Synthesis and effect of epoxy in lamination for Kevlar / E-glass hybrid composites

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Abstract. A combination of their unique stiffness and strength, hybrid composites has great potential in a variety of industries, including medium-duty automotive, aircraft, and submarines. In order to evaluate the performance of kevlar/E-glass epoxy composites in this article concentrated on their fabrication and testing. It is well known that the composition has a major impact on the mechanical properties and functional traits of the composite. In order to ascertain the ideal epoxy mix, we thus used a manual layup technique to produce three unique composite sheets designated as P (2:3), Q (2:4), and R (3:2). Research follow ASTM guidelines while analyzing the mechanical parameters, concentrating on tensile strength and binding strength to assess overall structural integrity. As a way to find the interlayer laminar strength between Kevlar fibre and epoxy provide information on interfacial properties, delamination experiments were also carried out. Comparing composite sample P (2:3) to other compositions, our results showed that it had the lowest swelling ratio and the best mechanical qualities. Composite sample Q (2:4), on the other hand, showed the best interlaminar characteristics and adhesion capabilities. The significance of composition mix in attaining targeted performance attributes in hybrid composites is highlighted by these findings.

Keywords. Mechanical characterization, Evaluation, epoxy, Lamination, Kevlar, Composites.

1 Introduction

Composite materials can be produced through various distinct processes, and two commonly known types are metal matrix composites and fiber-based composites [1]. In any composite, the primary property that plays a major role is the binding strength between the interlaminar layers. This strength depends on the quantity and quality of the resin, fiber, and hardener used. It also relies on the orientation of the fiber and the number of layers of the ply [2]. Throughout history, there has been a continuous interest in exploring various aspects of composite materials to enhance their mechanical strength, binding energy, and interlaminar holding ability. The development of composites stemmed from the pursuit of

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high-strength and temperature-resistant materials [3]. Indeed, the exploration of material properties and advancements in material science has progressed from metals to alloys and, ultimately, to composite materials. While metals and alloys have played a significant role in various industries, the search for new materials with enhanced properties led to the development and widespread adoption of composite materials. [4]. Even though composite materials are composed of different materials with distinct properties, as a whole, they exhibit superior properties that surpass those of their individual components. When each constituent material is considered separately for the fabrication of a new composite material, it yields remarkable results. Each constituent material possesses unique properties. For example, some materials may be brittle in nature while others may be ductile. However, when these distinct materials are combined, the resulting composite material inherits the favourable properties of the parent materials. This synergistic combination of properties makes composites highly desirable and offers advantages that individual materials alone cannot achieve [5]. Usually, it can be observed in the material world that materials strong in tensile strength are weak in compressive strength, and vice versa. However, a composite material is the one that possesses both of the best tensile strength and compressive strength [6]. It is because of the fact that all original materials possess the isotropic properties and the composite material is anisotropic material. In any distinct position its properties are [7].

The composite material obtains its unique features from its multi-layered structure, where the layers are bonded together using a combination of epoxy resin, silicon powder, and a hardener. Over time, composite materials have been broadly classified into three categories: MMCs (Metal Matrix Composites), PMCs (Polymer Matrix Composites), and CMCs (Ceramic Matrix Composites). MMCs are composed of metals as the dominant material, PMCs are composed of polymers, and CMCs are composed of ceramics. In the present study, a Kevlar-epoxy reinforced composite material was selected to investigate its mechanical properties and assess the influence of epoxy. The choice of using a Kevlar composite was motivated by its advantageous characteristics, such as its lightweight nature, high strength, and exceptional wear resistance. Kevlar fibres are widely utilized in aerospace applications and emerging marine structural applications because of their remarkable strength-to-weight ratio and resistance to wear [8, 9, 10]. In fact, Kevlar composites possess remarkable strength, being approximately five times stronger than steel. This exceptional strength is attributed to the interatomic bonding within Kevlar composites, which is significantly stronger than the conventional van der Waals intermolecular connections found in other materials. To further enhance the utilization of these materials from a cost perspective, the concept of hybrid composites emerged [11,12]. Since the fabrication of hybrid composites has started, the manufacturing cost has been reduced, and the widespread usability of Kevlar/e-glass composites has increased [13]. There are numerous applications that have emerged since the development of glass fibre hybrid composites, particularly in electronic applications such as printed wire boards and circuit boards [14, 15, 16]. The lay direction, Kevlar fibre angle, number of plies, resin to hardener ratio, volume fraction etc are the key parameters in deciding the strength andother mechanical properties of the Kevlar / e-glass hybrid composites. Out of all the binding ability of the adhesive material and the resin, hardener majorly makes the matrix phase that influences the overall competency of the composite. Depending on the particular needs of the application, the good composition for a Kevlar/E-glass epoxy fiber composite can be determined. In this investigation, Kevlar/E-Glass epoxy Hybrid composite sheets were made using variable percentages of fibers and optimal composite swelling conditions and enhance its mechanical characteristics, such as tensile strength and binding strength.

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2 Materials and Methods

2.1 Fabrication of Composites

To produce a robust composite using E-glass and Kevlar-49, each layer with a thickness of around 0.5 mm is combined with high-quality hardener and epoxy resin to ensure a strong adhesive bond. The manufacturing process involves arranging the Kevlar-49 fibre in the middle, sandwiched between E-glass layers on the top and bottom. In this study, hybrid composite laminates labelled as P, Q, and R were created using a hand layup technique. The quantities of epoxy resin and hardener were measured according to the procedure depicted in Figure 1. The properties of the materials employed, including E-glass, epoxy, and Kevlar, can be found in Table II [19, 20].

Table 1. Layup procedure of fibres

Layer details	P	Q	R
No of layers	5	6	5
E-glass	2	2	3
Kevlar-49 fiber	3	4	2
epoxy/ resin	2	3	4
Hardener	3	2	2

Table 2. Properties of Materials

Parameter	E-glass	Kevlar	Epoxy
Strength of Fiber	340	2761	-
Strength of Laminate	1510	1445	13-41
Laminate Density (g/cc)	2.596	1.48	1-1.13
Strength to Weight ratio	559	989	27

2.2 Tensile properties of the hybrid composite

The tensile properties of the hybrid composite samples (P, Q, and R) were determined according to the standard test method ASTM D638. The specimens used for the tensile testing had dimensions of thickness = 5mm and length = 150mm. A load was applied gradually, starting from 0kN and reaching up to 5kN. Various parameters were determined for each sample, including tensile strength, strain rate, and modulus [21,22].

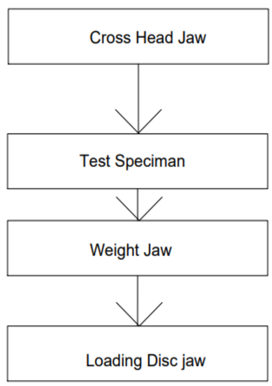

Fig. 1. Semantic Line diagram of tensile test machine

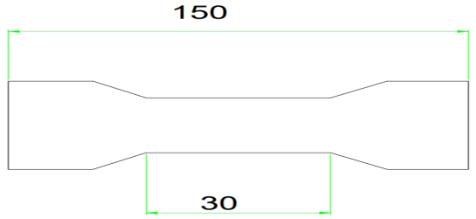

Fig. 2. Specimen Dimension

2.3 Binding strength (Peel Test) of the hybrid composite

The peel removal test is an important procedure that evaluates the bonding capability between the plies of a composite material. Among the various test methods available, the 90° and 180° peel tests are commonly employed [23,24]. In this study, the 90° peel removal test was chosen, which involves gently removing the plies one by one in a perpendicular direction to the workpiece. The loaded sample load for peel test is showed in Figure. During the 90° peel removal test, the force required to peel off the plies is measured. A higher force indicates a stronger material with better internal bonding, while a lower force suggests weaker bonding. The measurement of peel removal force is typically recorded as the force required per unit length (N/mm) [25, 26].

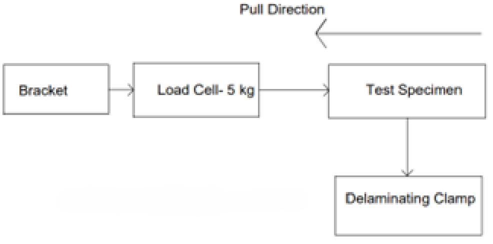

Fig. 3. Schematic line of peel off setup

2.4 Testing of HARDNESS

The hardness of a composite material is an important parameter that plays a significant role in defining its overall strength and durability. In this study, the hardness of the hybrid composite materials was evaluated using a Rockwell hardness test machine, which provides a hardness value represented by the C number. Figure 5 illustrates the setup for the hardness test, where the prepared composite material sample is placed on a pan. An indenter is then used to apply force onto the surface of the material. The hardness value is determined based on the impression made by the indenter on the material's surface and the same is presented in the respective results and discussion section [27,28,29].

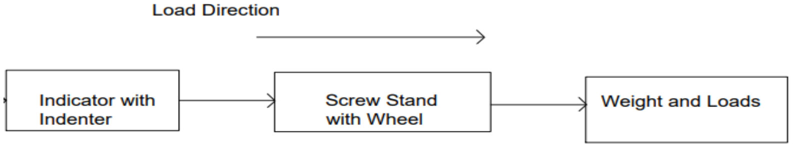

Fig. 4. Schematic line of Hardness Test Setup

2.5 Testing of Density

This is one of the fundamental and important tests to ascertain the packing of the material in the given volume. It will lay an arena to understand the material dispersity and uniformity of packing within the given volume. The dimensions of prepared composite specimen considered for testing of the density is length =24 mm, width = 24 mm and thickness = 0.2 mm. The density of the sample is found by keeping the sample in the cuboid channel closely such that no gaps will be found and based on the weight of the material that has occupied for unit volume its density will be assessed and can be expressed in $\frac{N}{mm^2}$ [30,31].

2.6 Water Absorption Test

This is the test performed to assess the ability of the composite material to show its intendedness to absorb the water. This quality of the material to absorb the water when immersed in the water containing vessel signifies the quality of the material [32,33]. To perform the test at first the sample is weighed and then it is immersed completely in distilled water for about 24 hours at room temperature i.e., 30^o C. After the time got lapsed then the sample is been taken out and then its weight will be tested based on the difference in the weights the composite material strength will be assessed.

3 Results and Discussions

3.1 Tensile Test

The results of the tensile test are given in the below Figure 1. Figure 2. and Figure 3. As the 3 samples are prepared from 3different compositions the variations in the tensile strength are clearly distinguished. From the Figure 7. For the sample P it can be evident that at the strain of 3 mm the tensile strength has changed the slope and increased steeply. The highest tensile strength is observed as 1987 MPa at strain of 5.87mm.

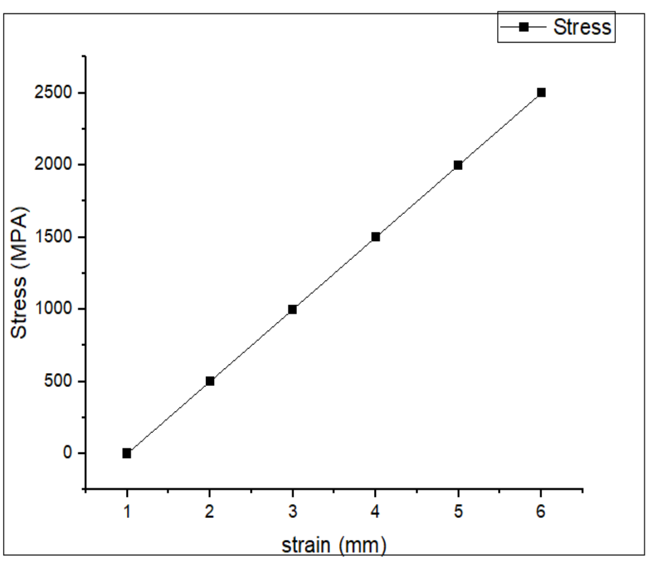

Fig. 5. Sample P

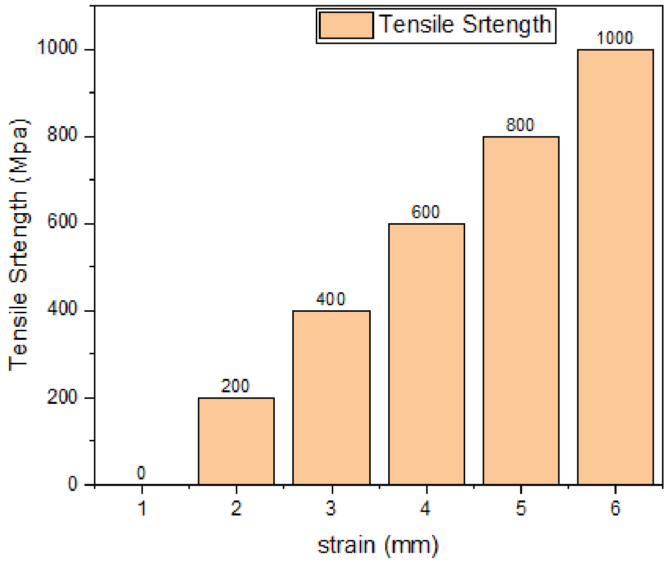

Fig. 6. Sample Q

From the Figure 2. For the sample Q it can be evident that at the strain of 3 mm the tensile strength has changed the slope andincreased steeply again at the strain of 5 mm the tensile strength has changed its slope and shown a steady downfall. However, the net tensile strength is increased to the end and its value is found to be maximum at 6 mm of strain and corresponding tensilestrength is 779 MPa.

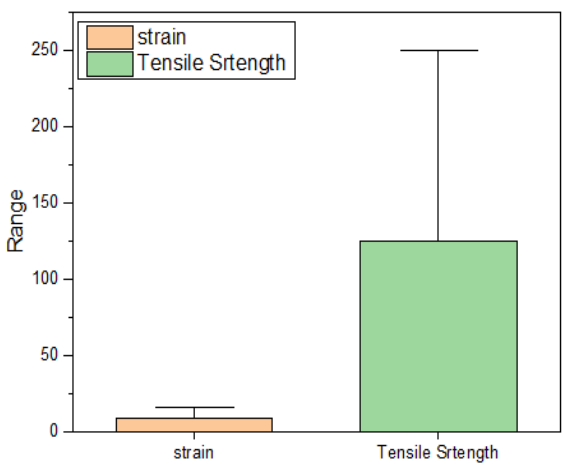

Fig. 7. Sample R

From the Figure 3 For the sample R the strength vs strain curve is quite similar to the mild steel. That is the test results have yielded similar properties of isotropic material such as mild steel or aluminum even though the material used is an anisotropic(composite material). The tensile strength is increased till 3.5mm of strain and its value has reached 145 MPa and then it reached to local peak of 160 MPa at 4.5 mm. Then it fell down to a value of 142

MPa at 6.7 mm of strain. In similar fashion it has attained to a peak of 175 MPa for the strain of 7.8mm. Then it went on declining and reached to least value of 105 MPa for the strain of 14.8mm.

3.2 Peel off Test

Peel off test results shows the significant outcomes in terms of binding strength of the composite material. From Figure 4, Figure 5 and Figure 6 it can be seen that for the sample Q there is a steady and uniform range in peel force is observed. For the sample P and sample R the peel off force has shown more variations in the considered range. As the three samples were made from three different sources of materials hence the peel off force required is also altered accordingly. But as a whole the sample P,Q have resulted in similar outcomes and sample R has shown quite less peel off force.

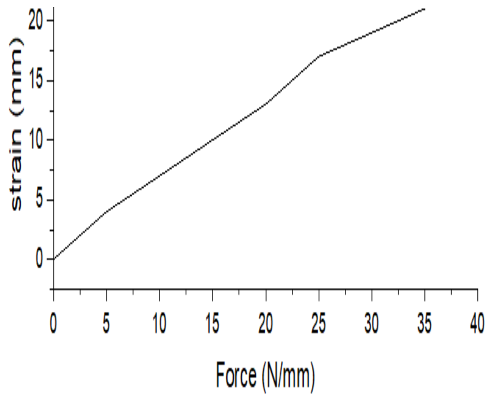

Fig. 8. Sample P

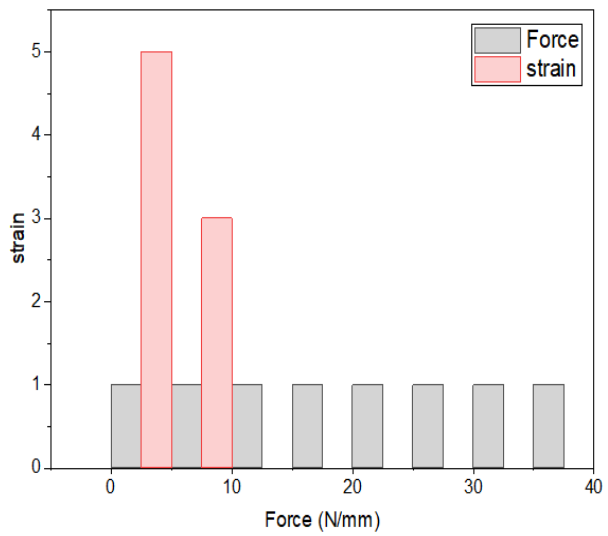

Fig. 9. Sample Q

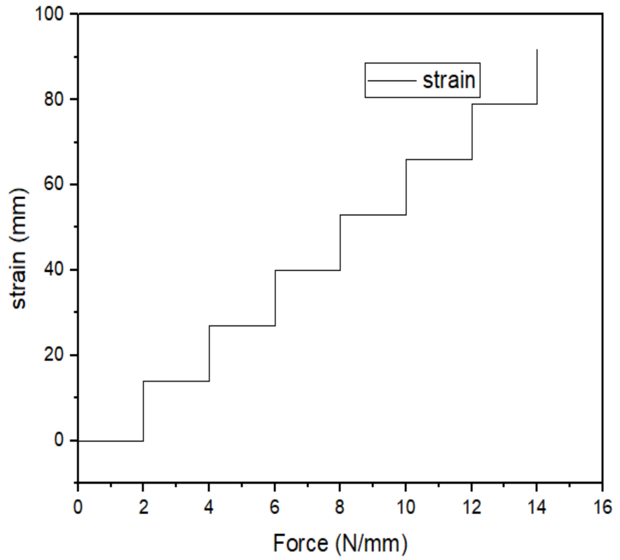

Fig. 10. Sample R

3.4 Hardness Test

The hardness for the samples P,Q and R have resulted in different outcomes as it can be seen in Figure 7. Sample P has obtained the hardness value of 94.887 and sample Q has observed 91.66 and sample R has observed 83.67. From these outcomes it can be witnessed that sample P is harder among the three samples and sample R is least in hardness.

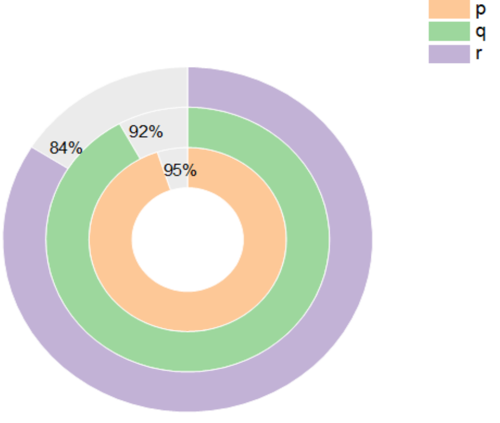

Fig. 11. Hardness test results

3.5 Density Test

The outcomes of the density test are given below in Figure 8. In the graph three parameters are interpreted and they have shown the sample P density is higher than other samples and the density is found least for sample R. However, sample Q and R density are nearer compared P and Q. The weights and Mean values are also obtained in similar fashion.

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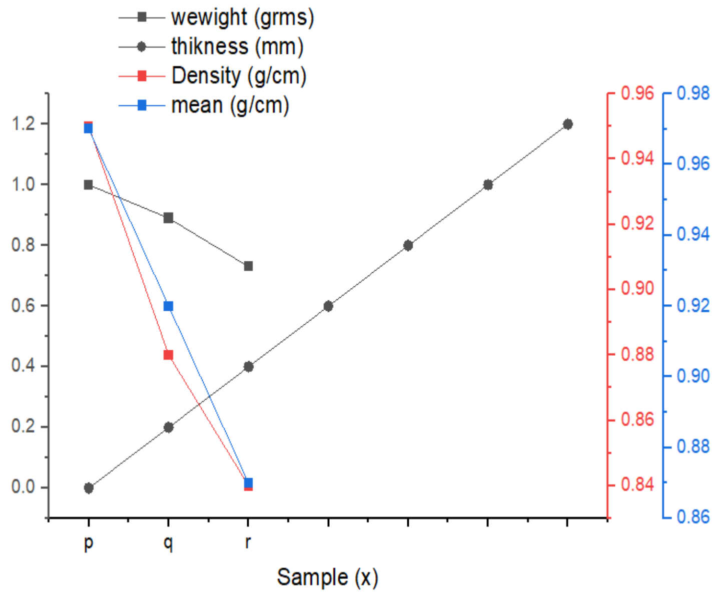

Fig. 12. Density test results

3.6 Water Absorption Test

The water absorption test has yielded the result of material strength with respect to swelling ratio. The swelling ratio can be calculated using below equation no 1.

$$\text{Swelling ratio } \% = \left(\frac{\text{Wet Laminate} - \text{Dry Laminate}}{\text{Dry Laminate}}\right) *100$$

Out of the three samples analyzed the sample B has got more swollen and its swelling ratio is 1.31 followed by A 1.23 and least swelling ratio is for sample C i.e., 1.19. Usually, the materials with less swelling ratio are preferrable for all practical purposes.

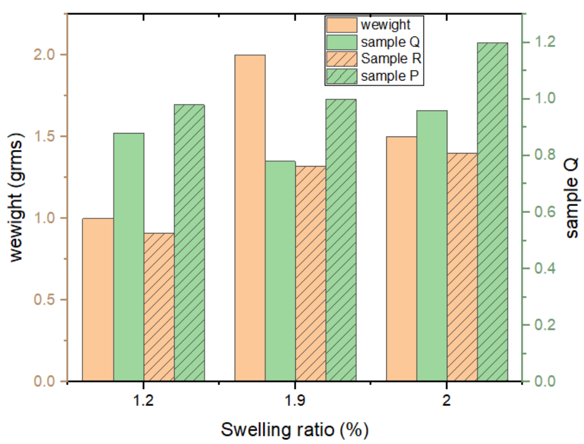

Fig. 13. Water absorption test results

4 Conclusions

From the above experimental analysis, it can be concluded that the samples three have shown the significant outcomes with respect to the mechanical properties. However, the following observatory conclusions are arrived by the end of the experimental and testing work.

- Tensile test has shown that P is stronger than other two.
- Peel off test has shown that sample P and Q are moderate and sample R is stronger.
- According to hardness test sample P is harder among all.
- As per density test sample P is denser than all other samples.
- As per water absorption test Q and P are stronger followed by R.

As a whole sample P is preparatory method and composition is suggested for further analytical investigations.

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