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Mechanical Investigation of Basalt/S-Glass Fiber Reinforced Epoxy Hybrid Composites for High Temperature Application

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ABSTRACT

The work presents the mechanical investigation of composite materials that are meant to perform under different temperature condition with the application of tensile loading. The composite under study is developed using reinforcement materials made out of basalt and S-glass fiber reinforced with polymer matrix composite (epoxy resin) by hand layup technique with different compositions by changing the fiber layer sequence starting with pure form to hybrid once (fiber architecture). The test results reveals, that the tensile properties of the hybrid composites with fiber architecture of 2/2 basalt mixed S-glass fiber reinforced with epoxy composites are at its optimal level in both normal and elevated temperature conditions. Basalt fiber being good temperature resistant and S-glass fiber having high strength, with this hybrid combination, the material has out played under tensile force being applied when compared with other samples under test.

Keywords: Basalt; Epoxy; S-glass; Fiber architecture; Hybrid; Temperature; Polymer matrix; Reinforcement.

1. Introduction

Basalt fibers are a remarkable class of materials that have gained significant attention and recognition in recent years. Derived from basalt rock, these fibers exhibit exceptional mechanical, thermal, and chemical properties, making them highly desirable for various industrial applications. As an alternative to traditional materials like glass and carbon fibers, basalt fibers offer unique advantages that have sparked widespread interest among researchers, engineers, and manufacturers [1].

Basalt, a volcanic rock formed from the solidification of lava, serves as the raw material for producing basalt fibers. It is an abundant resource found in various regions around the world, making basalt fibers an environmentally friendly choice compared to fibers derived from non-renewable sources. The manufacturing process involves melting basalt rock at high temperatures, extruding it into fine filaments, and then assembling these filaments into yarns or roving's. The resulting fibers possess a distinct combination of properties that make them suitable for a wide range of applications [2].

One of the key advantages of basalt fibers is their exceptional strength-to-weight ratio. They exhibit high tensile strength, providing excellent load-bearing capabilities while remaining lightweight. This property makes basalt fibers ideal for applications where weight reduction is critical, such as aerospace and automotive industries. Additionally, basalt fibers offer excellent resistance to corrosion, chemicals, and ultraviolet (UV) radiation, ensuring long-term durability and performance in harsh environments [3].

Another noteworthy characteristic of basalt fibers is their remarkable thermal properties. They have a higher melting point compared to many other common fibers, enabling them to withstand elevated temperatures without significant degradation. This thermal stability makes basalt fibers suitable for applications involving high-temperature environments, like fire-resistant textiles, insulation materials, and composite structures for aerospace and industrial applications [4]. Furthermore, basalt fibers possess excellent insulating properties, both electrically and acoustically. They exhibit low electrical conductivity, making them useful in applications requiring electrical insulation. Basalt fiber-based composites also demonstrate sound-absorbing properties, making them valuable in noise reduction and acoustic insulation applications. The versatility of basalt fibers extends to their compatibility with various matrix materials, including polymers, metals, and ceramics. This compatibility allows for the production of basalt fiber-reinforced composites, which combine the unique properties of basalt fibers with the specific advantages of the chosen matrix material. Such composites find applications in industries such as construction, infrastructure, marine, and sports equipment, where enhanced strength, durability, and lightweight characteristics are desired [5]. The suitability of basalt fiber with different thermosetting resins opens up a wide range of possibilities for composite material applications. Basalt fibers exhibit excellent compatibility with various thermosetting resins, allowing for the development of composite materials with enhanced mechanical, thermal, and chemical properties. Here are some examples of the suitability of basalt fiber with different thermosetting resins. Epoxy resin is one of the most commonly used thermosetting resins in composite manufacturing. Basalt fibers have shown exceptional adhesion and compatibility with epoxy resin matrices. The combination of basalt fibers and epoxy resin results in composites with high strength, excellent impact resistance, and good fatigue properties. These composites find applications in aerospace, automotive, marine, and structural engineering industries [6].

The significance of basalt fiber reinforced with epoxy polymer composites lies in their ability to combine the exceptional properties of basalt fibers with the versatile characteristics of epoxy resin matrices. This combination results in composite materials that offer a wide range of benefits and find numerous applications across various industries. Basalt fibers possess excellent tensile strength and stiffness, and when embedded in an epoxy matrix, they reinforce the material, enhancing its overall mechanical properties. Basalt fiber reinforced epoxy composites exhibit improved strength-to-weight ratios, high tensile and flexural strength, and excellent impact resistance. These enhanced mechanical properties make them suitable for applications requiring lightweight and durable materials, such as aerospace components, automotive parts, sporting goods, and structural elements. Basalt fibers possess high resistance to elevated temperatures, and epoxy resins also exhibit good thermal stability. When used together, basalt fiber reinforced epoxy composites can withstand high temperatures without significant degradation, making them ideal for applications in the aerospace and automotive industries, where thermal stability is crucial [7].

The good chemistry of basalt fibers with other synthetic fibers in composite manufacturing opens up new possibilities for creating hybrid composites with enhanced properties. Basalt fibers exhibit compatibility and synergy with several synthetic fibers, allowing for the development of composite materials that combine the strengths of different fiber types. Basalt fibers and glass fibers share similar manufacturing processes and possess comparable properties, making them highly compatible. The combination of basalt and glass fibers in a composite offers a balance between the high strength and stiffness of glass fibers and the exceptional resistance to temperature and chemicals provided by basalt fibers. These hybrid composites find applications in automotive, construction, and infrastructure sectors, where a combination of strength, durability, and thermal stability is required [8].

The good interaction between basalt fibers and other synthetic fibers allows for the tailoring of composite materials to meet specific performance requirements. By blending different fiber types, engineers and manufacturers can

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optimize the properties of the final composite, such as strength, stiffness, impact resistance, heat resistance, and lightweight characteristics. Additionally, the combination of different fibers can also improve the resistance to delamination and provide a more robust material system. It is worth noting that the compatibility and performance of hybrid composites depend on several factors, including the fiber types, fiber orientations, fiber volume fractions, and the chosen matrix material. Thorough testing, optimization, and understanding of the interaction between the fibers are necessary to achieve the desired properties in the composite [9].

Conducting a literature review on basalt fiber reinforced polymer composites for high-temperature applications is crucial to address the growing need for materials capable of withstanding extreme thermal conditions. Such a review helps researchers and engineers gain insights into the current state of knowledge, optimize composite performance, guide material selection and design choices, compare with alternative materials, and foster innovation in this field. By consolidating existing knowledge and identifying areas for further research, a literature review plays a vital role in advancing the development and application of these composites in high-temperature environments. **Vikas Sharma et al.,** conducted the mechanical testing revealed that both glass and basalt fiber-reinforced epoxy composites exhibited enhanced mechanical properties compared to the pure epoxy matrix. The addition of fibers improved the tensile and flexural strength, stiffness, and impact resistance of the composites. The results indicated that increasing fiber content generally led to higher mechanical properties. However, a saturation point was observed, beyond which further fiber addition resulted in diminishing returns [10].

Raajesh Krishna et al., have highlighted that, the addition of both glass and basalt fibers significantly enhances the mechanical properties of epoxy composites compared to the pure epoxy matrix. The incorporation of fibers increases the tensile and flexural strength, stiffness, and impact resistance of the composites. The results indicate that increasing fiber content generally leads to improved mechanical properties, but there is a saturation point beyond which further fiber addition offers diminishing returns [11]. **Vikas Sharma et al.,** studied the influence of filler percentage on the physical and mechanical characteristics of basalt fiber reinforced epoxy composites. The addition of fillers in the composites alters their density and water absorption properties. Moreover, the mechanical properties, including tensile strength, flexural strength, and impact strength, are affected by the filler content. They also added that, these findings emphasize the importance of carefully selecting and optimizing the filler percentage in basalt fiber reinforced epoxy composites to achieve the desired physical and mechanical properties. Future research endeavors can focus on exploring different filler materials, investigating the effect of filler morphology and surface treatment, and studying the long-term durability and performance of these composites in real-world applications [12].

Anand et al., stated the influence of weave pattern on the mechanical properties of basalt fabric reinforced epoxy composites. Twill weave reinforced composites generally exhibited superior tensile and flexural properties compared to plain weave reinforced composites. The increased number of interlacing points in the twill weave pattern enhanced load distribution and load-bearing capacity within the composites. Both plain and twill weave reinforced composites demonstrated improved impact resistance compared to neat epoxy [13]. **Ramesh et al.,** have demonstrated in their work regarding the significant influence of the Kevlar/Basalt fiber combination on the mechanical properties of hybrid composites. The hybridization of Kevlar and Basalt fibers leads to improved tensile, flexural, and impact properties compared to composites reinforced with a single fiber type. The complementary characteristics of Kevlar and Basalt fibers, including high strength, stiffness, toughness, and impact resistance, result in a synergistic effect, enhancing the overall mechanical performance of the hybrid composites [14]. **Nitish Kumar et al.,** studied the effect of fiber orientation on the mechanical properties of bidirectional basalt fiber reinforced epoxy composites. Composites with fibers aligned parallel to the loading, bending, and impact directions generally exhibited higher tensile strength, flexural strength, and impact strength, respectively. The misalignment of fibers with the respective directions resulted in reduced mechanical properties [15]. **Hassan et al.,** showed that, the integration of flax, basalt, and glass fibers in the composite structure enhances load-bearing capacity, stiffness, and resistance to bending forces. The hybridization of these fibers allows for improved mechanical properties [16]. **Raajesh Krishna et al.,** have highlighted the significant influence of surface treatment and stacking sequence on the mechanical properties of basalt/glass epoxy composites. Surface treatment of the fibers improves the interfacial adhesion and enhances the mechanical performance of the composites. The choice of stacking sequence allows for tailored mechanical behavior by optimizing load transfer and stress distribution [17].

Sudhir et al., findings highlighted the significant influence of temperature on the mechanical properties of these composites, including reductions in strength and stiffness. The proposed structural classification system enables a better understanding of the composite's behavior at elevated temperatures, facilitating the design and analysis of structures using Basalt FRP composites [18]. **Jingjing et al.,** in their work stated the understanding of the behavior of Basalt fiber/epoxy resin composites under tensile loading, aiding in the design and development of high-performance composite materials for various applications. Further research can explore advanced fabrication techniques, investigate the effects of environmental conditions and long-term durability, and optimize the composite's performance through tailored fiber-matrix interactions [19]. **Amruth et al.,** have showed the results, which demonstrate that these laminates exhibit high tensile and flexural strengths, good interlaminar shear strength, and excellent impact resistance. The properties are attributed to the inherent mechanical properties of basalt fibers and the effective fiber-matrix interaction in the epoxy matrix [20].

Bozkurt et al., stated in their work, that the combination of aramid and basalt fibers offers improved tensile strength, modulus, bending strength, and stiffness compared to single-fiber composites. The hybridization enables tailored mechanical properties and failure modes, enhancing the versatility and performance of the composites [21]. **Omer et al.,** have revealed the impact test results of the basalt/aramid hybrid composite laminates and compare them with those of pure basalt and pure aramid laminates. They report that the hybrid laminates exhibited improved impact resistance compared to the individual fiber-reinforced laminates. The energy absorption capacity of the hybrid composites was found to be higher than that of the pure basalt laminates, indicating a positive hybridization effect. The authors attribute this enhancement to the distinct energy absorption mechanisms offered by basalt and aramid fibers [22]. **Ahmed et al.,** showed that, the Basalt composites has superior impact resistance and energy absorption capacity at high strain rates, outperforming glass textile composites [23].

Karvanis et al., investigated the mechanical properties of basalt fiber/epoxy composites, it highlights that the tensile and flexural strength of the composites increase with the incorporation of basalt fibers due to their high strength and stiffness. Furthermore, the basalt fibers can act as a reinforcement to resist crack propagation and enhance impact resistance [24]. **Qiang et al.,** have provided the valuable insights into the mechanical properties of basalt fiber composites for transportation applications, further research is needed to address several aspects. Exploring the effects of temperature variations, vibration, and aging on the mechanical performance and structural integrity of basalt fiber composites [25]. **Ramnath et al.,** present the tensile strength of basalt fiber composites, which reflects their ability to resist applied forces without undergoing deformation or failure. Basalt fiber composites exhibit high tensile strength due to the inherent strength of the basalt fibers and their excellent adhesion to the matrix material. The strength can be influenced by various factors, including fiber volume fraction, fiber orientation, and interfacial bonding between the fibers and matrix [26]. **Muhamad et al.,** showed that, the stacking sequence has a significant impact on the tensile and flexural properties of glass fiber epoxy composites hybridized with basalt, flax, or jute fibers. Optimizing the arrangement of these fibers allows for tailoring the mechanical properties of the composites to meet specific application requirements. The findings open avenues for further research and hold promise for the industrial implementation of these hybrid composites in various sectors, thereby contributing to advancements in lightweight, high-performance materials [27]. **Dalinkevich et al.,** have explored the use of basalt fibers as reinforcement in polymeric composites. Basalt fiber-based composites offer enhanced mechanical properties, such as increased strength, stiffness, and impact resistance. The paper investigates the effects of fiber content, orientation, and matrix material on the performance of the composites. The results demonstrate the potential of basalt fiber composites for lightweight and high-performance applications [28].

Sapuan et al., showed that by varying the volume fraction and orientation of the basalt and woven-glass fibers, the mechanical properties of the composites can be tailored. The paper provides insights into the optimal fiber hybridization parameters for maximizing specific properties, such as strength, stiffness, and ductility [29]. **Vemu Vara Prasad et al.,** have presented that, the mechanical properties of the reinforced basalt and carbon fiber composite laminate. Tensile testing reveals the composite laminate's strength, modulus, and elongation at break. Flexural testing evaluates its resistance to bending loads, while impact testing assesses its energy absorption capability. The results demonstrate the synergistic effects of the basalt and carbon fibers, leading to improved mechanical performance compared to single-fiber composites [30]. **Russell et al.,** the optimization of surface treatments for basalt fibers to maximize the mechanical properties of the composite. Factors such as treatment methods, duration, and concentration are critical parameters in achieving optimal results. The paper emphasizes the importance of balancing the surface modification effects with any potential drawbacks, such as fiber degradation or increased manufacturing [31].

Chelliah et al., showed that the Tensile and flexural testing results demonstrate the influence of fabric reinforcement on the strength, stiffness, and deformation behavior of the composites. The findings indicate that basalt fabric-reinforced composites exhibit higher tensile and flexural strength compared to glass fabric-reinforced composites. The mechanical properties are attributed to the inherent properties of the fabric reinforcements [32]. **Chandrasekaran et al.,** have exhibited that, the composite material exhibits enhanced strength, stiffness, and impact resistance, making it suitable for automotive structural applications when basalt and glass reinforced with epoxy polymer composite [33]. While the literature review highlights the remarkable properties and potential applications of basalt fiber reinforced polymer composites, there is a notable research gap in understanding the long-term durability and performance of these composites in real-world high-temperature environments. Although basalt fibers possess excellent thermal stability and are suitable for high-temperature applications, it is crucial to evaluate their long-term behavior and performance under sustained elevated temperatures.

Shaikh et al., insights into the behavior of basalt, E-glass, S2-fiberglass, and carbon fiber reinforced epoxy laminates, offering useful information for material selection in various engineering applications. The utilization of finite element analysis allows for a comprehensive comparative analysis, contributing to the understanding of the mechanical performance of composite laminates [34]. **Bonsu et al.,** study sheds light on the performance of these composites under corrosive conditions, offering insights for marine engineering applications. The research contributes to the understanding of the durability and long-term behavior of the composite materials in marine environments, which is crucial for ensuring the structural integrity of marine structures [35].

Joshua et al., have presented a thorough investigation into the quasi-static strength of composite laminates made from Kevlar fibers with either basalt-epoxy or glass-epoxy matrices. The study provides valuable insights into the mechanical behavior and performance of these intra-woven composites, aiding in material selection for structural applications. The research contributes to the understanding of the strength characteristics of Kevlar-based laminates and their potential for enhancing mechanical properties in specific engineering applications [36]. **Karolina et al.,** presents a comprehensive investigation into the combined effect of aramid and basalt fibers on the mechanical, thermal, and dynamic properties of polylactide hybrid composites. The study provides valuable insights into the synergistic enhancements achieved through the hybridization of these fibers, highlighting their potential for improving the overall performance of composite materials. The research contributes to the understanding of fiber-reinforced polymer composites, offering valuable knowledge for designing and optimizing hybrid composites for various applications [37]. **Shaise et al.,** research provides valuable insights into the mechanical properties and bond characteristics of these composite materials. The study contributes to the understanding of geo-polymer composites and offers important information for the development of sustainable construction materials with improved tensile strength and bonding performance [38]. **Kandasamy et al.,** presents a comprehensive study on the fabrication process and characterization of hybrid composites made from Basalt, ATH (aluminum trihydrate), and Epoxy. The paper provides valuable insights into the manufacturing techniques and mechanical properties of these hybrid composites, contributing to the understanding of their potential applications. The research findings are significant for industries seeking to explore the benefits of hybrid composite materials in terms of improved mechanical performance and enhanced fire resistance [39].

Existing studies primarily focus on mechanical properties, such as tensile strength, flexural strength, and impact resistance, while limited research has been conducted on the long-term effects of temperature exposure on these composites. High-temperature environments, such as those encountered in aerospace and automotive applications, can subject the composites to thermal cycling, oxidative degradation, and thermal expansion mismatches, potentially affecting their mechanical properties and overall performance over time. To bridge this research gap, further investigations are needed to assess the long-term durability, stability, and mechanical properties of basalt fiber reinforced polymer composites under sustained high-temperature conditions. This research can involve accelerated aging tests, thermal cycling experiments, and extended exposure to elevated temperatures to simulate

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real-world operating conditions. Additionally, the effects of temperature variations on the interfacial bonding between the fibers and matrix should be examined to understand potential degradation mechanisms and optimize the composite's performance in high-temperature environments. Addressing this research gap would provide valuable insights into the behavior of basalt fiber reinforced polymer composites over an extended period, enabling engineers and manufacturers to design and develop materials that can withstand extreme thermal conditions.

Understanding the long-term performance of these composites would contribute to their successful implementation in high-temperature applications, ensuring reliability, safety, and durability in industries such as aerospace, automotive, and other fields where thermal stability is crucial.

2. Materials and Methods

2.1. Materials for Developing Composites

S-glass fiber of 190 gsm and basalt fiber of 380 gsm were used as reinforcements to fabricate composites. Polymer matrix used was epoxy – a thermoset of grade L-12 in combination with hardener K-6 in a ratio of 100:10 grams as per manufacturer’s instruction. All the materials used in manufacturing the composites are all shown in the figure 1.

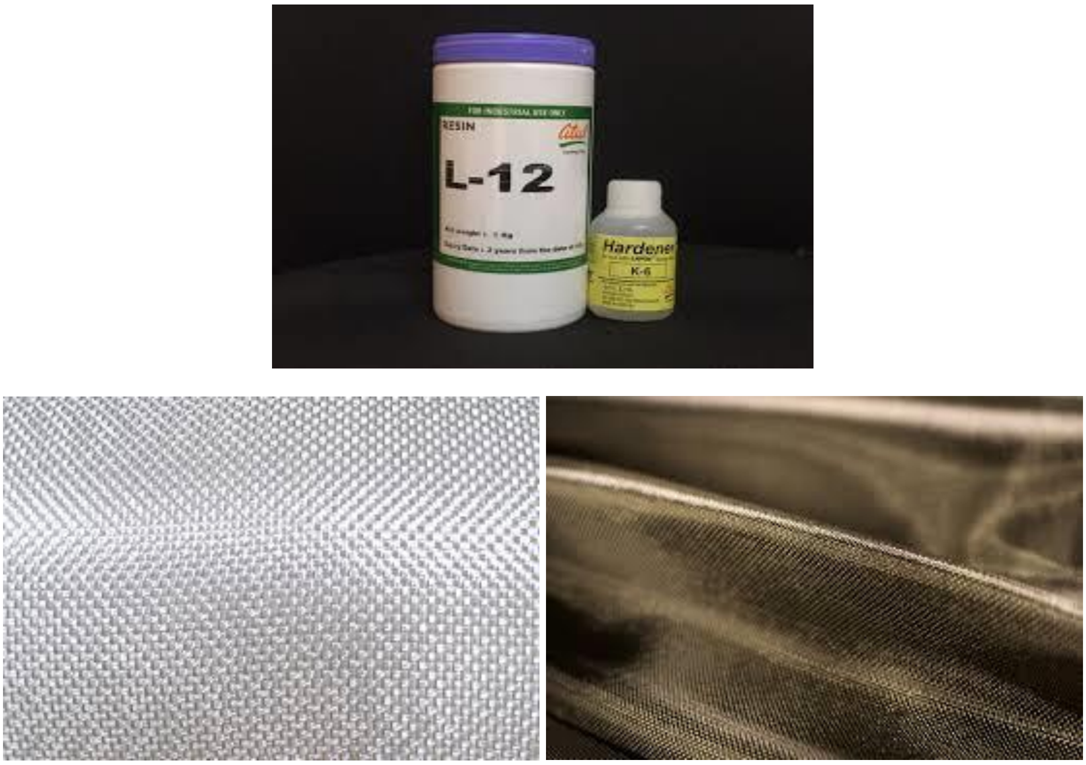

Figure 1. Materials used in manufacturing the composites

2.2. Method of Manufacturing Composites

Hand layup technique is followed to produce composites of required combination as shown in the figure 2. The hand layup technique is a manual process used to fabricate composite materials by arranging reinforcing fibers and applying resin layers by hand. It involves the careful placement of fibers onto a mold or substrate, followed by the application of resin to impregnate and bond the fibers together. The process includes steps such as fiber arrangement, resin application, consolidation, curing, and finishing. Hand layup allows for flexibility in fiber

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orientation and can be used to create composites with specific properties. Although it requires attention to detail and craftsmanship, it is a versatile technique that can produce strong and durable composite materials for various applications. The required laminate thickness is obtained from predetermined fiber matrix calculation at the proportion of 55:45. The samples are cut from the prepared laminate ready for the test as per ASTM standard using AJM technique and later dried in the oven to ensure moisture content are eliminated from the samples [40].

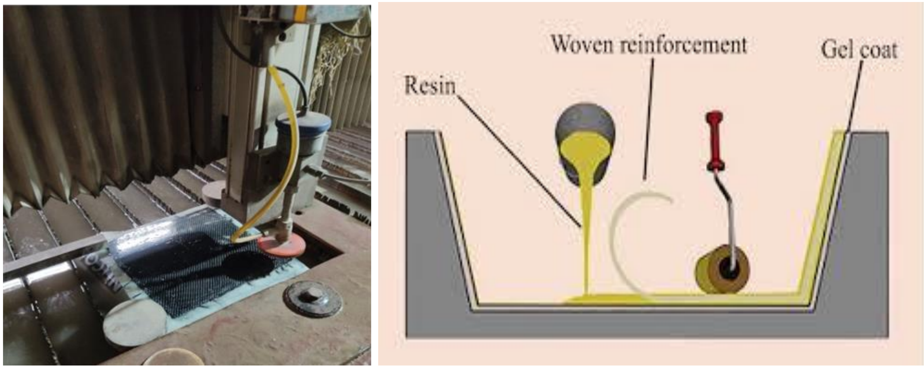

Figure 2. AJM & Hand Layup Technique

The laminates were prepared in different combinations are shown in the table 1.

Table 1. Composite Material Configurations

Synthetic Fibers		Polymer matrix	Fiber Orientation	Sample code
S-Glass (w.t%)	Basalt (w.t%)	Epoxy (w.t%)		
55	0	45%	PURE	S1
0	55	45%	PURE	S2
27.5	27.5	45%	1/1	S3
27.5	27.5	45%	2/2	S4

3. Mechanical Testing

3.1. Tensile Test

Tensile test of the samples prepared was conducted according to ASTM D638 [34] at room and high temperature. ASTM D 638, also known as the "Trailblazing Tensile Test," is a standard test method that pushes materials to their limits, unveiling their inner strength and resilience. It is like a daring expedition through uncharted territory, where specimens face the challenge of stretching to their breaking point, revealing their true character. In this extraordinary journey, specimens are carefully prepared and subjected to tension, as if engaged in a tug-of-war with destiny itself. A mighty machine, known as the universal testing machine, exerts a force upon the specimens, measuring their ability to withstand this external pressure. It's a battle between the specimen's structural integrity and the relentless force being applied, where the outcome determines their mechanical properties. During this remarkable test, data is collected and analyzed to assess important characteristics such as yield strength, ultimate tensile strength, and elongation. These measurements provide valuable insights into the material's ability to withstand stretching forces and its capacity to stretch without breaking, revealing the hidden potential within. Just as explorers chart new territories, ASTM D 638 charts the material's performance under tension, uncovering its strengths and weaknesses. It serves as a guidepost for engineers and scientists, illuminating the path towards designing safer and more durable products, all while unraveling the captivating story of a material's tensile prowess [34]. The tensile test was carried out using computerized universal testing machine with the span length of 57 mm at a cross speed load of 5 mm/min. The set of samples were tested in two different environments: at 29 °C and 100 °C.

4. Results and Discussions

4.1. Tensile Properties – Composite Materials

Tensile testing plays a crucial role in quality control during the manufacturing process of composites. By subjecting samples to tensile forces, manufacturers can ensure that the produced materials meet the required specifications and exhibit consistent mechanical properties. Table 2 & 3 shows the tensile properties of composites. Tensile testing allows for the determination of a composite material's ultimate tensile strength, yield strength, and modulus of elasticity. These parameters provide critical information about the material's ability to resist external forces and its overall structural integrity.

Table 2. Tensile Properties of Composites at Room Temperature

Temperature Condition: 29°C					
Sample code	**Material Configuration**	**UTS (MPa)**	**E (GPa)**	**Peak Load (N)**	**Maxi. Displacement (mm)**
S1	S-E-C	294.8	11.36	8604.40	5.2
S2	B-E-C	284.6	17.27	6284.60	3.5
S3	1/1 B-S-E-C	298.7	11.29	10006.1	4.7
S4	2/2 B-S-E-C	330.5	10.03	10262.3	4.9

Table 3. Tensile Properties of Composites at Elevated Temperature

Temperature Condition: 100°C					
Sample code	**Material Configuration**	**UTS (MPa)**	**E (GPa)**	**Peak Load (N)**	**Maxi. Displacement (mm)**
S1	S-E-C	181.5	4.79	6055.2	5.0
S2	B-E-C	178.3	4.63	6206.1	5.2
S3	1/1 B-S-E-C	218.7	6.50	5684.1	4.8
S4	2/2 B-S-E-C	244.6	6.52	6194.2	4.8

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The specimens were placed in the oven and subjected to the necessary high temperature as per the requirements. Subsequently, they underwent tensile testing following the ASTM D638 [34] standard, with a cross speed load of 5 mm/min and a span length of 57 mm. The test outcomes indicate that the sample with a 2/2 B-S-E-C/S4 material configuration demonstrated the highest tensile strength and Young's modulus at both room temperature (29°C) and high temperature (100°C), with values of 330.50 MPa and 244.6 MPa, and 10.03 GPa and 6.52 GPa, respectively. When comparing the tensile properties of the composites at normal and high temperature conditions, it is evident that the tensile strength decreased by approximately 26%. This decrease can be attributed to the significant impact of temperature on the mechanical properties of fiber-reinforced polymer (FRP) materials. High temperatures can cause a degradation of the bond between the fibers and the matrix, leading to reduced matrix resistance during deformation. Figure 3, illustrates the effects of temperature on the tensile strength of various composite laminates. In FRP composites, the tensile strength decreases as the temperature rises due to the degradation of the matrix materials at elevated temperatures.

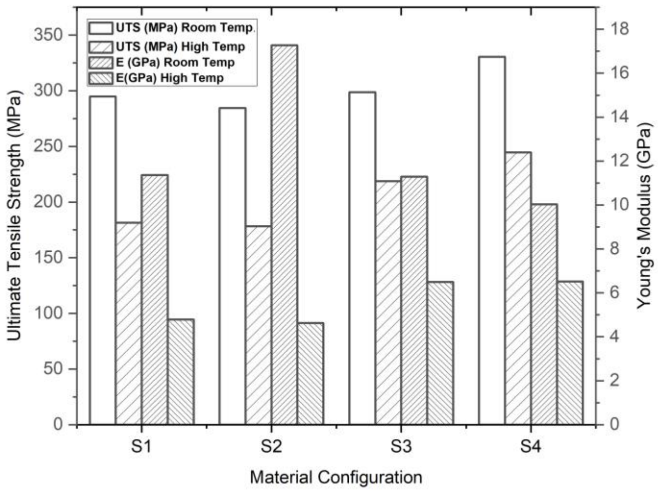

Figure 3. Comparison of Tensile Properties at Different Temperature Conditions

Figure 4. Specimen Failures

Figure 4 shows the tensile failure of the hybrid composite samples at both the temperature conditions. The samples of 2/2 Basalt/S-glass fiber reinforced with epoxy hybrid composites when subjected to tensile force under room and elevated temperature conditions exhibit the delamination, fiber pull outs and longitudinal breakage of the fibers, special the basalt fiber being the majority, this is due to the mechanical understanding of basalt fiber in terms of strength being low when compared to S-glass fiber in the hybrid combination. Looking into the composition of the basalt fibers, the material would have been quite hard to bear the tensile load in both the temperature conditions.

5. Conclusions

In conclusion, the conducted tensile testing on the specimens subjected to high temperature revealed valuable insights. The sample with a 2/2 B-S-E-C/S4 material configuration exhibited superior tensile strength and Young's modulus at both room and high temperatures. However, when comparing the tensile properties between normal and high temperature conditions, a decrease of approximately 26% in tensile strength was observed. This reduction can be attributed to the adverse influence of temperature on the mechanical properties of FRP materials. The high temperature environment caused a degradation of the fiber-matrix bond, leading to reduced matrix resistance during deformation. The findings highlight the importance of considering temperature effects when assessing the tensile strength of composite laminates, as the matrix materials' degradation becomes evident at elevated temperatures.

6. Future Recommendations

Future scope of work for the given content could include the following:

Conduct further tensile testing on the specimens at a wider range of high temperatures to gain a more comprehensive understanding of the material's behavior. This would involve subjecting the samples to temperatures beyond the currently tested range to investigate the threshold at which significant degradation occurs. Perform tests to assess the time-dependent behavior of the material at high temperatures. This would involve conducting creep tests or stress relaxation tests to understand how the material's mechanical properties evolve over time under sustained loads. Explore the possibility of modifying the FRP material composition to enhance its resistance to high temperatures. This could involve incorporating different types of fibers or matrix materials with improved thermal stability, or adding additives that can mitigate the degradation effects caused by elevated temperatures. Conduct a detailed investigation into the failure mechanisms observed in the specimens subjected to high temperatures. This would involve examining the fracture surfaces using microscopy techniques to identify any specific modes of failure and understand the underlying causes.

Declarations

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The study has not received any funds from any organization.

Competing Interests Statement

The authors have declared no competing interests.

Consent for Publication

The authors declare that they consented to the publication of this study.

Authors’ Contributions

All the authors took part in literature review, research and manuscript writing equally.

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