Experimental investigation on multi-layered filament wound basalt/E-glass hybrid fiber composite tubes

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Abstract
In this study, the mechanical damage of Basalt/E-glass hybrid fiber-reinforced polymer composite tubes was evaluated experimentally using Micro hardness on transverse direction, uni-directional static tensile loading, and Quasi-static compressive loading. The Burn-off test method has been studied for the volumetric fraction of hybrid composite tubes. The multi-layer hybrid composite tubes composed of eight layers of plies at constant fiber tension of 20N, a constant mandrel rotation speed of 45 RPM and constant winding angle of ±55° for basalt fiber and ±90° for E-glass fiber were fabricated through a 3-axis filament winding machine with a seamless amalgamation of the stage by stage curing in the furnace. Eleven tube arrangements with fiber content proportion of {100%, 25:75%, 50:50% and 75:25%} with various stacking sequence were studied. The test results provide that these mechanical property's behavior was moderately affected by the proportion of fiber content and most of the time affected by the variation of layer stacking sequence. Adding 50% of basalt and 50% E-glass fiber sharing of BGH7 hybrid combination of basalt laminate placed in the outer side increases the mechanical characterization compared to the 25% and 75% sharing of basalt and E-glass fiber. The fractured fibrous matrix of the tensile specimens and compressive specimens was assessed using a scanning electron microscope (SEM).

1. Introduction
Fiber-reinforced polymer (FRP) composites are rapidly being used in a variety of industrial fields, particularly in pipes. Installation charges for FRP composite pipes are very low, making them more popular in various applications. Pipelines are increasingly being used in operation around the world to address rising transportation demands for strategic fluids with reducing prices. For an instance, in many pipeline industries, fiber polymer composite pipes are used to transport water, oil, chemicals, and natural gas. Due to its essential uses in various industries, such as cooling tower water pipelines, biomaterials, oxygen pipeline utilization in hospitals, thermal power plants, and other applications [1–3]. The composite’s novel composition is typically created by merging two foreign elements that are placed in the host matrix. Since the two materials are combined, the resulting product has improved qualities. Because these fiber composite structures have outstanding characteristics such as a lighter weight to high strength ratio, ductility, elasticity, they can resist corrosion and has a long lifespan. Due to these mechanical and chemical characterizations make fiber composite tubes’ application constraints significantly important [4–6]. Ahmad Y Al-Maharma et al has reviewed in detail the main critical factors influencing the polymer fiber composites. The authors suggested that the material properties of reinforcement and hosting resin, hybridization of the reinforcement, packing pattern of the length and orientation of fibers, and the addition of Nano-fillers in the matrix give an improvement in the mechanical characterizations [7].

In general, the fiber volume fraction plays a vital part in composite fabrication processes because it is a key stress carrier in almost any research. In every composite product, the stacking sequence is the second most
significant component after fiber volume; it determines the weaknesses and strengths on the core part and the periphery surfaces. Although resins play a crucial role in transferring load from one fiber to another, they are chosen based on compatibility with different types of fibers. Over the years, several experts have worked on composite pipelines depending on a variety of application aspects. Every researcher’s goal was to develop mechanical qualities that seem to apply to their applications [8–11]. Park and Jang work on carbon fiber, where carbon fiber composites are applicable to stress concentrations. The main disadvantage of the carbon composites industry is the high cost of production which forces the use of its fiber with very low loadings, toxic and proper safety measures need to be followed because of hazardous to living beings. Also, the authors combined the carbon-polyethylene fibers with epoxy matrix, based on their findings, the superior mechanical properties of the hybrid-based composite are strongly dependent on the position of the reinforcing fibers. As a result, the carbon fiber was placed at the external (outer shell) layer, the composite demonstrated a high level of strength [12]. Chensong Dong has done an optimization study on carbon/S-glass hybrid composite pipes under flexural loading and he obtained the less failure load track in the middle range of S-glass fiber covered with carbon fiber hybrid composite pipe also gives the best hybrid combination with minimum cost and weight reduction [13]. Some inorganic and organic fibers are currently existing on the bazaar, but many of them are inability in structural strength or survivability and are expensive for use in high-end loadings [14]. In the latest generations, the polymer composites industry has been taken by storm by an increase in research interest with an inorganic fiber of basalt fiber with extensively high mechanical properties, superb stability, great chemical resistance eco-friendly, non-toxic, simple to process, and economical [15, 16]. Basalt fiber is produced by extruding basalt–occupying molten magmas volcanic rock establish in fluid lava. The basalt fiber extrusion process is more energy effective and simpler than that of any competitive fiber. Basalt fiber has possible advantages in the production of basalt-epoxy composites, which are lighter in weight and also have strong load-conveying aspects properties useful in the transportation instrument body buildings and military vehicle fuel tanks. And this fiber was involved in making exclusive hybrid composite materials for building construction applications. As a result, it is critical to reduce production and delivery costs without sacrificing CFRP-based composite mechanical properties. Basalt outperforms carbon in terms of tensile strength and compression resistance, and it is significantly less expensive than carbon-based fibers [17–19]. As previously stated, basalt fibers promising nature, low cost, and effective properties could make basalt a viable candidate for reinforcement in E-glass-based composites. There are several accounts of reports available that describe the incorporation of basalt fibers with various reinforcements within composite laminates [20]. Lopresto et al correlated the performance of basalt and E-glass reinforced thermoset resin composite plate and delivered a better response in tensile and compressive behavior on basalt composite. Their findings suggested that basalt should be used instead of glass [21]. Since the basalt fiber possesses high thermal and vibration damping properties, S Ilangovan et al has studied the effect of 1.5% weight percentage of silicon nanoparticles with epoxy resin in basalt and glass composite tubes fabricated by filament winding technique. Also, they deliver the basalt silicon Nanocomposite epoxy composite tubes have a high response in hardness and vibration damping than the glass epoxy Nanocomposite tubes [22]. Yang et al studied the axial compressive behavior of the hybrid basalt and coconut fiber epoxy composite tubes and the predicted results are affected by the size of the specimen, fiber-oriented design, and stacked positions. They confined the improvement in the ductility and compressive strength because of more amount of basalt fiber content in composite tubes. Basalt fibers have recently been used in the building industry, and it has also been used as an external or internal reinforcement in concrete materials. This combination would not only be financially beneficial, but it would also be long-lasting and lightweight, extending its use of basalt in hybrid composites [23].

The factors that affect the filament wound tube composite’s mechanical behavior with fiber orientation, fiber tension, and fiber roving type has a significant impact on the ultimate end product’s performance. Many scholars have investigated hardness, quasi-static tensile, and compression qualities as basic mechanical properties. However, before material characterization, it is essential to fabricate composites that meet the needs of the application. We have discovered that the filament winding technique is the most suited approach for the manufacturing of polymer composite tubes based on various literature studies and the opinions of many researchers [24–26]. The physical and mechanical properties of glass fiber reinforcement composite tube structures are influenced by the applied tow tension during filament winding, according to a study by Mertiny et al increasing the fiber tow tension results in a large increase in fiber compaction, which benefits component strength [27]. High mechanical strength and stiffness are produced by optimizing the winding speed during the manufacture of composite tubes or tanks, Mohammad Firdaus Abu et al have evaluated the 6-speed combinations and found that ±55° is the optimal winding speed for glass fiber epoxy composite pipes. And Srikumar Biradar et al has studied the tribo-mechanical and physical characterization of filament wound glass vessel composites. The authors identified stacking sequence, hoop and helical winding pattern (±55°/±90°) and hoop and helical layers give better results in pressure vessel applications. Due to the brittleness of the fiber composites if the winding angle gets reduced the strength of the composite will increases but the stiffness will be
reduced. While splitting the optimized winding pattern on the outer layer the mechanical properties of the glass epoxy composite vessel improved. And the perpendicular winding pattern on the middle layer gives more stiffness \[28, 29\]. Subrata et al have explained the stacking sequence effects on the hybrid composites reinforced by glass/jute fibers with seven combinations, the glass fiber laminates placed on both sides show high improvement of 10.7% in tensile strength and 21.5% in tensile modulus than other stacked sequences \[30\].

Several researchers have concentrated on different polymer composites such as glass, basalt, carbon, Kevlar, and aramid fibers, as seen by the relevant literature studies. The various fabrication procedures, as well as influential aspects and mechanical qualities, are investigated according to the applications and needs of various researchers. Many authors emphasized the importance of mechanical qualities in their published works. We focused on many parameters during the fabrication of plain and multi-layer hybrid composite tubes in this study. The influencing aspects of sharing two dissimilar fiber content with four combinations, eleven various stacking sequences of composite tubes, with optimized winding tension and mandrel rotation speed and optimal stage by stage curing processing time consistency throughout the fabrication process. To identify the extraordinary operating environmental conditions of composite tube products, the constructed hybrid composite tubes are subjected to basic mechanical characterization. Finally, the analyzed specimens were subjected to morphological analysis to determine the root causes of failure.

2. Materials and method

In this study unidirectional basalt fiber roving (1200 Tex, 13 diameter micron size) supplied by Arrow Technical Textiles private limited company and unidirectional E-glass fiber roving (2400 Tex 13 diameter micron size) supplied by SaiSakthi enterprises company were used as the reinforcements for the hybrid composites which has a density of 2.6 g cm\(^{-3}\) and 2.58 g cm\(^{-3}\) as shown in figure 1 respectively. The Araldite low viscosity bisphenol-A epoxy resin matrix and Aradur HY951 hardener used for the composites which were provided by SaiSakthi Enterprises private limited company with the corresponding volume fraction of resin-to-hardener was 2:1 was mixed for 30 min. To obtain the best resin and to assist the curing and drying process, Cobalt actuates solution and Peroxide acid solution were added to the indicated resins in the proportions of 1.5 percent weight and 15 percent weight accordingly \[31\]. The mechanical properties of fibers and matrix used as received from the suppliers are shown in table 1.

![Figure 1. (a) Basalt fiber roving  (b) E-glass fiber roving.](image-url)

| Table 1. Properties of reinforcement and resin matrix. |
| --- |
| S.No. | Properties | Epoxy | E-glass | Basalt |
| 1 | Density (g cm\(^{-3}\)) | 1.15 ± 0.01 | 2.58 ± 0.01 | 2.60 ± 0.01 |
| 2 | Elastic Modulus (GPa) | 3 ± 0.01 | 70.0 ± 0.01 | 90 ± 0.01 |
| 3 | Tensile Strength (MPa) | 79 ± 2 | 1970 ± 402 | 3200 ± 433 |
| 4 | Poisson Ratio | 0.35 | 0.2 | 0.3 |
| 5 | Linear Density (tex) | — | 2.4 k | 1.2 k |
| 6 | Filament Diameter (μm) | — | 17 | 13 |
Table 2. Description of basalt/glass epoxy fiber composite laminates.

| S. no. | Specific details | SPEC. name | Stacking sequence | Fiber content | Fiber orientation |
|--------|------------------|------------|-------------------|---------------|-------------------|
| 1.     |                  | G_8        | G_8               | 100% G        | ±90°              |
| 2.     | (BGH1)           | G_6B_2     | 25% B             | 75% G         | ±90°–±55°         |
| 3.     | (BGH2)           | G_1B_2G_3  | 25% B; 75% G      | ±55°–±90°     |
| 4.     | (BGH3)           | B_2G_2B_2G_2 | 50% B; 50% G    | ±55°–±90°     |
| S. no. | Specific details | SPEC. name | Stacking sequence | Fiber content | Fiber orientation |
|--------|-----------------|------------|-------------------|--------------|------------------|
| 5.     | (BGH4)          | B₂B₂G₂G₂   | 50% B:            | ±55°–±55°–    |
|        |                 |            | 50% G             | ±90°–±90°     |
|        |                 |            |                   | ±90°–±90°     |
| 6.     | (BGH5)          | G₂G₂B₂B₂   | 50% B:            | ±90°–±90°–    |
|        |                 |            | 50% G             | ±55°–±55°     |
| 7.     | (BGH6)          | G₂B₂B₂G₂   | 50% B:            | ±90°–±90°–    |
|        |                 |            | 50% G             | ±55°–±90°     |
| 8.     | (BGH7)          | B₂G₂G₂B₂   | 50% B:            | ±55°–±90°–    |
|        |                 |            | 50% G             | ±90°–±55°     |
| S. no. | Specific details | SPEC. name | Stacking sequence | Fiber content | Fiber orientation |
|-------|-----------------|------------|-------------------|---------------|------------------|
| 9.    |                 | (BGH8)     | B<sub>6</sub>G<sub>2</sub> | 75% B: 25% G | ±55°–±90°        |
| 10.   |                 | (BGH9)     | B<sub>3</sub>G<sub>2</sub>B<sub>3</sub> | 75% B: 25% G | ±55°–±90°–±55°   |
| 11.   |                 | B<sub>8</sub> | B<sub>8</sub> | 100% B | ±55°               |

B-Basalt fiber; G-Glass fiber; BGH1 to BGH9-hybrid stacking combination from the inside to the outside of the tube where the process is performed.
E-glass/Basalt hybrid, pure basalt, and E-glass composite tubes were manufactured using a filament winding technique with two different combinations of winding orientation angles ($\pm 55^\circ$ for basalt and $\pm 90^\circ$ for E-glass) for eleven laminates. Along with constant winding tension of 20 N and constant mandrel rotation speed of 45 RPM are maintained. The variation of angle winding pattern essentially gives the tubes more strength than the normally used optimum angle of $\pm 55^\circ$ to fill the space of study with this lamination under various mechanical testing [32]. According to laminate plate theory, multi-layer sandwich structures of increasing thickness by stacking different fibers reduce the lack of stiffness compared with plain fiber [33]. In traditional filament winding, a $\pm 90^\circ$ layup gives consolidation and resists internal or external pressure in high-pressure fluid transportation [34]. Eleven configurations of tube pattern were intended with the effect of variable fiber content {100%, 25:75%, 50:50%, and 75:25%} for different stacking sequences, and the composition ratio of hybrid fibers is shown in Table 2.

2.1. Fabrication of hybrid composite specimen

The CNC Technologies Pvt. Limited 3-axis filament winding machine with CNC controlled spindle located on MIT campus and schematic diagram of filament winding technique is shown in Figures 2 and 3. A 39.8 mm diameter composite tube mandrel was prepared for production. Before being inserted into the filament winding machine, the mandrel was cleaned and polished to ensure the smooth inside surface of the composite tubes. To make fiber attach to the mandrel more easily and be segregated, a very thin layer of resin called gel coat is sprayed on the mandrel with a 0.8 mm thick gel coat spraying device. The fiber roving is split into various segments of nylon bobbins. The fiber roving from the all-nylon bobbins passes through the stainless-steel rod for uniform fiber stiffness and pay-out eye for uniform fiber tension. Further, the fiber is running through the resin bath
along with the comb structure component and wound on the mandrel, and the orientation of the specimen was varied with the help of movement of the horizontal carriage. The hybrid composite tubes have a 40 mm internal diameter and a 1000 mm overall length, with an average thickness of 4 mm are shown in figure 4 and the table 3 shows the dimensions of composite tubes produced [35].

After filament winding, the hybrid tube laminates are cured in an oven having accurate temperature control. Initially, the raised temperature of the oven from room temperature to 120 °C in 5 min with a heating rate of 2° to 4 °C per min. Hold the temperature between 120 °C ± 5 °C for 2 h. And raise the temperature of the oven from 120 °C to 150 °C in 3 min with a heating rate of 4 °C per min, and hold the temperature at 150 °C ±5 °C for 4 h. Then switch off the oven and allow the component to cool naturally and open the door and remove the mandrel when it is below 40 °C.

### 2.2. Sample preparation

The cutting process of the sample was done using a high-speed tile saw for mechanical testing of Burn-off test, microhardness test, tensile test, and compression test as per ASTM standards.

### 2.3. Burn-off method

The fiber and matrix content affect the material’s mechanical characterization and its properties in hybrid composites. Due to the volume fraction of each component at different winding angles and various hybrid stacking, sequences of basalt and E-glass fibers by filament winding techniques play a major role in hybrid laminates. According to ASTM D2584 burn-off test method to determine the proportion of the raw materials contained in hybrid composite materials by removing the matrix in a furnace. In the burn-off method, a 4-L
Digiquel electric muffle furnace with a heating limit of 900 °C was used to remove epoxy matrix from hybrid laminate structures. The specimen taken for my study with 10 mm × 10 mm dimensions according to the ASTM D2584 standard, the test process was followed. The heating temperature and time were set to 500 °C and 2 h, respectively. At 30 min time intervals, the weight of the specimen was measured and then the burning was continued. The process was repeated until the weight of the specimen was less than 0.001 g. This testing method is the most efficient technique for allowing the matrix resin to be calcined gradually, which provides an accurate characterization of the quality of the hybrid laminate structure. Figure 5 explains the burn-off test procedure for the hybrid laminate [36].

2.4. Micro-hardness test
The micro-hardness testing is fundamental testing carried out at room temperature (27 °C) using ZwickRoall ZHV10 microhardness tester equipped with Diamond square pyramid indenter with the included angle at the tip of 136 °C as shown in figure 6. The specimen (30 mm tube length) was performed under the ASTM E384 standard for micro-indentation hardness of fiber composite material. Loads of 10 N were applied for 15 s each between the time of contact with the diamond and the withdrawal of the load. Micro-hardness was calculated at five different locations on the transverse side of the eleven hybrid stacking sequences of the samples [37].
2.4.1. Tensile test
Tensile testing is a fundamental Tribology test that involves applying a controlled tensile load to a test object until it fractures. For my tensile study, the specimen was cut from the cut portion of the hybrid composite pipe according to the dump bell-shaped ASTM D638 standard. The cut section of the tensile test specimen with 4 ± 0.12 mm thickness sharing 8 layers of plies and 25 mm width along an extensometer with a gauge length of 50 mm is used to determine the deformation of the test specimen. The ASTM tensile test pattern with tensile testing machine image is shown in figure 7. Which was performed at a quasi-static loading rate of 2 mm min$^{-1}$ using a Standard Universal Tensile Machine (UTM) with a load of 300 KN at room temperature (27 °C). All stress and strain data were recorded as both pure and hybrid stacked sequence specimens were tested until a final failure occurred. The varied stacking sequences of the traction samples were evaluated in addition to the microstructure investigation [38, 39].

2.4.2. Quasi-static compression test
Compression testing is an essential mechanical test, in which the test specimen is subjected to a controlled crushing pile till buckling failure occurs, intending to prevent bulk buckling of the specimen by constraining it and limiting the gauge length region within acceptable limits. The test specimens were cut in regulatory requirements with ASTM D3410 firm plastic compression features. Throughout the testing, the compression test was done at a near-static load rate of 2 mm min$^{-1}$. In this compression study, the specimen measurement used is 40 mm inner diameter, 150 mm length, and 4 ± 0.40 mm thickness with composing of 8 laminate layers, along specimen cross-sectional area is 533 mm$^2$. The compressive properties of circular test specimens are tested according to standard. The Universal Testing Machine (UTM) was utilized for testing, with a load of 300 KN at room temperature (27 °C) and an instrument image displayed in figure 8. The data is saved in a worksheet format by the Blue-Hill software [40, 41].
2.4.3. Morphological analysis
Damage in polymer fiber composites will normally depend on the fiber type, fiber orientation, volumetric fraction, matrix type, stacking sequence, and interfacial fiber matrix binding. To understand the failure mechanism of the fabricated hybrid composite under different loading conditions of tensile-tested specimens along the cross-section side, the surface morphologies of top surfaces of the composite laminates and compression tested specimens fractured surfaces of the composite laminates were inspected using a scanning electron microscope. Since the clean sample was essential for the clarity of the image, the fractured surfaces were coated with gold and retained in an ionizer. And the image was taken by submitting the surface to a voltage of 15 kV. Figure 9 shows the scanning electron microscope instrument.

3. Result and discussion

3.1. Fiber volume fraction
As part of the hybrid composite rule, the basalt/E-Glass hybrid volumetric fraction Burn-off test is calculated using the equations indicated below. Since in this process the fiber content 100%, 25:75%, 50:50%, and 75:25% is chosen for the manufacture of pure and hybrid multilayer composites. The computation of the volume fraction for hybrid fiber composite will be shared in these percent ratios in this test [43, 44].

\[ M_C = M_F + M_M \]
\[ V_F = M_F / \rho_F \]
\[ V_M = M_M / \rho_M \]
\[ \rho_C = \rho_B V_B + \rho_G V_G + \rho_M V_M \]

| S. no. | Specimen stacking sequence | Mass of composite (g) | Mass of matrix (g) | Mass of fiber (g) | \( V_F \) (cm\(^3\)) | \( V_M \) (cm\(^3\)) | \( V_C \) (cm\(^3\)) | \( V_MV \) |
|-------|--------------------------|---------------------|------------------|-----------------|----------------|----------------|----------------|--------|
| 1.    | G\(_8\)                  | 2.358               | 0.845            | 1.513           | 0.586          | 0.735          | 1.321          | 0.444  |
| 2.    | (BGH1)                   | 1.996               | 0.633            | 1.363           | 0.526          | 0.550          | 1.076          | 0.488  |
| 3.    | (BGH2)                   | 2.412               | 0.900            | 1.512           | 0.584          | 0.782          | 1.366          | 0.427  |
| 4.    | (BGH3)                   | 1.806               | 0.690            | 1.199           | 0.462          | 0.600          | 1.062          | 0.435  |
| 5.    | (BGH4)                   | 2.703               | 0.854            | 1.849           | 0.713          | 0.742          | 1.435          | 0.490  |
| 6.    | (BGH5)                   | 2.982               | 0.913            | 2.069           | 0.798          | 0.793          | 1.591          | 0.501  |
| 7.    | (BGH6)                   | 2.302               | 0.870            | 1.432           | 0.552          | 0.756          | 1.308          | 0.423  |
| 8.    | (BGH7)                   | 2.103               | 0.777            | 1.326           | 0.512          | 0.675          | 1.187          | 0.431  |
| 9.    | (BGH8)                   | 1.898               | 0.653            | 1.315           | 0.506          | 0.567          | 1.073          | 0.471  |
| 10.   | (BGH9)                   | 2.083               | 0.794            | 1.289           | 0.386          | 0.690          | 1.076          | 0.358  |
| 11.   | B\(_8\)                  | 2.124               | 0.586            | 1.538           | 0.592          | 0.509          | 1.101          | 0.537  |
5. \(V_c = V_F + V_M\)

6. \(V_{FV} = V_F/V_C\)

7. \(V_{MV} = V_M/V_C\)

Where,

- \(M_C\) — Mass of Composite Specimen (g)
- \(M_F\) — Mass of Fiber; \(M_B\) — Mass of Basalt fiber; \(M_G\) — Mass of E-glass Fiber (g)
- \(M_M\) — Mass of Matrix (g)
- \(\rho_B\) — Density of Basalt fiber; \(\rho_G\) — Density of E-glass fiber; \(\rho_M\) — Density of matrix. (g cm\(^{-3}\))

Figure 10. (A)–(K) weight of specimen Vs Time due to the burn-off test of plain and hybrid composites.
$V_c$—Volume of Composite specimen; $V_B$—Volume of Basalt fiber; $V_G$—Volume of E-glass fiber; $V_M$—Volume of Matrix ($\text{cm}^3$)

$\text{VF}_V$—Fiber volume fraction

$\text{VM}_V$—Matrix volume fraction

Table 4 delivers the burn-off test results determined by solving the above equations. The fiber volume fraction of 0.534, 0.444, and resin volume fraction of 0.463, 0.556 were obtained in the volumetric fraction of the pure basalt and E-glass composite. In the case of total fiber loading in hybrid laminate shares basalt and E-glass fiber content of 25:75% fiber volume fraction value 0.488 and 0.427 and the hybrid epoxy resin volume fraction value 0.512 and 0.573 respectively. Similarly, the fiber content of 50:50% ratio of basalt and E-glass fibers shares the fiber volume fraction in the range of 0.42 to 0.50 and epoxy resin range of 0.49 to 0.57 for each hybrid composite stacking sequence. Total fiber volumetric fractions of 0.471 and 0.358 are achieved in hybrid
laminates with 75:25 percent basalt and E-glass fiber content, accordingly, with epoxy resin volume fractions of 0.643 and 0.463. The variations in the fiber volumetric fraction with four different fiber content shares (100%, 25:75%, 50:50%, and 75:25%) in the same dimension of the hybrid composite with constant winding angles (±55°, ±90°) and different stacking sequence. In fiber-reinforced plastics, the fiber volume fraction gives much vital role in defining the mechanical performance of the composites structure. In this study, the volume fraction of total fiber attains approximately 40%–50% and the matrix attains approximately 50%–60%. Because of the lab-scale filament winding strategy employed to manufacture these tubes, there are variations in the portion of epoxy delivered after penetration.

Figures 10 (A)–(K) indicates the results of the combustion test composite specimens of mixed single and double hybrid fibers. Initially, the weighted specimens are heated to 500 °C, then for every 30 min time lap, the specimens are weighted predominately. The resin was rapidly burned within the first hour of heating. Keep on heating the hybrid laminate; the specimen slowly turns white E-glass and light brown basalt. At some stage, the weight of the specimens remains the same for a brief period. Because the epoxy resin matrix was completely burned away. The weight of the fibers was noticed using a weight balance of precision of 0.001 g.

### 3.2. Microhardness test

The inclusion of basalt-epoxy composite improved the microhardness since E-glass has a low hardness, with the lowest average value of the plain E-glass epoxy composite being 66.95 HV and the highest average hardness value of plain basalt epoxy composite has 102.03 HV achieved with Micro Vickers hardness test equipment under 10 N load condition in this study. The micro-hardness values will be enhanced by inserting basalt fiber in varied proportions on the hybrid form employing filament winding technology with optimized process parameters as shown in this work. However, due to the mixing of epoxy resin and diverse physical qualities, the fiber stacking sequence has a significant impact on the hardness value. All of these hybrid composites were subjected to the same 10 N load test condition as followed for plain E-glass and basalt epoxy composites. Initially, basalt fiber with a 25% fiber content on the total fiber volume fraction achieves average values of 75.11 HV and 77.53 HV, indicating a significant increase in hardness value. The hardness value ranges from 78 HV to 96 HV while basalt fiber content is increased by 50% on the total fiber volume fraction. With a 75% increase in basalt fiber content on the overall fiber volume fraction, average hardness values of 96.01 HV and 97.03 HV are achieved. Table 5 lists the microhardness values for the composite materials which have been developed. Because of the greater impact on the hybrid stacking sequence and filament winding orientation in this hybrid combination, the stacked hybrid composite has the highest average hardness value with more quantity of basalt fiber content. Raajeshkrishna et al studied the mechanical properties of woven glass basalt fabric epoxy composites plates using hand layup methods, compression, vacuum resin infusion, and vacuum bagging technique and found that increasing the basalt fiber content in hybrid composites improves hardness characteristics [45]. Due to the combined two fiber-reinforced composites with different stacking sequences, the composite is projected to have more flexibility than the flexibility of each fiber component of the composite. The greater modulus of elasticity fiber provides stiffness and load-carrying capability, but the low modulus fiber makes the hybrid composite more durable and cost-effective. Researchers have not yet examined the relation between hardness and other composite qualities like strength in the longitudinal and transverse directions. This makes research in this field interesting, and it is partially the reason for this proposal’s development [46]. However, the hardness value of the multi-layer hybrid composites has notably risen of the material change at the analyzing locations. Where the micro-hardness observations were still at their peak in the transverse region of the specimens, as these values would represent the reaction of the stiffer basalt fiber on the hybrid fiber composites.
3.3. Static tensile test

The laminate was subjected to experimental tensile loading to assess the linear properties of hybrid composite materials. The tensile test was performed with three specimens of the same dimensions for each combination, as per ASTM standard. The coefficient of variation and standard deviation of each combination is reduced when all trails are combined, and the test results are more precisely reflected. The experimental results of the tensile properties for plain basalt composite, plain E-glass composite, and multi-layer hybrid fiber composites are summarized in Table 6. The failure modes of hybrid composite materials subjected to tensile loads are affected by the type of reinforcement mixture with different stacking sequences and variable winding angles. Because some manufacturing defects such as voids, fiber waviness, and specimen dimensions such as edges and final effects are considered essential effects. A picture of the all-tensile composite specimens after failure is shown in Figure 11.

The test result of plain basalt/epoxy and plain E-glass/epoxy composite of constant winding angles with 100% single fiber content, tensile graph line increases linear manner to its maximum value then drops suddenly in final fracture load. Aniber et al has explained the comparative tensile study on the plain E-glass thermosetting epoxy resin polymer composite with fiber orientation of $(\pm 90^\circ)$ gives an improvement in tensile properties than thermoplastic resin mixed hybrid composite. Andjafarbazadeh et al has investigated the effect of E-glass, carbon, and Kevlar polymeric filament winding tubes and estimated the tensile properties of E-glass composite with fiber orientation of $\pm 45^\circ$ gives less impact than other composites. Bulut et al investigates the influence on mechanical properties in basalt/epoxy composite laminate with an exact fiber orientation of $(\pm 55^\circ)$ which is extremely similar to my base test result from this study. Figure 12 also displays peak strength in the plain basalt and E-glass composite stress-strain graph, which was cross-checked with previous investigations [47–49].

The E-glass epoxy composite has a minimum tensile strength in comparison with the multi-layer hybrid composites and Basalt-epoxy composite. The modes of failure were observed as the brittle fracture of the matrix

| S. no. | Stacking sequence | SPEC Nos. | Peak Force (KN) | Tensile strength (MPa) | Highest peak strain at third specimen (%) | Highest modulus at third specimens (GPa) | Coefficient of variation for tensile strength (%) | Standard deviation for tensile strength (σ) |
|-------|-------------------|----------|----------------|------------------------|------------------------------------------|-----------------------------------------|---------------------------------------------|------------------------------------------|
| 1.    | G_1               | 1.       | 11.190         | 109.683                | 1.623                                   | 0.07                                    | 0.809                                       | 1.6                                       |
|       |                   | 2.       | 11.279         | 110.561                |                                         |                                         |                                             |                                           |
|       |                   | 3.       | 11.372         | 111.472                |                                         |                                         |                                             |                                           |
| 2.    | (BGH1)            | 1.       | 11.433         | 112.254                | 0.0658                                  | 1.7                                     | 0.699                                       | 1.25                                      |
|       |                   | 2.       | 11.506         | 112.972                |                                         |                                         |                                             |                                           |
|       |                   | 3.       | 11.594         | 113.834                |                                         |                                         |                                             |                                           |
| 3.    | (BGH2)            | 1.       | 13.243         | 128.953                | 0.134                                   | 0.98                                    | 1.19                                        | 1.569                                     |
|       |                   | 2.       | 13.377         | 130.254                |                                         |                                         |                                             |                                           |
|       |                   | 3.       | 13.539         | 131.837                |                                         |                                         |                                             |                                           |
| 4.    | (BGH3)            | 1.       | 13.896         | 137.112                | 0.0543                                  | 2.57                                    | 0.580                                       | 1.28                                      |
|       |                   | 2.       | 13.954         | 137.683                |                                         |                                         |                                             |                                           |
|       |                   | 3.       | 14.056         | 138.693                |                                         |                                         |                                             |                                           |
| 5.    | (BGH4)            | 1.       | 13.704         | 135.753                | 0.0754                                  | 1.82                                    | 0.546                                       | 1.11                                      |
|       |                   | 2.       | 13.771         | 136.415                |                                         |                                         |                                             |                                           |
|       |                   | 3.       | 13.854         | 137.241                |                                         |                                         |                                             |                                           |
| 6.    | (BGH5)            | 1.       | 17.914         | 174.602                | 0.0834                                  | 2.14                                    | 0.899                                       | 5.02                                      |
|       |                   | 2.       | 18.050         | 175.935                |                                         |                                         |                                             |                                           |
|       |                   | 3.       | 18.238         | 177.759                |                                         |                                         |                                             |                                           |
| 7.    | (BGH6)            | 1.       | 14.279         | 140.752                | 0.0813                                  | 1.760                                   | 0.627                                       | 1.58                                      |
|       |                   | 2.       | 14.373         | 141.682                |                                         |                                         |                                             |                                           |
|       |                   | 3.       | 14.459         | 142.530                |                                         |                                         |                                             |                                           |
| 8.    | (BGH7)            | 1.       | 18.938         | 186.235                | 0.0564                                  | 3.36                                    | 0.965                                       | 6.61                                      |
|       |                   | 2.       | 19.194         | 188.548                |                                         |                                         |                                             |                                           |
|       |                   | 3.       | 19.323         | 189.820                |                                         |                                         |                                             |                                           |
| 9.    | (BGH8)            | 1.       | 13.317         | 132.254                | 0.1120                                  | 1.2                                     | 1.298                                       | 6.08                                      |
|       |                   | 2.       | 13.590         | 134.961                |                                         |                                         |                                             |                                           |
|       |                   | 3.       | 13.645         | 135.510                |                                         |                                         |                                             |                                           |
| 10.   | (BGH9)            | 1.       | 14.901         | 149.688                | 0.1543                                  | 0.99                                    | 0.985                                       | 4.44                                      |
|       |                   | 2.       | 15.057         | 151.254                |                                         |                                         |                                             |                                           |
|       |                   | 3.       | 15.198         | 152.667                |                                         |                                         |                                             |                                           |
| 11.   | B_1               | 1.       | 21.452         | 208.784                | 0.0382                                  | 5.56                                    | 0.827                                       | 6.08                                      |
|       |                   | 2.       | 21.631         | 210.523                |                                         |                                         |                                             |                                           |
|       |                   | 3.       | 21.810         | 212.270                |                                         |                                         |                                             |                                           |
and the fracture of the fiber gradually, depending on the orientation of the fibers. According to this, basalt composite and its hybrids have higher strength and elasticity modulus than E-glass composite. The contribution of basalt fiber to the composite influences the entire constitutional interaction. Dissimilar basalt epoxy and E-glass epoxy shows the substantial non-linear manner of the tensile behavior arising from the presence of dislocation in the fibers. Even though proper stacking and varying the fiber orientation in dissimilar fibers the stress-strain curve appears as close to linear manner. The highest tensile strength value among the three tested specimens of plain E-glass epoxy laminates was 111.472 MPa applied load of 11.183 KN. Upon introducing 25% basalt fiber and 75% E-glass fiber content by volume in BGH1 and BGH2 these stacking sequences the strength is increased by 2.09%, 16.74% to 113.834 MPa, 131.837 MPa with peak applied force of 11.622 KN, 13.331 KN than pure E-glass composite. Figure 13 depicts the peak strength on the stress versus strain graph for this combination. The insertion of more E-glass fiber laminates at the outer side along with basalt fiber laminate at the inner side in BGH1 and insertion of E-glass fiber laminates at the inner and outer side along with basalt fiber laminate at the middle in BGH2 in hybrid stacking of (number of layers) fiber content causes the fracture

| S. No | Stacking Sequence | Tensile tested specimen |
|-------|-------------------|-------------------------|
| 1.    | G₅                | ![Image 1]               |
| 2.    | (BGH1)           | ![Image 2]               |
| 3.    | (BGH2)           | ![Image 3]               |
| 4.    | (BGH3)           | ![Image 4]               |
| 5.    | (BGH4)           | ![Image 5]               |

*Figure 11. Pictures of the all-tensile tested fiber composite specimens after failure.*
propagation in the tensile characteristics were the E-glass fiber is placed in stress analysis. The use of Basalt fiber in E-glass fiber combined with epoxy resin results in a small increase in strength and stiffness.

Subsequently by 50% basalt and 50% E-glass fiber content by volume in BGH3, BGH4, BGH5, BGH6 and BGH8 strength is increased by 21.76%, 20.72%, 45.83%, 24.45% and 52.02% to 138.693 MPa, 137.241 MPa, 177.759 MPa, 142.53 MPa and 189.82 MPa in peak load of (13.987 KN, 13.795 KN, 17.912 KN, 14.388 KN and 19.053 KN) respectively. The basalt fiber joins the glass fiber at the very first plie and ends with the E-glass plie in the BGH3 hybrid combination. On one side, the basalt fiber laminate will withstand the applied stress to some extent, while the glass fiber placed side will fracture initially, due to its behavior and fiber winding angles. Similarly, the hybrid sequence of the BGH4 and BGH5 in the inner or outer location leads to E-glass fiber breakage first, followed by basalt fiber fracture. In the hybrid composite of BGH6, the E-glass fiber is placed in both ends with basalt fiber are in between the hybrid. The imposed load will initially influence the E-glass fiber from both ends, followed by the basalt fiber. The failure of the E-glass fiber laminate takes quickly because of its low strength nature the fracture propagation hybrid will take place. The hybrid composite of 50% basalt fiber blend on the hybrid composite laminate stacked sequence of BGH7 gives more tensile properties.
than other stacked sequences. The outer side of the primary basalt plie hybrid fiber dispersion and the inner side of the E-glass fiber dispersion may have a greater influence than the other stacked sequence. Because of the unidirectional loading of this hybrid composite sequence, the basalt fiber on the outer side has a higher strength. Furthermore, the inner E-glass fiber seems to be accountable for the increase in displacement up to the specimen being broken. When compared to a 25 percent blend of basalt fiber in basalt/E-glass epoxy, a 50 percent basalt fiber ratio provides a little more improvement but a significant improvement over a simple E-glass epoxy composite. Figure 14 depicts the peak strength on the stress versus strain graph for this combination.

The blending of 75% basalt and 25% E-glass fiber content by volume in BGH8 and BGH9 strength is increased by 19.46%, 31.19% to 135.51 MPa, 152.667 MPa with a peak load of 13.614 KN and 15.675 KN respectively. The graph for stress versus strain for this combination along with peak strength representation has been shown in figure 15. As expressed in table 6 increasing the fiber content of basalt fiber on the total fiber volume fraction results in the same improvement in elastic modulus. This occurred because specimens with higher basalt fiber content had a higher stress concentration, which led to the reduction strain to failure and consequently a lower hybrid effect. Embedding low-modulus E-glass fibers with high-modulus basalt fibers lowers the stress concentration factor on basalt fibers, leading to a greater hybrid effect. However, increasing basalt fiber reduces the strength and strain rate by varying the fiber stacking and fiber content at a specific stage. Because our goal is to make these brittle composite materials more ductile by increasing their strength and stiffness. However, as compared to a 50 percent basalt fiber blend, it produces fewer results, and at a certain point, the failure mode occurs owing to brittle fracture.

As compared to a pure E-glass/epoxy composite, the tensile properties of the basalt/E-glass hybrid composite show an improvement. Fiore et al found that the tensile response of each of the basalt and E-glass fibers perfectly correlated with the tensile features of E-glass/basalt laminates. Fiore et al reported that basalt fiber hybridization laminated plates had such an excellent tensile fracture response over E-glass fiber laminated plates in a survey of E-glass/basalt laminated plates. For basalt/E-glass hybrid fiber tubes, a similar tensile characteristics response was detected. Basalt fibers have a high strain to failure ratio, which accounts for their
Figure 14. Tensile properties of 50:50% hybrid basalt/E-glass composite tubes.

Figure 15. Tensile properties of 75:25% hybrid basalt/E-glass composite tubes.
superior tensile response [50]. So, it is more suitable with the blending of 50:50% fiber ratio in total fiber volume fraction. This work is carried out by the applications status of harmful fluid transportation, taking into account the weight reduction ratio, enhancing the strength and stiffness. The ultimate non-linearity of the generated composites is reduced by hybridization with suitable fiber content sharing, variable winding angle, and diverse stacking sequence. When compared to the basic characteristics, the fiber stacking sequence is more important, even though basalt fiber volume fraction governs the overall tensile performance of the continuous filament basalt/E-glass laminated composite. As a result, basalt fiber laminate with an enhanced winding angle will take over the majority of applied load, and crack propagation will be restrained.

### 3.4. Quasi-static compression test

To evaluate the compressive properties of hybrid composite materials, the fiber composite laminate was subjected to experimental quasi-static axial compressive loading. The compression test was carried out according to ASTM standards with three specimens of identical dimensions for each combination. When all trials are combined, the coefficient of variation and standard deviation of each combination is significantly reduced, and the test results are more exactly reflected. Table 7 describes the experimental results of compressive properties for plain basalt composite, plain E-glass composite, and multi-layer hybrid fiber composites. The choice of reinforcement combination with different stacking sequences various fiber content combinations and diverse winding angles affects the failure modes of hybrid composites subjected to compressive forces. Some manufacturing issues, such as voids and fiber waviness, as well as specimen dimensions including boundaries and finishing, are considered as critical effects. According to Gimi et al the responsiveness of GRP pipes rises as the hybrid fiber content rates vary, and as a result, the energy absorbed increases and the damage brings down. The increased use of glass fiber in pipes pushed delamination damage to the foreground of damage growth, and this delamination damage was a major factor in failure damage in experiments. In many situations,
delamination damage lowered the durability and displacement characteristics of GRP pipes, but somehow it concentrated the resultant damage. The delamination region in the applied compressive load was extended by local buckled zones in the impact area, and the damage was subsequently exhibited as tearing damage in the direction of the fiber winding angle. Ozbek O et al studied the glass, carbon, and basalt fiber intraply hybrid and non-hybrid reinforced pipes on the axial compressive load which affects modifying winding angles with pure composites that may be high in strength but low in ductility, where researchers show improved axial compressive strength. However, when it comes to hybridization, they achieve a minor reduction in strength while boosting ductility. The base pure composite pipe compressive properties are used as a reference in their investigation, and the attained result is significant with my study.

Basalt composite and its hybrids have a higher compressive strength and elasticity modulus than E-glass composite. The load-displacement curve appears with appropriate stacking and modifying the fiber orientation with dissimilar fibers. Figure 16 shows the highest pure glass and basalt composite pipe axial compression strength obtained at 111.613 MPa, applied load of 59.49 KN with peak displacement of 21.65 mm and 175.328 MPa applied load of 93.45 KN with peak displacement of 9.057 mm. Along with introducing 25% basalt fiber content. Figure 17 shows the load-displacement curve by volume in BGH1 and BGH2 these stacking sequences has the highest compressive strength of 130.544 MPa and 135.767 MPa with a peak applied load of 69.580 KN and 72.360 KN of peak displacement 11.657 mm and 11.95 mm which is 15.63% and 19.52% more than the compressive strength of pure E-glass composite pipe. In hybrid stacking of (number of layers) fiber content, insertion of more E-glass fiber laminates on the outer side along with basalt fiber laminate on the inner side in BGH1 and insertion of E-glass fiber laminates on the inner and outer side along with basalt fiber laminate in the middle in BGH2 gives an improvement in compressive strength over the plain E-glass fiber composite. The usage of Basalt fiber in E-glass fiber mixed with epoxy resin increases the strength slightly.

Figure 16. Compressive load-displacement characteristic of plain basalt and E-glass composite tubes.

Figure 17. Compressive load-displacement characteristic of 25:75% hybrid basalt/E-glass composite tubes.
Consequently by 50% basalt fiber content by volume in BGH3, BGH4, BGH5, BGH6 and BGH8 axial compressive strength is increased by 23.288%, 28.224%, 31.222%, 29.956% and 32.353% to 141.032 MPa, 148.292 MPa, 152.908 MPa, 150.938 MPa and 154.692 MPa in peak load of (75.17 KN, 79.04 KN, 81.5 KN, 80.45 KN and 82.451 KN) along with peak displacement of (13.095 mm, 14.28 mm, 14.79 mm, 14.84 mm and 17.09 mm) respectively. When compared to a basalt/E-glass-e composite with a 25% basalt fiber blend, a 50 percent basalt fiber ratio gives a slight but considerable improved performance over a pure E-glass epoxy composite. Figure 18 shows the peak load on the load-displacement graph for this combination. In the BGH3 hybrid combination, the basalt fiber joins the glass fiber at the first plie and concludes with the E-glass plie. The basalt fiber laminate on one side will sustain the applied force to some extent, however, the E-glass fiber laminate on the other side will initially fracture due to its behavior and fiber winding angles. Similarly, at the inner or outer location, the hybrid sequence of the BGH4 and BGH5 causes E-glass fiber breakage first, followed by basalt fiber fracture. E-glass fibers are put in both ends of the BGH6 hybrid composite, with basalt fibers in the middle. The E-glass fiber will be the first to be affected by the given load from both ends, followed by the basalt fiber. Because of its low strength, the failure of the E-glass fiber laminate occurs quickly, resulting in fracture propagation on hybrid composite tubes. The hybrid composite laminate stacked sequence of BGH7 with a 50 percent basalt fiber

Figure 18. Compressive load-displacement characteristic of 50:50% hybrid basalt/E-glass composite tubes.
blend has better tensile qualities than other stacked sequences. The inner side of the E-glass fiber dispersion and the outer side of the primary basalt plie hybrid fiber dispersion may have a bigger influence than the other stacked sequence. The basalt fiber on the outer side has a higher strength due to the unidirectional axial compression loading of this hybrid composite tube sequence. Furthermore, until the specimen is broken, the inner E-glass fiber appears to be responsible for the increase in displacement.

The blending of 75% basalt and 25% E-glass fiber content by volume in BGH8 and BGH9 axial compressive strength is increased by 24.539%, 30.537% to 142.833 MPa, 151.838 MPa with a peak load of 76.13 KN and 80.93 KN along 13.031 mm and 15.85 mm respectively. The graph for load-displacement for this combination along with peak load representation has been shown in figure 19. When the percentage of basalt fiber in the total fiber volume fraction is increased, the elastic modulus improves as well. This happened because specimens with a higher basalt fiber content had a higher stress concentration, which resulted in a lower hybrid effect and reduced strain to failure. The stress concentration factor on basalt fibers is reduced when low-modulus E-glass fibers are embedded with high-modulus basalt fibers, resulting in a stronger hybrid effect. By altering the fiber stacking and fiber content at a certain stage, increasing basalt fiber reduces the strength and strain rate. Because we want to increase the strength and stiffness of these brittle composite materials to make them more ductile.

In this study, axial compressive testing can be used to examine the effect of various process parameters on the axial compressive mechanical properties of plain and multilayer hybrid fiber composite tubes. We have primarily concentrated on the comparison of plain and hybrid fiber-reinforced polymer composite materials as just a tube in this dissertation. This research focuses on the hybrid (Basalt and E-Glass) fiber reinforcing including an epoxy matrix. With the addition of basalt fiber, however, the compression behavior of E-glass fiber encased composite tubes improves in terms of tube strength and stiffness factor. Hybridization has the benefit of increasing compression strength. As a result, blending a 50:50 percent fiber ratio in the total fiber volume fraction is more appropriate and gives much improvement than the other combination. The fiber composite tube behaves with literally homogenous collapsing such as petal contraction, buckling of the fiber composite laminates, and brittle failure making a lot of noise owing to an instant collapse of the Composite structures, according to the various failure modes of the fiber composites.

3.5. Morphological analysis

The composites employed in this investigation were properly prepared to avoid poor fiber wetness, which results in lower stress propagation across the fiber-matrix interface and a way to maximize porosity. This is especially true for multi-layer hybrid fiber with porous laminates, which allow the resin to infiltrate and fill gaps. However, figure 20(a) shows, there are indications of fiber pull-out at the rough fracture surfaces, while the pull-out lengths are small, indicating a more or less uniform fracture. The Tensile tested region creates a stress concentration zone which might act as a crack initiator on subsequent layers and produces improper delamination crack propagation on fiber orientation meets the fiber matrix week interface make fiber breakage. Figures 20(b) and (d) SEM micrographs indicate that the E-glass and basalt fiber in the hybrid composites are properly mixed effectively. Fiber surfaces with residual epoxy wreckage indicate good fiber-epoxy adhesion and matrix agglomeration. Low-viscosity epoxy resin can infuse through the fiber wall gaps due to the matrix crack structure of E-glass fibers in multi-layer hybrid composites. Indeed, the hybrid fiber dislocation in between stacked hybrid composites creates a mechanical interlinking mechanism that boosts the fiber-matrix interfacial shear strength. In figure 20(c) when composites are cured quickly, they tend to have more voids in them. SEM
analysis of tensile fracture specimens done at random points across the cured tubes employed in this study revealed that the composites have high consistency and low void content. It shows clear visualization in the multi-layer hybrid composites glass and basalt fiber bundles pull out fracture regions, along with two different fiber orientations with high interlaminar binding of fiber and matrix. Micro-photographic examination of the surface damage of basalt and E-glass hybrid fibers reveals severe brittle fiber failures occur. Figure 20(e) shows a failure of matrix debonding and delamination due to the increase in brittleness of the epoxy resin makes fiber crack interface in damage area with indications of matrix ductility failure.

Figure 21 below shows macrostructure and microstructure photographs of samples after crushing analyses using two fiber materials, different fiber stacking sequences, winding orientations, and a constant parameter of fiber tow tension with mandrel rotation speed. The increase in fiber content with different stacking sequences resulted in inner and outer irregular dividing behavior patterns of the basalt and E-glass fibers delivering influence on the axial compressive analysis, which had a major effect on failure mechanisms on crushing. The microstructure SEM analysis is reviled at a specific location in all tested specimens. In crushed tubes displayed fiber-matrix fracture, the portion is featured as local micro buckling mode. This failure mode is interconnected to a crushing process that causes substantial matrix deformation and fragmentation along the fiber line, breaking the pipe into two massive squeezed sections. The fractured wall’s ultimate deformation pattern had
Table 1. Properties of the specimens tested.

| S.No. | Sequence | Tested specimens image | Fractured microstructure image (SEM) |
|-------|----------|-------------------------|--------------------------------------|
| 1.    | G8       | ![Image](image1.png)    | ![Image](image2.png)                |
| 2.    | (BGI1)   | ![Image](image3.png)    | ![Image](image4.png)                |
| 3.    | (BGI2)   | ![Image](image5.png)    | ![Image](image6.png)                |
| 4.    | (BGI3)   | ![Image](image7.png)    | ![Image](image8.png)                |
| 5.    | (BGI4)   | ![Image](image9.png)    | ![Image](image10.png)               |
| 6.    | (BGI5)   | ![Image](image11.png)   | ![Image](image12.png)               |

Figure 21. Pictures of the all-compression tested fiber composite specimens after failure.
expanded outwards. During the crushing operation, some of the fibers were twisted and severed from the outer wall layer. This shows that this type of failure mode absorbs a lot of energy. Weakened matrix materials or poor adhesion among both matrix and fiber are typically linked with fiber micro-crack failure. The aggressive type of failure and local buckling behavior is coupled, where buckling of transverse fibers caused matrix wrinkling and cracking, which led to growth. Fiber kinking is a zone across the specimens caused by a large twist of the fibers and severe shearing deformation of the matrix. Although fibers that are weaker in compression such as Basalt fiber don’t break, the fibers are often broken at each kink zone boundary. Kinking is typically considered to be just the final irreversible stage of micro buckling, where enormous bending loads in the micro buckle fiber have
resulted in fiber fracture but it is also seen to be a separate failure process [53]. Finally, failures were detected in most specimens with different modes of fiber de-bonding, matrix fragmentation, fiber pull out, fiber-matrix delamination, and fiber breaking.

4. Conclusion

In comparison to pure E-glass and pure basalt fiber reinforced composites with equivalent strength, the influencing aspects of sharing two dissimilar fiber content with four combinations, eleven various stacking sequences of composite tubes were fabricated using filament winding technique gives the hybridization has lower weight and cost. The static tensile, Quasi-static compression and Microhardness characteristics of basalt fiber-reinforced composites hybridized with glass fibers have been investigated in the present study. The fiber volume fraction in fiber-reinforced polymers plays an important role in characterizing the mechanical performance of the composite structure. The volume fraction has been investigated by the burn-off test method which results in the volume fraction of total fiber attaining approximately 40%−50% and the matrix attains approximately 50%−60% for all pure and multi-layered hybrid fiber composite tubes. The Microhardness result shows 75% basalt fiber content stacked hybrid composite tubes has the highest average hardness value than other fiber content combination, because of the larger impact on the hybrid stacking sequence and filament winding orientation in these hybrid combinations. Experimentally examined static tensile and compression test results of two dissimilar fibers using four combinations of E-glass basalt fiber stacked hybrid composite tubes. Even though the basalt fiber volume fraction influences the overall tensile and compressive performance of the continuous filament basalt/E-glass laminated composite, the fiber stacking sequence is more essential in the basic properties. Both tensile and compressive strength are improved when 50 percent of the fiber content is shared. The layer stacking sequences for pipe composition have a significant impact on the tensile and compressive loading behavior. Especially high-strength fibers (basalt fiber) on the outside, improve the mechanical characterization. The microstructure analysis of the tensile and compression tested specimens fracture failure is analysed.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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