Estimation of Tensile and Compression Properties of 2D Woven Jute and Kevlar Hybrid Laminate

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Abstract. In this study, the mechanical properties of a 2D woven novel hybrid laminate containing jute in the warp direction and Kevlar in the weft direction as reinforcement material is compared with four different weaving patterns. The hybrid laminates were tested for its tensile strength, elongation percentage and compressive strength. The results show that under the condition of identical composition of the matrix element, similarity in the thickness of the laminates and same stacking sequences, the weaving patterns exhibit profound influence on the tensile and compressive properties. The plain weaving pattern exhibited lowest tensile strength and compressive strength while the highest values for the two properties was observed from the hybrid laminate having twill weave pattern.

Keywords. 2D woven, hybrid laminate, jute warp, Kevlar weft, tensile strength, compressive strength

1. Introduction

Laminate is a composite material that consist of reinforcement in the form of whiskers, loosely filled continuous fibres or woven fabrics along with a suitable binding element which serves as the matrix. In the case of woven fabrics, the fibres are laid along two different direction called as warp (longitudinal direction) and weft (lateral direction) [1]. This arrangement makes the reinforcement material to achieve isotropic behaviour. Woven fibre laminates attains properties like high strength and stiffness [2]. Hybrid laminate is a type of composite which contain two or more reinforcement materials stacked in layers within the matrix [3]–[5]. The selection of reinforcement materials is significant to introduce desirable characteristics to the hybrid laminates. Kevlar fibres are used as reinforcement in laminate materials because of its desirable properties like high tensile strength and low density which make it an ideal choice for defence utility items like bullet proof armours [6]. However, it has drawbacks such as non-biodegradability, high cost and non-eco-friendly nature. Natural fibre reinforced laminates offers properties that are not obtainable from its synthetic counterparts [7]. Hybrid laminates containing both natural and synthetic fibres as the reinforcement materials are gaining acceptance in various applications such as building construction, automobile structures, locomotive panels, aircraft structures, defence equipment and marine parts because of the ability to tailor its properties.

Many researchers analysed the influence of the fibre type, its length, orientation and stacking sequences to ascertain its potential to maintain desirable properties under the influence of different types of loads [8]–[11]. Typically, the hybrid laminates contain a monolithic fibre in a given layer of the stack. The stacking order in such cases affects the performance of the hybrid laminates under different working conditions [12]–[20]. Few researchers have considered different weaving patterns and determined its
mechanical properties [8], [10], [21]–[24]. An investigation carried out on a hybrid laminates made of woven fabrics glass and Kevlar reinforcements revealed that the fibre orientation and stacking sequence had profound influence on the mechanical properties like tensile strength, flexural strength and interlaminar shear strength [14]. Increase in the diameter of the individual fibre strands increases the tensile strength of the woven fibres, while reducing the compression strength and flexural strength [25]. Presence of contaminants in the binding element deteriorates the tensile, flexural and impact strengths of composite materials [3].

In this research work an attempt is made to study the mechanical properties of hybrid laminates that contain different types of weaving pattern in the reinforcement material. A novel hybrid laminate is developed that contain both jute and Kevlar as the reinforcement fibres in the same layer of the stack. This study compares the mechanical properties like tensile strength, compressive strength and elongation percentage of 2D woven Kevlar-jute reinforced hybrid composites.

2. Materials and Methods

2.1. Reinforcement material

Jute and Kevlar were chosen as the reinforcement materials to make the hybrid laminates. Kevlar is a synthetic organic fibre that belongs to the family of aromatic polyamide. Kevlar has characteristics like superior strength, resistance to chemicals, thermal stability and ability to retain properties under UV lights. It is widely preferred for military and ballistic applications such as bullet proof vests, military helmets, armours for defence vehicles [26]. Jute fibres are naturally occurring fibres, which are widely available around the globe. Typically, jute fibres were used for construction of handicraft items. However, it is gaining recognition for use in industrial products because of its beneficial mechanical properties [7]. The properties of Kevlar fibres and also jute fibres are shown in table 1.

Table 1. Mechanical properties of the reinforcement fibres [27].

| Properties                  | Kevlar | Jute |
|-----------------------------|--------|------|
| Density (g/cm³)             | 1.44   | 1.3  |
| Tensile strength (GPa)      | 3.6    | 0.93 |
| Modulus of elasticity (GPa) | 62     | 53   |
| Elongation percentage (%)   | 2.8    | 1.6  |

![Four types of weave pattern used in the study.](image)

Continuous fibres of jute and Kevlar were twinned manually before weaving it into the reinforcement material. The reinforcement material was woven by laying jute fibres along the warp direction and the Kevlar fibres along the weft direction. Four different weaving patterns were selected to make the hybrid reinforcements as shown in figure 1. The thickness of the woven fabric was 1.5 mm. Each of the four woven hybrid laminates were cut to the size of 500 mm X 500 mm.
2.2. Matrix element
The hybrid laminate material requires a matrix element that functions as the binder. The binding element was prepared by mixing ten parts of resin (LY556) to one part of the hardener (HY951). The resin and hardener were mixed 10 minutes before manufacturing the hybrid laminates and stored in an air tight container. Provisions was given to the container to connect it to the machine used for fabricating the hybrid laminates.

2.3. Fabrication of hybrid laminate

a. Plain weave
b. Basket weave
c. Twill weave
d. Satin weave

Figure 2. Different weaving patterns of the reinforcement.

Figure 3. Staked layers of reinforcement in the hybrid laminate.

The hybrid laminates were produced using Vacuum Assisted Resin Transfer Moulding (VARTM). The mould was made using aluminium. The mould had rectangular cavity with detachable lid at its top. Bolts were used to fix the lid to the mould. Three ports were provided to the rectangular cavity. Two of those ports were provided at the opposite sides of the cavity. They functioned as the inlet and outlet to allow the premixed binding material to enter into the cavity. The third port was provided in the detachable lid and was used to remove the air inside the cavity. This port was connected to a venturi aspirator which
again was connected to an air compressor. One of the side ports was connected to the sealed container having the binding material. A second venturi aspirator was connected to the inlet port to transfer the binding material from the sealed container. The other port was connected to the venturi aspirator through the flexible hose. Manually adjustable valves were provided to all the three cavities. Flexible hoses were used to connect the ports to the respective venture aspirators. Adjustable frame was used inside the cavity to vary the thickness of the produced laminates [28].

Prior to the fabrication process, the aluminium mould was cleaned using a clean cloth dipped into acetone to remove any dirt inside it. The frame was set inside the cavity and the cut fabrics having plain weave patterns were placed within the frame. Three layers of the plain-woven fabrics were placed inside the cavity. The lid was then placed to close the cavity and secured using bolts. The valves attached to the inlet port and outlet port was closed. The third port was opened and the compressed air was allowed to flow through the venturi aspirator. Because of this the air from the cavity was sucked out to create a negative pressure of 0.966 bar [29]. The valve connected to the third port was closed and then the binding material was allowed to flow into the cavity by opening the valve connected to the inlet port. Compressed air (2 bar) was used to transfer the content from the sealed container through the second venturi aspirator. The pressure was maintained for five minutes to ensure that sufficient quantity of binding material enter into the cavity. The valve connected to the outlet port was opened and observed till the binding material started flowing out through the valve. The inlet and outlet valves were closed and the compressed air supply was terminated. The flexible hoses were removed and the mould was transferred to an oven. The temperature in the oven was maintained at 80 °C for 45 mins to ensure that the binding material cured properly. The mould was taken out of the oven and allowed to cool to the room temperature.

The hybrid laminate produced via VARTM was taken out of the mould and the procedure was repeated to produce the remaining three hybrid laminates. Figure 2 shows the four hybrid laminates containing different weaving patterns, i.e., plain, basket, twill and satin that was made for this study. Figure 3 shows the stacked layers of the hybrid reinforcements within the binding material which functioned as the matrix.

2.4. Mechanical testing

2.4.1. Tensile strength.

Tensile test specimen were cut from each 2D hybrid laminates according to ASTM D3039 standards [30], [31]. Figure 4 shows the tensile test specimen cut from each weaving pattern. Five specimens were cut from each weaving pattern. Each specimen was dried at 50 °C for a duration of 24 h before subjecting to the tensile test. The length of the test specimen was maintained parallel to the warp direction of the fibres. The tests were carried out in an atmosphere of 30 °C and 77 % relative humidity. The tensile test
was carried out by loading the specimen in the Universal Testing Machine (UTM) (FIE-Blue Star, India; Cap: 0-100 kN; Model: Instron-UNITEK-94100). The movable jaw of the UTM was allowed to traverse at 5 mm/min. The force transmitted at the change in the length of the specimen was recorded.

2.4.2. Compressive strength.
The compressive test specimen was cut from each weaving pattern of the 2D hybrid laminates according to ASTM D6641 standards. Five test specimens from each weaving pattern were cut and dried at 50 °C for a duration of 24 h before subjecting to the compressive test. The compression tests were carried out in the Universal Testing Machine (UTM) (FIE-Blue Star, India; Cap: 0-100 kN; Model: Instron-UNITEK-94100). The movable jaw of the UTM was allowed to traverse at 5 mm/min. The force transmitted at the change in the length of the specimen was recorded.

3. Result and Discussion

3.1. Effect of weaving pattern on tensile strength
Figure 5 shows the stress vs strain curve for the four different laminates considered for this study. The hybrid laminate with plain weaving pattern exhibited the lowest stress of 18 MPa. The basket weave pattern enhanced the stress in the produced laminates by two folds. The hybrid laminate with twill weave pattern developed the highest stress of 63 MPa compared among all the produced hybrid laminates in this study. The three hybrid laminates having plain, basket and twill weave pattern exhibited brittle characteristics. However, the hybrid laminate having satin weave pattern exhibited ductile behaviour. The peak stress exhibited by this hybrid laminate was 26 MPa. The stress vs strain curves for the hybrid laminates show that the weaving pattern has profound influence on the stress and strain behaviour. This indicates that the changes in the fibre arrangement along the weft direction enhanced the maximum stress distributed through the reinforcement fibres. While the change in fibre arrangement in the warp direction induced ductile characteristics to the reinforcement fibres. It can be inferred that the fibres in the warp direction has capability to increase the stress distribution along the 2D stacked layers of the hybrid laminates.

Figure 5. Stress vs strain curves for the hybrid laminates.

Figure 6 shows the tensile strength variation in the four hybrid laminates having different weaving patterns. The hybrid laminate having plain weaving patterns of jute and Kevlar fibres exhibited the lowest tensile strength of 19.55 MPa. However, the rearrangement of Kevlar fibres along the weft direction aided in absorbing of the load that was noted in stress strain curves as in Figure 5. All the four hybrid laminates and the same binding material and the same number of stacked layers of reinforcement materials. The variation in the tensile strength in the produced hybrid laminates justifies that the weaving patterns had an influence in the mechanical properties of the produced laminates. The change in the fibre configuration in weft direction as in the case of twill weave pattern increased the tensile strength by 3.41 times that measured from plain weave configuration. This is the highest tensile strength exhibited by the four hybrid laminates considered in this study. Satin weave pattern improved the tensile strength of the hybrid laminate by 48.9 % compared to that of the plain weaving pattern.

Figure 6. Tensile strength of the hybrid laminates.
Figure 7 shows the elongation properties of the hybrid laminates produced for this study. It is observed that the hybrid laminate having plain weaving pattern exhibited an elongation of 6%. The elongation percentage increased for the other hybrid laminates having different weaving patterns. Similarly, to the tensile strength, the elongation percentage of hybrid laminate having twill weaving pattern exhibited the highest elongation of 30%. The huge variation in the elongation percentage compared to its counterpart having plain weaving pattern indicates that the Kevlar fibres arranged in alternating stacking sequence along the weft direction offered required stability to the jute fibres in the warp direction. As a result, the jute fibres were able to absorb more load while retaining its ductility before failing under the applied load. However, in the case of basket weave, the Kevlar fibres were woven to make diagonal traverse. This arrangement was able to absorb higher load than the hybrid laminate having plain weave pattern. However, the increase in stress with the applied load and the diagonal traverse of the weft fibres restricted its ability to undergo expansion under the applied load. In the case of sating weave, the Kevlar fibres were woven with two consecutive fibres along alternating jute fibres in the warp direction. This arrangement reduced the ability of jute fibres to absorb the applied load thereby restricting the load transferring capability of the fibres compared to the twill weave pattern.

3.2. Effect of weaving pattern on compressive strength

Figure 8 shows the variation in the compressive strength of the four hybrid laminates produced for this study. It is found that the plain weaving pattern developed a compressive strength of 52.8 MPa. The basket weave pattern increased the compressive strength of the hybrid laminates by 17.42%, while that of the satin weave increased by 68.18%. The highest compressive strength of 105.6 MPa was exhibited by the hybrid laminate having twill weave pattern. The trend was similar to that observed from the tensile test.

4. Conclusion

Four hybrid laminates having different weaving patterns in the 2D arrangement of the reinforcement fibres such as plain, basket, twill and satin were produced using Vacuum Assisted Resin Transfer Moulding. All the hybrid laminates had the same proportion of the binding material comprising of epoxy resin. The thickness and stacking sequences of the four hybrid laminates were maintained as the same. Stress strain graph revealed that twill weave pattern was capable of absorbing greater force compared to the other three hybrid laminates. Comparing the tensile and compression properties of the hybrid laminates revealed that the twill weaving pattern developed the highest tensile strength of over 66 MPa. The elongation percentage of the hybrid laminates increased from 6% to 30% when the weaving pattern was plain and twill. However, the other two weaving patterns exhibited low tensile strength and elongation percentage than twill weave pattern. Compressive tests revealed identical trend as that observed from tensile strength under the same loading condition.
Figure 9. Tensile vs Compressive strength of the hybrid laminates.

Figure 9 shows the relation between the tensile strength and the compressive strength of the four hybrid laminates produced for this study. It is observed that the hybrid laminates had the ability to withstand compressive force. This is because of the epoxy resin that were used as the binding material and also matrix element. Interestingly, the plain weave pattern produced lowest tensile strength of 19.55 MPa and lowest compressive strength of 52.8 MPa. The other three weaving pattern improved the tensile strength and compressive strength of the produced hybrid laminates. The highest tensile strength of 66.73 MPa and maximum compressive strength of 105.6 MPa was observed form the hybrid having twill weave pattern.

5. References

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