C1, (c) C2 and (d) C3 glass fibre-reinforced polyester composite.

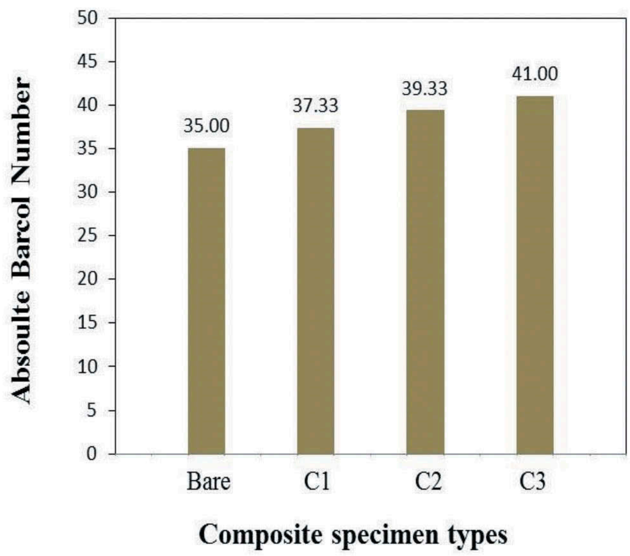


Figure 8. Barcol hardness of (a) bare, (b) C1, (c) C2 and (d) C3 glass fibre-reinforced polyester composite.

3.3. Hardness test

The effect of filler contents on hardness of glass fibre-reinforced polyester composite is presented in Figure 7. It can be seen that hardness of the glass fibre-reinforced polyester composite increased with increasing the alumina content in the matrix. The observed harness values of the bare, C1, C2 and C3 type of composite were 35B, 37.33B, 39.33 B and 41B, respectively. As a result, the increment of hardness valuesof C1, C2, and C3 type of composite were about 6.65, 12.37 and 17.14%, respectively, from that of bare glass fibre-reinforced polyester composite.

This was as expected that, the increasing of filler content in the matrix resulting in increasing of density of the overall composites as presents itself at the fibre and matrix interphase, thus increased the hardness value, as reported elsewhere (Kinloch 2013; Mohamed, Mahmoud, and Eimahallawi 2009). In other words, the pressing or penetration of intender by significant force is an action in hardness testing, so the fillers and matrix have to be an effective stress transfer medium to the fibres although poor interfacial bonding strength. Moreover, the present author observed the inclusion of fillers did not affect the surface quality of C1, C2 and C3 glass fibre-reinforced polyester composites, due to the fact that hardness value does not increase with present of void and pores (Figure 8).

4. Conclusion

In the present study, the mechanical properties such as impact energy and hardness of the glass fibre-reinforced polyester composite was improved by 10 and 12.37%, respectively, with addition of Al_2O_3 particles to the matrix at 1wt %. Further increasing the percentage of filler content could be seen that there was reduction of impact energy, but increasing of hardness value. This was due to the fact that effective stress transferred at the fibre/matrix interphase because of the presence of alumina particle even with poor interfacial bonding strength, while loading was compressive. However, the tensile strength and modulus of the Al_2O_3-filled glass fibre polyester composite was slightly lower than that of bare glass fibre-reinforced polyester composite, because of the tensile properties are more sensitive for how particles presented as network in the matrix. According to the the macroscopic study of the tensile fracture surfaces of specimen presented in this paper, it was also evident that increasing of alumina content resisted the flow of resin inside the tow of fibres and failed specimen with fibrous at the fracture end, due to poor interfacial bonding strength. But still, the present author expects that varying of fillers content within 0 to 1wt% at multiple intervals can possibly improve the tensile properties. So, this has been one of the interests of our future work.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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