

Modelling, Fabrication and Characterization of Kevlar Reinforced Composite



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Abstract Kevlar fibre reinforced epoxy composites are extensively used for various applications. In this study, Kevlar fibres are used as reinforcement in the modified epoxy resin matrix. Epoxy resin is modified using polyetherimide (PEI). The content of polyetherimide in epoxy is derived up to 10 wt%. Mechanical properties improvement is observed around 7.5 wt% and 5 wt% of polyetherimide in blended epoxy as compare to pure epoxy. In the present work, Kevlar fibre in mat form is first introduced with epoxy resin. Then other samples were made by blending epoxy with different percentages of polyetherimide. Fabricated composites are subjected to various mechanical properties evaluation tests. Results exhibit an increase in strength values. Tensile, shear and impact strength is maximum for composite samples having 7.5 wt% PEI. Flexural strength is maximum for samples with 5 wt% PEI. DSC and TGA of samples are also done for material characterization of composites. During the TGA testing, the degradation of samples in the Nitrogen gas atmosphere at two different stages, 250–350 °C and 450–600 °C, are observed, where significant wt. loss has occurred. The DSC analysis of Epoxy resin and PEI-blended resin shows two different glass transitions at 90°C and 220°C, respectively.

Keywords Kevlar fiber · Composite · Polyetherimide

1 Introduction

For the past five decades, the utilization of fibre-reinforced components in engineering structures has been increasingly diversified from sports equipment and high-performance racing cars, to navy ships, helicopters and airplanes. There are

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several kinds of fibres being used in laminated composites, but Kevlar has been used extensively due to its lightweight, tensile strength, toughness, and resistance to impact damage [1].

Composite materials have been developed to achieve enhanced properties such as strength, toughness, and improved performance at high temperature, etc. Strengthening mechanism of composite strongly depends on the type of reinforcement [2]. Yue and Padmanabhan studied interfacial strength of Kevlar fibre reinforced in epoxy matrix using fibre pull out test. It was observed that treatment of fibres with organic solvents prior to composite fabrication results in enhanced interfacial shear strength by about 60% compared to an untreated fibrous composite. Kevlar fibres are crystalline polyamide fibres consisting of carbon, hydrogen, oxygen and nitrogen elements. As compared to contemporary fibers, they have low density and high tensile strength to weight ratio. The Kevlar fibres are preferred over the carbon fibres as they do not fail by brittle cracking, but exhibit excellent toughness [3, 4].

Generally, structures and laminates made of fibrous composites consist of different layers of unidirectional laminae. Each lamina is made of the same constituents but, individual layers may differ by the relative volumes of reinforcements and constituent materials in them. Use of continuous or discontinuous fibers, woven or nonwoven reinforcement, and the orientation of fibres with respect to common reference axis influence the properties of fibrous composites [3, 4].

Previous research has assessed the influence of fiber positioning on the tensile strength by means of fracture testing. Parameters like fibre length, matrix pouring and compaction methods, specimen size influence the properties of composites [5].

In a fiber-reinforced composite, the orientation of fibers with respect to sliding surface is an important parameter required for the determination of wear rate and friction coefficient [6]. Epoxy resins with shorter curing cycles are in high demand for commercial applications as they provide economy in composite fabrication and higher toughness for better damage tolerance [7].

Many researchers have investigated the influence of temperature and light irradiation on the tensile fracture behaviour of fibres, exposure to thermal and light irradiating environment degrades the tensile strength of fibers [8]. Jang, W. Lee, Turmel and Partridge presented the work on polyetherimide modified high-performance epoxy resin. Polyetherimide-modified epoxy resin system resulted in an improved fracture toughness [9, 10].

In this paper, it is clearly observed that Kevlar fibre is introduced with epoxy and modified epoxy with different percentage of PEI (5%, 7.5% and 10% by wt.). Composites were prepared by the hand lay-up method. After fabrication, composite materials were cut by composite cutting machine as per ASTM standard. To identify the composite material strength, material undergoes mechanical characterization such as tensile, flexural, ILSS and impact properties for the composite material.

2 Materials and Methods

2.1 Fabrication of Composites

Four different types of composite samples are prepared as shown in Figs. 1, 2, 3 and 4. One type of samples are fabricated using Kevlar fibre with the only epoxy and other three are fabricated using Kevlar fibre with polyetherimide (PEI) modified epoxy in varying percentages of PEI as 5%, 7.5%, and 10%. Composites are prepared by hand layup technique involving alternate layers of Kevlar fibres in mat form and layer of Epoxy (LY556) resin. Samples are subjected to hydraulic press. A total thickness of 3 mm is maintained after layer by layer fabrication of composite. Samples were cut by composite cutting machine.

Fig. 1 Samples of Tensile Test by ASTM D 3039-76

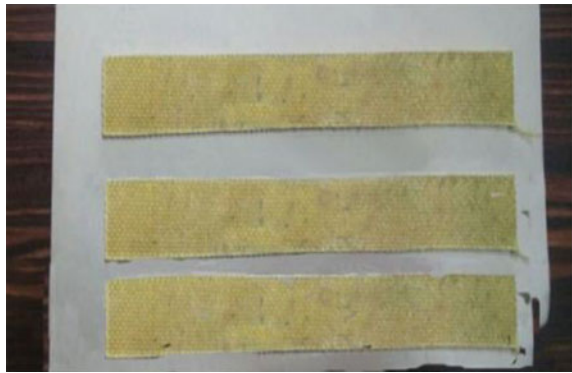


Fig. 2 Samples of Flexural Test by ASTM D 790-81

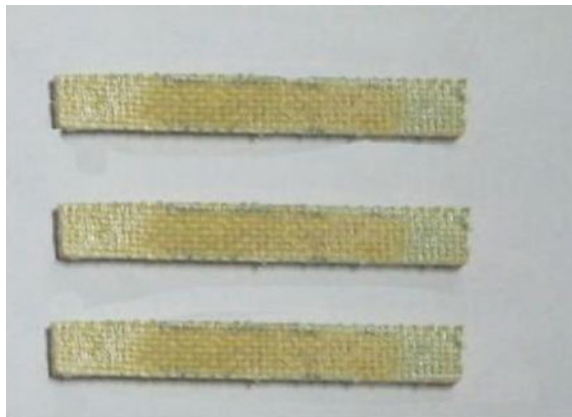


Fig. 3 Sample of ILSS test
ASTMD 2344-84

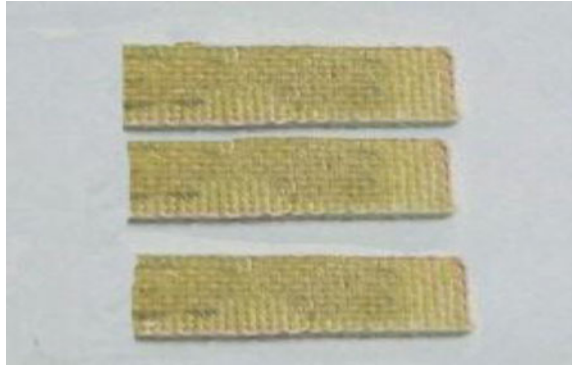
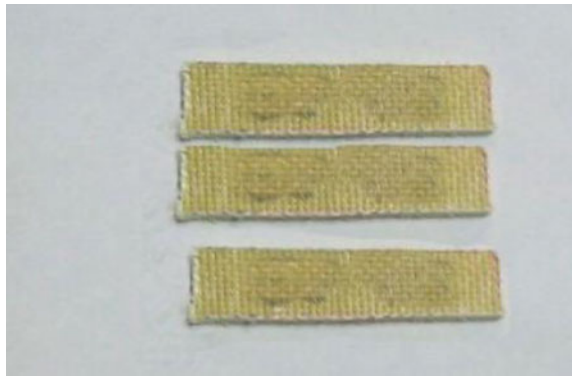


Fig. 4 Samples of impact
test by ASTM D 256



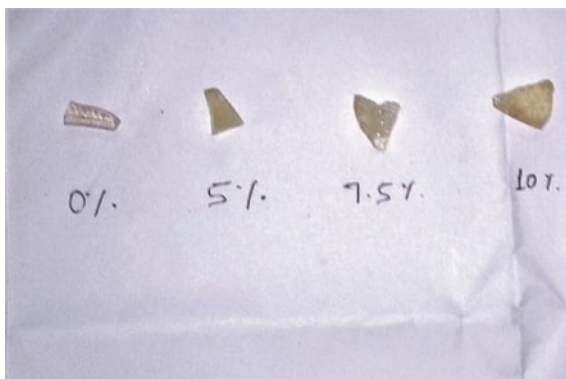
2.2 Mechanical Tests

Tensile strength of composite samples (Fig. 1) was evaluated in accordance with ASTM standard D 3039-76. The tensile test was performed at a recommended crosshead speed of 0.2 cm/min. Flexural strength of composite samples (Fig. 2) was determined by ASTM test method specified by D790-81. In this test, a composite beam specimen of rectangular cross section is loaded in a three-point bending mode. Interlaminar shear strength (ILSS) is defined as the strength preventing delamination, i.e. strength parallel to the plane of the lamination. ILSS is measured in a short beam shear test as per ASTM standard D 2344-84.

A flexural specimen (Fig. 3) with span (L)- depth (h) ratio of 5:1 is tested in three-point bending mode to produce a horizontal shear failure between the laminate piles.

The impact strength of the material is evaluated to find its toughness. In other words, impact strength indicates the capacity of the material to absorb and dissipate energies under shock or impact loading. ASTM standard D 256 is used to evaluate the impact resistance of fiber reinforced composite materials (Fig. 4).

Fig. 5 Samples of TGA and DSC



2.3 Thermal Gravimetric Analysis

Thermal gravimetric analysis (TGA) of the pure epoxy sample and other samples formed by blending PEI to epoxy have been performed. TGA provides information on the thermal stability of polymer samples (Fig. 5). TG analysis is carried out in the Nitrogen gas environment. Test chamber temperature was gradually increased at a heating rate of 10 °C/min from 30 °C to 600 °C. Such type of thermal analysis is carried out to understand the kinetics and thermodynamics of phase transformations in a variety of crystalline and non-crystalline materials. The major advantage of TGA is that it can be performed on non-crystalline, such as polymers and inorganic materials as well.

2.4 Differential Scanning Calorimetry

All the measurements of heat change values of the test samples as compared to standard reference were performed under nitrogen atmosphere. The masses of samples were 10–15 mg. Variation of differential heat for samples as a function of temperature can be plotted. Peaks in the plot indicate any phase transformation occurring in samples. Attributes like activation energy, amount of heat, transformation starting temperatures, etc., can be obtained from these plots.

3 Results and Discussion

In the unmodified epoxy, tensile strength comes out as 335.81 MPa, in modified epoxy with 5% PEI 344.23 MPa, with 7.5% PEI 427.39 MPa and with 10% PEI 313.81 MPa is found. Hence the tensile strength increases up to 7.5% then decreases

(Fig. 6). In the unmodified epoxy, flexural strength (Fig. 7) comes out as 166.48 MPa, in modified epoxy with 5% PEI 197.24 MPa, with 7.5% PEI 157.97 MPa and with 10% PEI 313.81 MPa is found. Hence, the flexural strength increases up to 5% then decreases. In the unmodified epoxy, shear strength comes out as 113.43 MPa, in modified epoxy with 5% PEI 100.69 MPa, with 7.5% PEI 136.39 MPa and with 10% PEI 117.21 MPa is found.

The results of the tensile test are different from flexural stress test because in tension only one type of stresses is predominantly observed in a specimen, however, under flexural load combination of tensile, bending and shear stresses are observed. The occurrence of a combination of stresses during bending affects the

Fig. 6 Maximum tensile strength of different samples

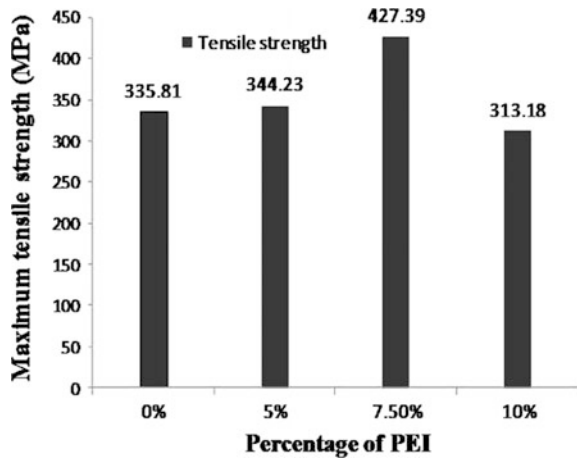


Fig. 7 Flexural strength of different samples

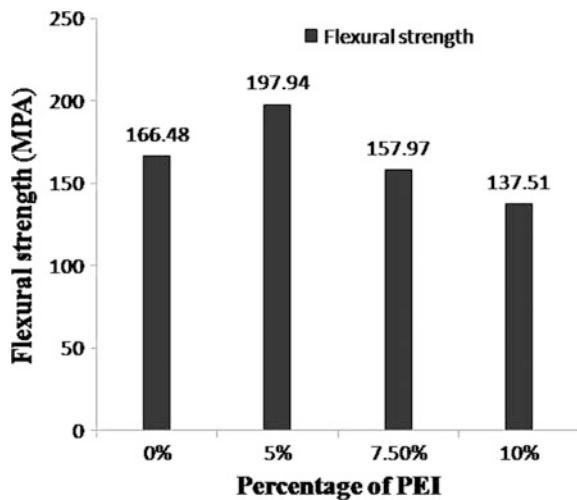


Fig. 8 Shear strength of different samples

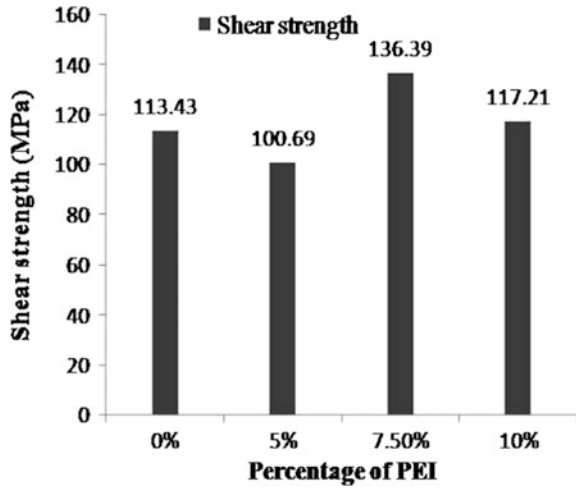
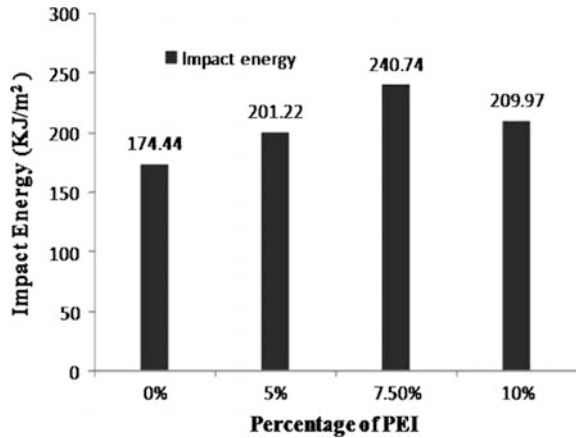


Fig. 9 Impact strength of different samples



strength of the material component. Thus, in tension test strength of the composite is maximum at 7.50 wt% of PEI and in flexural test strength is maximum at 5 wt% of PEI [11].

Interlaminar shear strength (Fig. 8) first decreases at 5% then increases at 7.5% then again decreases. In the unmodified epoxy, impact energy (Fig. 9) comes out as 174.44 kJ/m², in modified epoxy with 5% PEI 201.22 kJ/m², with 7.5% PEI 240.74 kJ/m² and with 10% PEI 209.97 kJ/m² is found. Hence, impact energy increases up to 7.5% then decreases.

ILSS and impact strength of the composite is higher for 7.5% PEI blending of epoxy as compares to any other percentage. It was observed earlier that the toughening effect of PEI, when blended with epoxy resin, depends on the amount of curing. Lack of curing is the major cause of variation of results [14].

Thermal stability of polyetherimide-reinforced Epoxy blends was carried out in Fig. 10. The degradation blend in the N_2 atmosphere shows two different stages at 250–350 °C and 450–600 °C, where significant weight loss has occurred. In the first stage a loss in the mass of epoxy resin is observed due to the decomposition of the end group in the epoxy network. The loss in the second stage is primarily due to the degradation of main chains of epoxy. The Thermal degradation temperature of PEI percent resin is at 600 °C. The char yield in EP3 containing the highest percentage of PEI is less as most of the epoxy chains degrade at a lower temperature and gives a higher percentage of residue content. It also seems that the degradation profile does not change with respect to increase or decrease in wt% of PEI. It can be attributed to the absence of a compatibilizing agent between the epoxide and imide rings.

DSC utilized to measure the glass transition temperature (T_g) and enthalpy change in samples when subjected to heating Fig. 11. The wetting/attractive and repulsive/dewetting behaviour depends on the dispersion and homogeneity and compatibility of blends. The DSC thermogram shows two different glass transitions at 90 °C and 220 °C of Epoxy resins and PEI blend, respectively. DSC plots shows the curing temperature of epoxy resin is in the range of 120–180 °C. Glass transition temperature of PEI is about 220 °C. Decomposition of samples is observed around 350–400 °C. It further shows the degradation profile due to chain breaking and chain disintegration within the molecules.

The cross-linking of polymeric modifiers with another polymer is the most important and significant factor which affects the mechanical properties of unfilled and filled polymer blend system. The curing process or the crosslinking prevents slippage between chains when deformation causing stresses are applied to the sample. The increase in the crosslinking behaviour of blended resin attributes the change in the physical properties and adhesion characteristics of these resins lead to

Fig. 10 TGA analysis of pure epoxy (EP), 5% PEI (EP1), 7.5% PEI (EP2), 10% PEI (EP3)

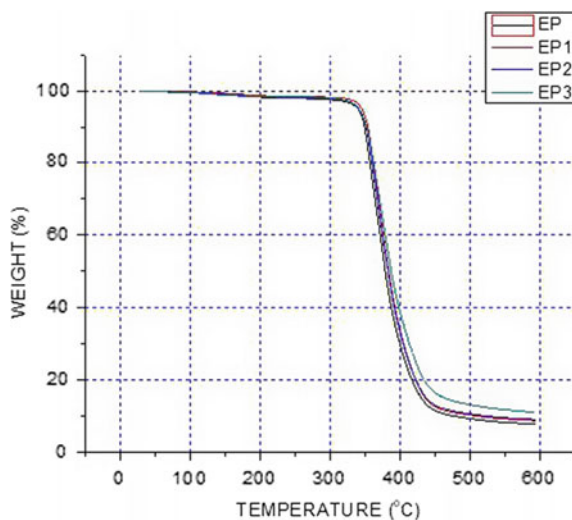
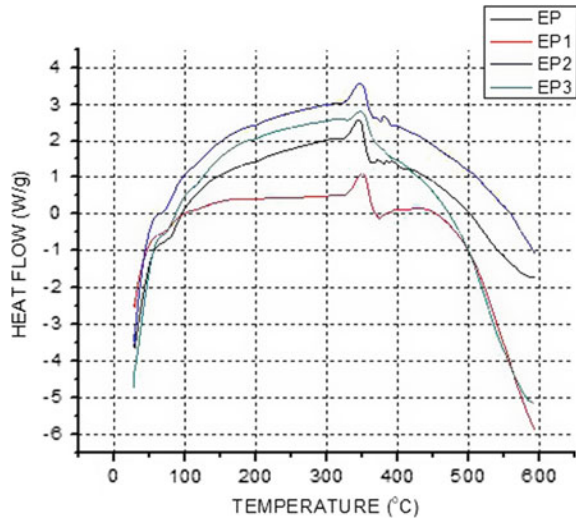


Fig. 11 DSC analysis of pure epoxy (EP), 5% PEI (EP1), 7.5% PEI (EP2), 10% PEI (EP3)



enhanced bonding of the fibre with the matrix. It further influences the mechanical behaviour of the polymeric blend/composite by restricting the slippage of layer to layer as well as the matrix to fabric debonding [12]. Epoxy polymers have inherently low toughness and impact resistance. To improve the toughness and mechanical properties, PEI is blended with the epoxy resin system. On blending the PEI in epoxy toughness level is increases as the impact strength is improved. From DSC curve it is observed that there are two distinct slope changes indicating glass transition temperatures for epoxy and for PEI. These slope changes are not very predominant also. Hence it can be inferred that the cross-linking between PEI and epoxy is not sufficient [13]. However, for 7.5% blending of PEI the cross-linking is better as compared to other samples.

4 Conclusions

In this work, an effort was made to develop Kevlar fibre with epoxy and PEI-blended epoxy-based composites to be used for defence purpose. Experimental investigations were performed to know the effect of fibre reinforcement in matrix material to achieve the desired outcome. Tensile strength is found to be maximum at 7.5% of PEI with epoxy as matrix material. Flexural strength is found to be maximum at 5% of PEI with epoxy as matrix material. Shear strength is found to be maximum at 7.5% of PEI with epoxy as matrix material. Impact strength is found to be maximum at 7.5% of PEI with epoxy as matrix material. DSC investigations show two different glass transitions at 90 °C and 220 °C of Epoxy resins and PEI blend, respectively.

In the present work, PEI is blended with epoxy and it has been observed that there is a reduction in both tensile and flexural strength when the PEI percentage was increased to 10% as compared to its lower percentages. DSC results exhibit that there are two glass transition slope changes, so we can conclude that the excess quantity of hardener, improper mixing or improper manufacturing sequence followed influences the cross-linking between epoxy and PEI and thus the property of the fabricated composite. It is, therefore, necessary to mix optimum percentage of hardener while preparing the epoxy-PEI blend with the aim to modify epoxy by PEI. The blending of PEI with epoxy also increases the brittleness.

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