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Tensile and Flexural Properties of Thermoplastic Filled Fibre Reinforced Polymer Composites

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Abstract

This paper presents the mechanical properties of polyether-sulfone (PES) filled basalt and glass fibre reinforced polymer composites. Three different weights of PES powder with 1, 3, and 5 wt.% were dispersed into resin using a mechanical stirrer before being impregnated into woven basalt and glass fibre composite laminates. Eight different composite systems were fabricated and tested under tensile and flexural loading according to ASTM D3039 and D790. The result deduced that the inclusion of PES enhanced the mechanical properties for both Basalt Fiber-Reinforced Polymer (BFRP) and Glass Fiber-Reinforced Polymer (GFRP) composites. In BFRP composite systems, adding 5wt.% of PES (5BF/PES) showed the highest tensile strength and modulus with 47% and 51% increment compared to neat BFRP. In GFRP composite systems, the inclusion of 3 wt.% PES (3GF/PES) showed an improvement of 34% for tensile strength and 5wt.% PES inclusion (5GF/PES) indicated the highest improvement of tensile modulus 106% as compared to neat GFRP. For flexural strength, a similar trend of improvement was found in BFRP and GFRP composite systems. The 5BF/PES showed improvement of 148% and 121% for flexural strength and flexural modulus, compared to neat BFRP. For GFRP composite systems, the 3GF/PES showed the highest flexural strength while 5GF/PES showed the highest flexural modulus of 39% and 71% improvement, compared to neat GFRP.

Disciplinary: Engineering mechanics, Engineering Materials, Advanced Materials, Mechanical Engineering.

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1 Introduction

Properties of Fibre Reinforced Polymer (FRP) composites depend on the reinforcement types, polymer matrix, manufacturing, and fabrication processes. The functions of a matrix in the FRP are to bind the fibre together, transfer loads, and protect the fibres from environmental attack and handling damage [1-2]. Epoxies have excellent overall properties in terms of their physical, mechanical, thermal, and also adhesion characteristics to fibres. The FRP with epoxy offers high strength, high stiffness to weight ratios, and good resistance to corrosion and fatigue [1- 4]. The properties of polymer matrices influence the overall properties of the FRP system. As the properties of the FRP composites depend on the polymer matrix, many researchers have investigated how to improve the matrix dominated composite by modifying the polymer through the addition of nanofiller. Based on the theoretical approach, stiffer and tougher resin provides better load transfer and lateral support to the fibres which allow better stability of the fibres and delay crack initiation and propagation.

The extensive use of synthetic fibres with polymeric materials has led to environmental problems due to the depletion of fossil raw materials such as petroleum and natural gas as well as the concerns on global warming issues. Due to this situation, the emergence of natural fibre and bio-composite to be used in many industries is much encouraged since it is considered as environmentally safe green composites. Green composites offer many environmental sustainability advantages such as recyclability and renewability of source material and reduce greenhouse gas emissions. Due to its higher tensile strength and elongation at break as compared to glass fibre, the use of basalt fibre (BF) has gained much attention to be implemented in a suitable application [5-10]. Many researchers have reported the mechanical properties of BF composites in the thermosets as well as in thermoplastics [5, 7-14]. The performance of Basalt Fiber-Reinforced Polymer (BFRP) composite can be improved with the modification of the fibre itself or on the polymer matrix. The knowledge of the toughening mechanism for this material can be increased with the further investigation based on experimental and prediction models.

The epoxy resin has excellent adhesion and mechanical properties, good chemical resistance and good adhesion properties. It is commonly used for construction, lamination, insulation, coatings and adhesion materials as well as in transportation industries. Despite its excellent properties, this material has several drawbacks owing to its brittleness and low resistance to failure due to the rapid crosslinking reactions leading to high crosslink density (spacing between the successive cross-link) [15-17]. Researchers have found that the overall properties of the system (compressive strength, fracture toughness, interlaminar shear, in-plane shear) can be achieved by modification of the resin using the nanofillers [18-21]. However, improper selection of fillers, resin, and fabrication methods contributed to the reduction in the system properties. Many factors need to be considered for resin modification using fillers, such as type and properties of the fillers along with their surface functionalization, compatibility of fillers to resin, degree of dispersion of fillers in resin, interfacial adhesion, fabrication methods, and curing conditions [19, 22-24].

The attempt to strengthen the matrix using secondary polymer or filler was realized by the addition of engineering thermoplastic such as Polyether-sulfone (PES). PES is a high-performance engineering thermoplastic with high modulus and good thermal stability contributing to good mechanical and thermal properties [25-27]. Owing to its superior performance, PES is expected to improve the strength of the epoxy resin. Hence, in this study, the PES was used as an additive material in the epoxy resin and embedded into the basalt and glass fibre to investigate its influence on the mechanical properties of the composite materials under tensile and flexural tests. It is expected to improve the mechanical properties of the developed composite materials. The motivation is to enhance the usefulness of the PES with natural fibre composites in any potential applications as an alternative approach to encourage the use of bio-composite materials.

2 Materials and Method

2.1 Materials

Basalt fibre originates from volcanic basalt rock. In this experimental work, woven basalt fibre with a thickness of 0.67 mm and a density of 2.67 g/cm^3 was used. The elastic modulus of basalt fibre was in the range of 85-87 GPa. Similar to basalt fibre, woven glass fibre with a diameter of 10-12μm and a density of 2.5 g/cm^3 was used. The elastic modulus of glass fibre was 50 GPa. The Konudur 250 OM-PL resin manufactured by MC-Bauchemie was used with a ratio of Part A (1): Part B (2) with a minimum curing time of 120 minutes at ambient temperature. This type of resin was chosen as it has a low viscosity. The thermoplastic filler used was polyether-sulfone (PES) powder with a melting point of 350°C.

2.2 FRP composites specimen fabrication

Initially, the PES powder was added into the resin at a given weight percentage of 1wt%, 3wt% and 5wt% and evenly mixed using the mechanical stirrer. The hardener was then poured into the mixture and stirred until completely mixed. Then, the basalt and glass fibre fabric with the dimension of 300 mm x 300 mm were stacked layer by layer using the hand lay-up method with the resin mixture as the adhesive material and underwent a vacuum bagging process for an hour to remove the air trapped between the layers. Then, the specimen was left for the curing process at room temperature for 24 hours. The laminate specimen was cut according to the tensile and flexural size specimen using the vertical bend saw cutter. The specimen's designation and their filler composition are tabulated in Table 1.

Table 1: Specimens' designation and filler composition.

Specimens designation	Resin : hardener weight (g)	PES weight (g)
Neat BFRP	0	0
1BF/PES	99 : 198	3
3BF/PES	97 : 194	9
5BF/PES	95 : 190	15
Neat GFRP	0	0
1GF/PES	99 : 198	3
3GF/PES	97 : 194	9
5GF/PES	95 : 190	15

2.3 Tensile test

The tensile test was performed on the rectangular specimen with the dimension of 25 mm × 250 mm × 4 mm according to ASTM D3039 to evaluate the materials tensile properties using 3382 Universal Testing Machine with 100 kN load cell (INSTRON, USA 2008). A minimum of five (5) specimens was prepared and tested for each system with a crosshead speed of 2 mm/min.

2.4 Flexural test

The flexural test was conducted based on the ASTM standard D790. The FRP composites specimen with the dimension of 80 mm length x 13 mm width x 4 mm thickness were bent under a three-point bending test configuration. The three-point bending flexural test was performed to determine the flexural modulus, flexural strength and flexural strain. These data were logged to a computer for analysis using INSTRON 3382 Universal Testing Machine at the crosshead speed of 1 mm/min. At least five (5) specimens were tested for each system.

3 Results and Discussion

3.1 Tensile properties

Figure 1(a) shows the tensile stress-strain curves of both BFRP and GFRP composite systems and Figure 1 (b) displays the examples of post-fractured specimens. From the curves, it was found that both FRP systems (basalt and glass fibre) with the addition of PES experienced better tensile properties as compared to the neat FRP. Figure 2 summarizes the data obtained from the stress-strain curves for overall systems. In general, it could be observed that the tensile properties of FRP/PES composites increased as the PES content increased. For the BFRP composite system, the tensile strength and modulus of 5BF/PES were the highest with 46.5% and 50.6% increment, respectively than that of neat BFRP. This was followed by 3BF/PES with 27.3% and 47.4% increment, and 1BF/PES with 12% and 10% increment in tensile strength and modulus, respectively as compared to the neat BFRP composites. As for GFRP composite system, 3GF/PES showed the highest tensile strength increment with 33.9%, followed by 1GF/PES with 10.3% and 5GF/PES with 9.8% increment compared to the neat GFRP composite. The reduction in tensile strength in 5GF/PES system as compared to other GF/PES systems could be attributed to the improper distribution or agglomerated PES in the system that has led to the stress concentration at the particular area in which they could not sustain excessive tensile loading and reduce the tensile strength value. However, the tensile modulus of GF increased as the PES content was increased. The 5GF/PES showed the highest improvement with 105.9%, followed by 3GF/PES with 67.4% and 1GF/PES with 55.8% improvement than neat GFRP composite. Comparing both FRP composite systems, it could be deduced that the FRP composite with PES possessed higher tensile strength and modulus due to effective reinforcement response between the fibre and high modulus PES filler in the resin. Almost similar results were reported in the literature where the good dispersion of PES in the epoxy resulted in a more effective stress transfer [28]-[29]. The BFRP composite showed higher tensile strength as compared to GFRP, indicating that this natural fibre exhibited promising potential as an alternative to synthetic glass fibre. Figure 3 shows the damaged specimens for GFRP and BFRP composites. In general, the failure mechanism involved in the GFRP composite was fibre breakage while BFRP composite consisted of matrix cracking, fibre breakage and fibre pull-out.

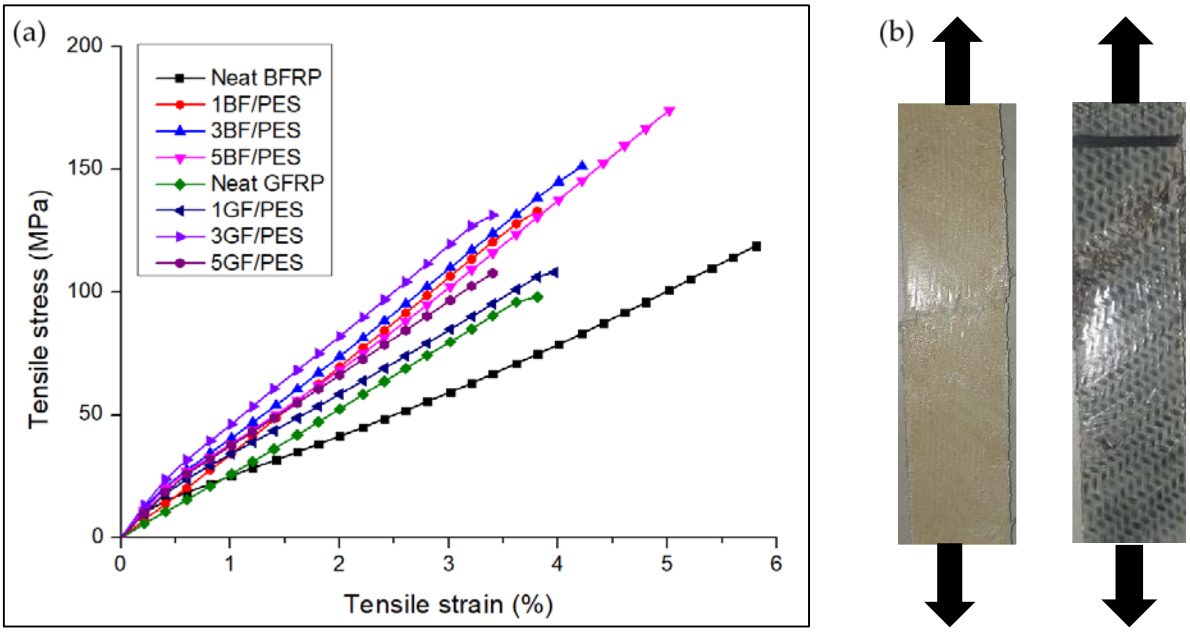

Figure 1: (a) Tensile stress-strain curves of neat FRP and FRP embedded with PES and (b) examples of fractured specimens under tensile loading.

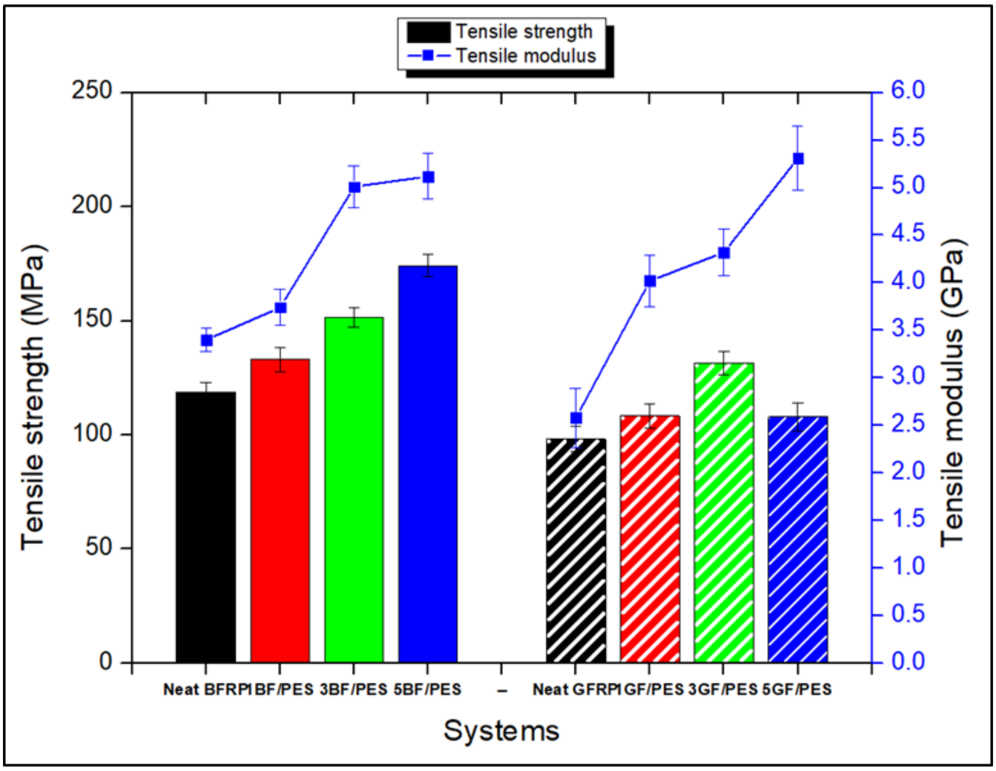

Figure 2: Tensile properties of neat FRP and FRP embedded with PES.

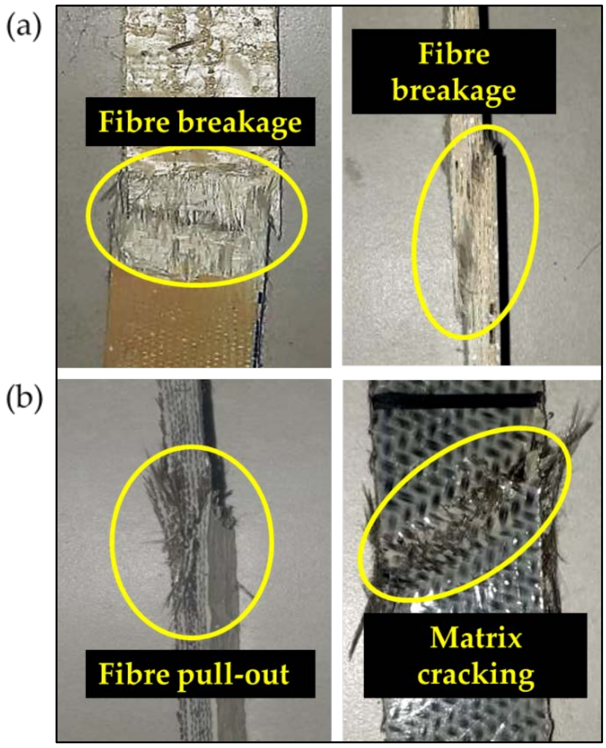

Figure 3: Damaged specimens (a) GFRP and (b) BFRP composites.

3.2 Flexural properties

Figure 4 illustrates the flexural stress-strain curves of neat BFRP, neat GFRP and both FRP systems with the inclusion of different PES contents. From these curves, the data were interpreted as in Figure 5. As seen in Figure 5, the flexural strength and modulus for both BFRP and GFRP composites increased as the PES contents increased. 5wt% PES addition in both BFRP and GFRP composites (5GF/PES and 5BF/PES) exhibited the highest improvement in flexural strength by 148% and 39.3%, respectively as compared to neat BFRP and GFRP. This was followed by 3wt% PES (3BF/PES and 3GF/PES) addition with 78.9% and 32.9% increment and 1wt% PES addition (1BF/PES and 1GF/PES) with 53.3% and 21.6% for BFRP and GFRP composites, respectively as compared to neat FRP composites. Flexural modulus also showed improvements of 120.7%, 36.9% and 6.5% for 5BF/PES, 3BF/PES and 1BF/PES, respectively when compared to neat BFRP. As for flexural modulus of GFRP composite, 5GF/PES, 3GF/PES and 1GF/PES showed increments of 71.4%, 48% and 23.9%, respectively as compared to neat GFRP. Hence, the results proved that the PES existence in the FRP composites enhances the flexural properties of the systems without sacrificing its strain values. This is expected as the matrix modification with PES develops strong interfacial bonding with fibre resulting in high flexural strength and modulus values which was also found in the literature [30]. The high elasticity modulus of PES, combined with an elasticity modulus of epoxy boosted the elastic modulus of PES modified epoxy system. This also introduces an additional mechanism of energy absorption as indicated by the area under the graph where a larger area shows higher energy absorption capability.

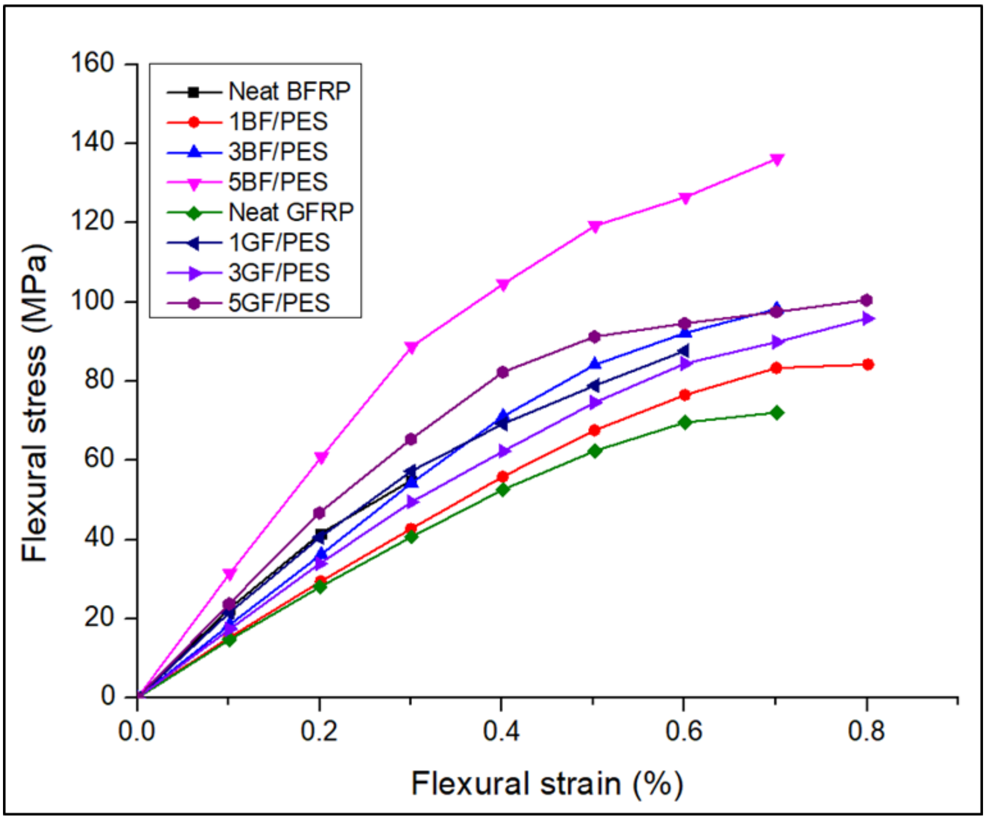

Figure 4: Flexural stress-strain curves of neat FRP and FRP embedded with PES.

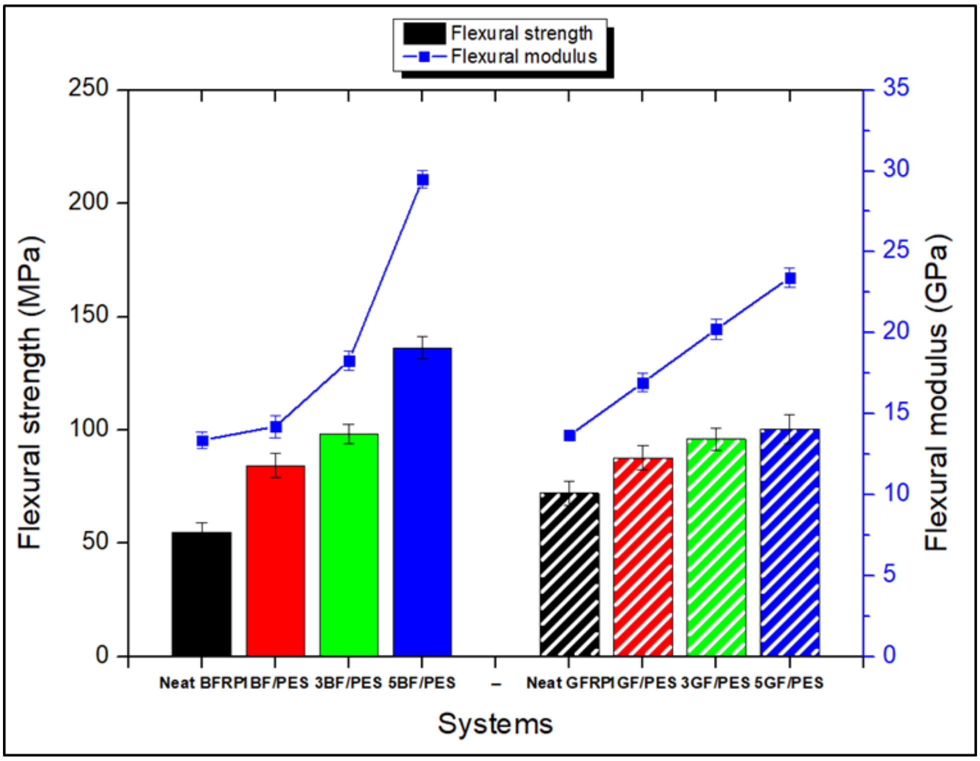

Figure 5: Flexural properties of neat FRP and FRP embedded with PES.

4 Conclusion

The effect of PES on the tensile and flexural properties of BFRP and GFRP composites has been successfully investigated. The results deduced that the addition of PES improved the tensile and flexural properties. This may be due to a well-dispersed PES filler within the epoxy matrix that resulted in the improvement of interfacial bonding between fibre and matrix and hence increased the tensile and flexural strength. The inclusion of high modulus PES also contributed to the increment in tensile and flexural modulus as well as introduced an additional energy absorption mechanism to the composite systems. Basalt fibre showed higher tensile and flexural properties than glass fibre. This indicates that this natural fibre has a huge potential as an alternative to synthetic glass fibre.

5 Availability of Data And Material

Data can be made available by contacting the corresponding authors.

6 Acknowledgement

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