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RESEARCH ARTICLE

Effects of Fiber Orientation on the Mechanical Properties of Bidirectional Woven Kevlar Epoxy Composite

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Abstract

Objectives: This study focuses on the mechanical behavior of different fiber orientations of bi-directional woven Kevlar fabric to improve the mechanical properties of the Kevlar epoxy composite materials. **Methods:** Here in this paper hand moulded composites are fabricated with the Bidirectional plain-woven Kevlar-49, Epoxy resin LY 556 and hardener HT972 and the configuration of the layer was symmetrical and contained 6 plies which arranged as C- (0/45/-45/45/-45/0), B- (0/60/-60/60/-60/0). The standard ASTM D 3039 for tensile test, ASTM D790 for flexural test and ASTM D256 was followed for the laboratory test. **Findings:** Polymer composite materials are popular due to its weight strength ratio. Bidirectional woven fiber is used for the analysis, where different fiber orientations are compared. From the analysis it is observed that, mechanical properties vary with different fiber orientations. **Novelty:** In this paper, tensile modulus, flexural modulus, and absorbed impact energy observed in the laboratory to find out the suitability of the Kevlar composite as a building material. The findings of this research are expected to have practical implications for the development of stronger and more durable polymer fiber composites in various structural applications.

Keywords: Kevlar fiber; Epoxy; Tensile test; Woven fabric; Fiber orientation

1 Introduction

The mechanical characteristics of a fiber-reinforced composite depend, not only on the properties of the fiber, but also on the degree to which an applied load is transmitted to the fibers by the matrix phase. However, composites tend to have high strength, high modulus, low density, and also have excellent properties such as high durability, stiffness, damping property, flexural strength and resistance to corrosion wear, impact etc.

However, the interface between the bi-directional woven fabric and the matrix is weak due to the magnitude of the frictional force and sliding velocity exerted on the fiber, depending on the direction of equilibrium, resulting in poor structural and low-fiber composite properties. Despite these challenges, the simplicity of production, economic advantages, and superior mechanical properties have made bi-directional woven reinforced composites popular. Plain weave is the most commonly used style in a bi-directional woven fabric, as it offers strength, durability, and resistance to snagging. This style involves interweaving the fill and warp to create a checkboard effect, with approximately 50% of each exposed on each face of the fabric. Fabricated kevlar composite shows better result than the guided value of plain kevlar fiber. Woven carbon, woven graphite composite performs better than plain carbon and graphite fiber respectively. It was observed that hybrid fiber composite withstanding more loading during flexural testing at low moisture content[(1)]. Alberto et al. noticed that 45^0 Unidirectional fibercomposite caused beam torque during bending[(2)]. In another research on jute fiber, failure strain was found to be highest at 0^0 -45^0 - 0^0 orientations of fibers and shows minimum at 0^0 - 0^0 -0^0 orientation[(3)]. Layered composite significantly influenced by the ratio of the adhesive layer thickness to the gluing area[(4)]. Zhou used a new apparatus for tensile testing of high-performance materials. The technique solved the problem of gripping and lack of force equilibrium in the testing of brittle solids and high-performance tapes and fibers[(5)]. The reinforcement increases strength significantly, type of matrix, the configuration of continuous fibers, the number of layers of the reinforcement affect the mechanical response[(6)]. The addition of fiber upto 50% improve the brittleness, flexural strength, and toughness of the composite material[(7)]. Harri et al. correlate the experimental tensile strength values of the randomly oriented short fiber reinforced polymer-based composites[(8)]. Orientation of reinforcements in a laminate is widely known to dramatically affect the mechanical performance of composites[(9)]. Yasser et al. studied with 0^0, 30^0, 45^0, 60^0 and 90^0 fiber orientation of unidirectional carbon fiber -epoxy composite and found that fiber orientation influences the young's modulus[(10)]. Berrahou et al., studied on 8 layers of different composites with different fiber orientation and experience fiber orientation effects the ultimate strength[(11)]. Zhao et al., identify the direction and distributions of fibers and prepare a specimen to increase the efficiency of fiber orientation measuring operations[(12)].

This study focuses on the mechanical behavior of different fiber orientations of bi-directional woven kevlar 49 fabrics to observe the properties of the composite materials. The findings of this research may have practical implications for the development of stronger and more durable polymer fiber composites in various applications.

2 Methodology

The first step to manufacture a composite material is to determine the optimal ratios of the matrix and the reinforcing material to achieve the best mechanical properties. For the analysis and experiments, the materials are taken, Bidirectional plain-woven Kevlar-49 fabric, for its high strength and high modulus properties. The thickness of fabric is 0.55 mm, density 1.44 g/cm^3, and surface density 400 g/m^2 Epoxy resin LY 556 and hardener HT972.

2.1 Fabrication

The woven fiber of the test specimen orientated, in an angle of approximate 45^0, 60^0. Here, the configuration of the layer was taken symmetrical and contained 6 plies and arranged as C- (0/45/-45/45/-45/0), B- (0/60/-60/60/-60/0).

Epoxy resin was manually mixed with a hardener at a ratio of 100:20, to get specimens designated as per ASTM. All the three Kevlar epoxy composite materials contain six layers of fabric and prepared in the same manner. At first, six layers of the Kevlar 49 fabric were prepared with (300*300) mm^2 dimensions with the accurate angle orientation as per requirement. Then, Kevlar 49 fabric layers were impregnated with a suitable amount of epoxy. A local anti-bubble roller was used with each layer to remove air bubbles. The six layers were placed above each other under slight compression inside the mould for 24 hours. The produced composite sheets were treated at room temperature for 8 hours to complete epoxy hardening. Finally, five of each testing specimens were cut from composite plate sheet by a hand cutter.

2.2 Machining

The standard ASTM was followed for the laboratory test. As per ASTM standard. From the three differently fiber oriented fabricated plate, five tensile specimens, five flexure specimens for three point loading test specimens and five test specimens for Izod Impact were prepared from each composite plate by a hand cutter.

2.3 Tensile test

According to ASTM D3039, five number of rectangular tensile specimens were prepared from each composite plates to obtain the average mechanical property of the composite material. The tensile test was performed with a load speed of 2mm/min. Specimen dimensions are 250mm x 12.5mm x 2.5mm with constant cross-sectional area.

Fig 1. Preparation of specimen

2.4 Flexure test

Flexural test was performed according to ASTM D790 by three point flexure test method, the specimen size 3.2mm x12.7mm x 125mm.

2.5 Izod test

Here, the weather conditions while conducting the test was 54% humidity at a temperature of 23 degree Celsius. Specimens were prepared and machined from the composite plates as specified by ASTM D 256 standard. Five samples from each composite plate were produced with the dimensions of 62.5x12.5x2mm.

3 Results and Discussion

3.1 Tensile Test

Tensile test was performed according to ASTM D 3039, the tensile properties of the samples are observed on both the specimen. The average tensile stress at break of specimen B is 174.23 MPa and specimen C is 2555.35 MPa.

Table 1. Tensile properties at different orientations

specimen	Tensile stress at break	Tensile strain at break	Modulus
B	174.23 MPa	3.9%	7032.18 MPa
C	255.35 MPa	4.56%	7454.61 MPa

Table 1 shows the tensile properties of the specimens, where 45^0 fiber orientated sample C shows the maximum tensile modulus 7454.61 MPa. Whereas strain at break of Band Care 3.9 % and 4.56 % respectively.

Figure 2 is the post-test condition of the specimen; it is clearly observed that specimens are delaminated on tensile test at failure.

Tensile modulus is important for evaluating the stiffness of a material. In other words, how much the material is expected to deform (elastically) when subjected to a particular load. The higher tensile modulus required more force to deform it. Here, specimen C shows higher tensile modulus than specimen B. So, specimen C stiffer than B.

3.2 Flexural test

Flexural strength is important for stress bearing restoration, it helps to determine the indications for which the material can be used. Table 2 shows the flexural properties of the differently oriented specimen. Where C has higher stress than B, but for flexural modulus specimen B shows higher values.

From Table 3, comparison observed between the maximum flexural modulus and tensile modulus of differently fiber-oriented specimens. Flexural modulus was higher on B specimen, but Tensile modulus is higher on specimen C.

Fig 2. Specimen after tensile test

Table 2. Flexural properties at different orientations

Specimen	Flexural stress	Flexural Modulus
B	72.47 MPa	14368.50 MPa
C	115.05 MPa	9499.28 MPa

Table 3. Flexural modulus and Tensile Modulus with different fiber orientation

specimen	Flex modulus	Tensile Modulus
B	14368.50 MPa	7032.18 MPa
C	9499.28 MPa	7454.61 MPa

Flexural modulus shows the tendency of a material to bend. Higher flexural modulus, indicate stiffer material and the lower flexural modulus indicates flexibility. Here flexural stress and flexural modulus is higher on specimen B, than the other specimen.

When compare with tensile stress and flexural stress of the specimen, on both the section it is found that tensile stress is higher than flexural stress. Flexural stress or flexural modulus shows the tendency to resist bending. But, in general, most of the materials failed due to its tensile stress for its various defects on the surface.

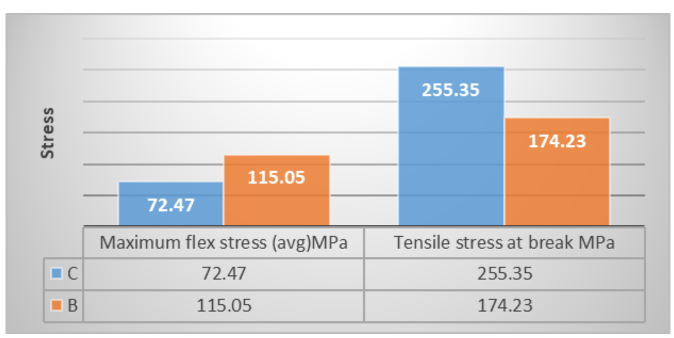

Fig 3. Comparison between tensile and flexural stress

After tensile and flexure test, impact energy test is observed. Impact energy is a measure of a given materials toughness and acts as a tool to study temperature dependent brittle ductile transition. So, here it is determined whether the kevlar epoxy material is brittle or ductile in nature. Here both the specimens absorbed higher energy due to impact.

3.3 Izod test

The Izod test most commonly used to evaluate the relative toughness and impact toughness of the materials and often used in quality control application where it is a fast and economical test. In industries, it is used in medical, automotive, and plastic industries and most commonly used to evaluate the relative toughness and impact toughness of the materials and often used in quality control application where it is a fast and economical test[(13)].

Table 4. Energy absorbed due to impact

Specimen	Energy- J/m
B	678.61 (Partial Break)
C	775.4 (Partial Break)

Table 4 indicates specimen C absorbed maximum energy 775.4 J/m and specimen B absorbed minimum energy 678.61, between these two specimens. Higher impact energy means higher toughness. The impact strength of all aramid composites is misleading due to partial fracture on testing and still have significant amounts of energy absorbing capability after the tests[(14)]. Here after the test, it also shows partial break on both the element and Scanning electron microscope (SEM) images (Figure 4) of the specimen also support it. In this test, specimen absorbed energy till yield and shows the ability to resist breaking by an impulsive load. So, these material can be used against high impulsive load.

Fig 4. SEM of specimen C after Izod impact test

4 Conclusion

In this study, composite materials were fabricated with different fiber orientations, and their mechanical properties were investigated. The results revealed significant variations in mechanical behavior attributed to the differing fiber orientations.

Specifically, the tensile test results demonstrated that specimen B exhibited a lower tensile modulus compared to specimen C. In contrast, the impact test results indicated that specimen C exhibited superior energy absorption capabilities when compared to specimen B. Furthermore, the flexural test results revealed that specimen B displayed a higher flexural modulus, signifying its enhanced performance in this regard. It is noteworthy that specimen C, which featured a fiber orientation of 45^0, outperformed specimen B, which had a fiber orientation of 60^0, in terms of tensile modulus and impact energy absorption. Conversely, specimen B exhibited superior flexural modulus.

In conclusion, this research highlights the vital role of customizing fiber orientation for enhancing composite mechanical properties, in line with the study goals. By incorporating precise quantitative data, not only solidify the findings but also offer practical insights for optimizing these materials. As wrap up, these measurable outcomes pave the way for actionable recommendations and exciting prospects in the realm of composite material development.

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