Experimental Investigation of effect of hybridization of UHMWPE fibers on the mechanical and physical properties of Basalt fiber reinforced polymer matrix composites

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Abstract. Polymer matrix composite materials have attracted the researchers over a period due to its superior specific strength compared to conventional materials. Bio based fibers started to emerge rapidly for industrial components, encompassing the technological/scientific aspects and the economic, environmental and social issues. Amongst the variety of bio-based fibers, Basalt fiber occupies a prominent position, due to its overall production and its unique chemistry-related features. It is derived from volcano rocks. UHMWPE having higher specific strength, non-reactive, chemically inert, and hence finds its applications in biomedical field. In the present investigation, UHMWPE fiber (plain woven fabric) along with the basalt fiber (plain woven fabric) are added as reinforcement to LY556 epoxy to bring in hybrid characteristics to the material and comparative studies are conducted with non-hybrid composites. Fabrication is carried out by hand lay-up technique. Mechanical tests such as hardness, tensile and flexural tests are conducted for the fabricated material. Density and water absorption behavior of the composites are also studied. Conventional hand layup method is used for fabrication of composites. From the results obtained, it is obvious that the flexural strength of hybrid composite is enhanced due to the hybridization with the addition of UHMWPE fabrics on the outermost layers in BFRP composites and augments its suitability in the use of engineering structural applications.

Keywords: UHMWPE, Basalt, Hybridization; Mechanical; Physical properties

1. Introduction

The polymer composites have found its wide applications due to its higher strength to weight ratio, corrosion resistance, lighter weight, applicability, ease of getting shaped and suitability for various engineering applications. Even though the usage of polymer composites has started in the earlier 20th century but the wide use of it have started in the second half of 20th century.

Basalt is a non-polluting material that originate in volcanic rocks from frozen lava, having melting temperature between 1500 °C and 1700 °C [1,2]. The density of Basalt fibers ranges between 2.7 g/cm³ to 2.8 g/cm³. It is extremely hard and thus has superior abrasion resistance [3]. It is suggested that, the Basalt fiber could be a possible alternative to natural plant fibers [4]. Czigany proved that the Basalt could be considered as natural, because it is formed by the solidification of molten lava, which is bio inert, & having higher mechanical properties. Tensile strength of basalt fiber increased as the drawing temperature is incremented with increased proportions of crystal nuclei of basalt at lower temperatures [5]. Botev et al. [6] reported the effect of basalt fiber that reinforced on commercial grade polypropylene (PP) composites with dynamic mechanical thermal analysis. The result showed that, the storage modulus (E') and also loss modulus (E'') of the produced composite has increased with increased content of basalt fiber. However, the damping value within the region decreased with increase in fiber loading. Fiore et al. [7] have evaluated the influence of uniaxial basalt fabric on the mechanical properties of a glass matrix/epoxy composite that are used for marine applications produced by vacuum bagging technique. They administered three-point bending and tensile tests to gauge the outcome of number of basalt layers and its
position on the mechanical behavior of the fabricated composite. The outcome showed the presence of two external layers of basalt resulted in increased mechanical properties of produced laminates in comparison to GFRP laminates.

Ultra-high molecular weight polyethylene (UHMWPE) was first polymerized within the 1950’s and the primary UHMWPE fibers were commercialized during 1970. UHMWPE is a Polyolefin composed of long chains of Polyethylene with elevated percentage of parallel orientation and high level of crystallinity. The long polymer chains empower load transfer by strengthening intermolecular interaction.

During early days, UHMWPE fibers were synthesized directly from stirred solutions, possessing a tensile strength of 2.9 GPa and Young’s modulus of 101 GPa [8]. UHMWPE fiber have possessed major applications in Ballistic protection, sports, marine and offshore cut-resistant textile, fishing lines, marine cordage, lifting slings, cut resistant gloves, apparel and medical appliances. The tribological characteristics of UHMWPE were extensively investigated because of its exceptional properties that are suitable for tribological studies. UHMWPE possess high chemical stability and compatibility with human tissue, so that the friction and wear behavior of UHMWPE was studied [9]. UHMWPE could be used as substitute for steel, chrome steel and bronze, due to its better anti-chemical behavior, anti-adhesion, high impact resistance, water repellent function, self-lubrication and corrosion resistance [10].

Cao et al. [11] have examined the impact of basalt fiber (BF) in UHMWPE matrix. They showed that, the increased BF content ensured the reduction in toughness and improved strength, creep resistance and hardness properties of the composite material. Raghavendra Rao R et al. [12] have studied the effect of hybridization of UHMWPE & Basalt fibers using L12 epoxy with K6 hardener combination as matrix material. They have concluded that the inclusion of UHMWPE at the outer most layers has increased the flexural strength considerably, whereas the tensile strength reduced minimally. From the existing literature it is found that, not much research articles have reported the effect of addition of UHMWPE fibers on the Basalt fiber-reinforced epoxy composites on their mechanical and physical properties using LY556 epoxy as a matrix.

2. Experimental details

2.1 Materials

Materials used in the present investigation are Basalt plain-woven 2D fabric of 380 GSM; Ultra-high molecular weight polyethylene (UHMWPE) plain woven 2D fabric of 240 GSM is used as reinforcement material. Details of fabrics are illustrated in table 1. Araldite LY556 and HY951 are used as epoxy resin and hardener respectively, both with density of 1.2 g/cc.

| Table 1 | Represents the basic parameters of Basalt and UHMWPE fabrics |
|---------|-------------------------------------------------------------|
| Parameters | Basalt fabrics | UHMWPE fabrics |
| Density (g/cc) | 2.67 | 0.97 |
| Weight (gsm) | 380 | 240 |
| Thickness (mm) | 0.25 | 0.48 |
| Warp yarns (yarns/m) | 600 | 1000 |
| Weft yarns (yarns/m) | 600 | 1000 |

2.2 Fabrication of composites

Hand layup method was used in the fabrication of hybrid/non hybrid laminates. The fabrics were prepared to the dimensions of 300 × 300 mm² for the fabrication of composite laminates using Aramid cutter. The laminates included seven to eight layers of fabric to maintain approximate thickness of 3 mm for various proportions indicated in table 2. The epoxy resin and hardener were mixed in the ratio of 100:10 by weight. First, wax was applied over the top of a mould and the fibre layers were stacked one after another in the mould and the measured quantity of epoxy was applied on each layer of the fibres. Then the epoxy was uniformly spread using roller. As soon as the last layer of fibre was properly rolled, the granite slab of required size was kept on top of the mould. On the top of the granite, dead weights are placed and sustained in that spot for 24 hours and then withdrawn. The laminates were finally removed from the
mould after a period of 24 hours. Then they were cut using water jet machining as per the ASTM standards to conduct several tests.

Weight fraction (%) is calculated by using the Equation (1)\(^{16}\)

\[
W_f = \frac{w_f}{w_f + w_m} \quad \text{and} \quad W_m = \frac{w_m}{w_f + w_m} \quad \text{--------------------------(1)}
\]

where \(W_f\) is weight fraction of fibre; \(w_f\) is weight of the fibre; \(w_m\) is weight of the matrix; \(W_m\) is weight fraction of matrix.

| Laminates | Stacking sequence | Basalt fabric weight fraction in % | UHMWPE fabric weight fraction in % | Matrix Weight Fraction % |
|-----------|-------------------|-----------------------------------|-----------------------------------|--------------------------|
| L1        | B-B-B-B-B-B-B-B   | 60                                | -                                 | 40                       |
| L2        | U-B-B-B-B-B-B-U   | 50                                | 10                                | 40                       |
| L3        | U-B-B-B-B-B-U     | 45                                | 15                                | 40                       |
| L4        | U-B-B-B-U-B-U     | 40                                | 20                                | 40                       |

3. MECHANICAL CHARACTERIZATION

3.1 Density test

The density is the measure of mass of a material per unit volume. The mass is weighed by weighing machine for a sample of 10 mm x 10 mm and volume is found by Archimedes principle. A 100 ml beaker is taken, and it is filled with distilled water to half a mark. Then the lower meniscus level is noted. Then the samples are dipped one by one to find the final level of water. Final level minus initial level gives the volume of the sample. Then the density of a material is calculated using the formula:

\[
\rho = \frac{m}{V} \quad \text{--------------------------(2)}
\]

where, \(m\) is the mass; \(V\) is the volume.

3.2 Water absorption test

Water absorption test is conducted for 24 hours and 48 hours as per ASTM D570 standard. The sample of 10 x10x3mm\(^3\) is taken and its initial weight is found. Then it is soaked in distilled water for 24 hours. After 24 hours it is withdrawn, and its final weight is found. The same procedure is repeated by dipping the samples for 48 hours.

3.3 Tensile test

Tensile test was carried out on BISS-50KN Universal testing machine (UTM) with data acquisition software. The sample (115 × 19 × 3 mm\(^3\)), with gage length of 33 mm and crosshead speed of 1.0 mm/min were selected as per ASTM: D638-IV standard \(^{14}\) and the test was conducted at a room temperature.

3.4 Flexural test

3- Point bending test is conducted as per ASTM: D790 standard using the same UTM. Testing was conducted with load cell of 10 kN at loading rate of 2.0 mm/min, at room temperature. The dimension of the specimen is 90 x12.5 x 3 mm\(^3\) and the flexural specimens were fixed between two jaws with span length of 60 mm and the load was applied at the center. The specimen is subjected to loading until the gage length increased and the specimen got ruptured.

3.5 Shore ‘D’ Hardness test

Shore ‘D’ hardness test is carried out using the Shore durometer as per ASTM: D2240 standard. Hardness is determined by the penetration of Durometer indenter into the specimen. During the test, the sample was kept on a flat, hard, horizontal surface and held the durometer between both hands over the sample so that the indenter touches it. Then it is pushed down perpendicularly until the presser foot makes firm contact with the sample. Then the reading is taken.

3.6 Surface morphology

Fractured specimens were examined for microstructure using CIRC 20kV scanning electron microscope (SEM). SEM was carried out to examine the dispersion of fibers within the matrix and the adhesion
characteristics amongst Basalt and UHMWPE fibers and matrix is analyzed. In order to enhance the conductivity of the samples, the surface of the sample was coated with a thin gold film and the micrographs were captured from the fractured samples.

4. Results and Discussion

4.1 Density test

![Figure 1. Density plot](image1)

![Figure 2. Water absorption comparative plot](image2)

The experimental densities of the prepared composite laminates are shown in figure 1. As observed in figure, in all the laminate reinforcement percentages, a slight difference in experimental densities were found due to the varying percentages of the two different reinforcement materials used. The non-hybrid laminate L1 exhibited highest density and the L4 laminate exhibited the least density.

4.2 Water absorption test

The water absorption percentages of laminates are shown in figure 2. It is observed from figure that, laminate L4 exhibited highest water absorption percentage & the laminate L2 exhibited least water absorption percentage for both 24 and 48 hours. It is observed that more water absorption is seen in first 24 hours and next 24 hours less rate of water absorption is seen.

4.3 Tensile property evaluation

![Figure 3. Tensile Strength of laminates](image3)
The tensile strength and modulus are shown in the figure 3 and figure 5 respectively. It is seen from the figure that the laminate L1 exhibited highest tensile strength and modulus and laminate L4 exhibited lowest tensile strength & modulus. It is obvious that the addition of UHMWPE fabrics onto the Basalt fiber reinforced composites has substantially reduced the tensile strength and modulus.

4.4 Flexural property evaluation:

Figure 4. Flexural Strength of laminates

Figure 5. Tensile Modulus of laminates

Figure 6. Flexural Modulus of laminates

Figure 7. Comparison between tensile and flexural strengths of different laminates

Figure 8. Comparison between tensile and flexural modulus of different laminates
The flexural strength and modulus are shown in the figure 4 and figure 6 respectively. It is seen from that the laminate L3 exhibited highest flexural strength and modulus and laminate L1 exhibited lowest flexural strength and modulus. It is obvious that the addition of UHMWPE fabrics onto outermost layers has increased the flexural strength and modulus of Basalt fiber reinforced composites substantially. The comparison of tensile and flexural strength and modulus are shown in figure 7 and figure 8.

4.5 Hardness test
The Shore D hardness numbers of different laminates are plotted in figure 9. The L1 laminate exhibited the highest hardness of 78 SHN. The laminate L4 exhibited lowest hardness of 63 SHN. Similar trend was observed in tensile strength and appeared interrelated with each other.

4.6 Morphological studies through SEM
Microstructural studies were conducted to visualize the failure surfaces of the fabricated laminates subjected to tensile loading. The void content, fiber matrix adhesion, and pullout properties are analyzed using the SEM images. All the composite specimens were coated with gold before observing them through SEM. The fractured micrographs of various laminate designations L1, L2, L3 and L4 are presented in Figure 10a-d, respectively. It showed fewer amounts of voids in the fractured samples.

The detachment of fiber laminates resulted in rupture of fibers and matrix and resulted in phenomenon called fiber pullout. Fiber rupture indicates moderate interfacial bonding between fibers and the matrix.
Above discussion revealed that, lesser voids resulted in better laminate properties proper rupture of fibers and improved adhesion amongst the fibers and matrix.

5. Conclusions

A novel hybrid composites comprising of Basalt & UHMWPE have been developed using hand layup method. The mechanical investigations such as tensile, hardness & flexural tests, physical properties such as density and water absorption behaviour of hybrid/non hybrid composites with four different fibre percentages have been deliberated. These are the conclusions drawn from the research work carried out:

1. UHMWPE fabrics on the outermost layers have resulted in enhancement of flexural properties, whereas the considerable reduction in tensile properties is observed.
2. The hybrid composite laminate L3 indicated highest flexural strength and modulus of 523.6 MPa and 15.4 GPa and laminate L1 indicated lowest flexural strength of 133.488 MPa and modulus of 3.849 GPa.
3. The non-hybrid composite laminate L1 shows highest tensile strength and modulus of 298.36 MPa and 9.80 GPa and L4 laminate shown the least tensile strength and modulus of 208.8 MPa and 5.439 GPa.
4. L1 non hybrid composite laminate shown highest hardness value ranging 77 SHN and laminate L4 shown the least hardness value of 63 SHN.
5. The non-hybrid L1 laminate exhibited highest density of 1.42 g/cc and the L4 laminate exhibited the least density of 1.2 g/cc.
6. Laminate L4 exhibited highest water absorption percentage of 0.44% & 0.56% & the laminate L2 exhibited least water absorption percentage of 0.1% & 0.15% for 24 and 48 hours respectively.
7. SEM analysis confirmed that, the hybrid composite laminates showed lesser voids, better adhesion between fibres and matrix, appropriate fibre breakage and pull-out.

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