SSRG International Journal of Mechanical Engineering
ISSN: 2348-8360/ https://doi.org/10.14445/23488360/IJME-V12I1P112

Volume 12 Issue 1, 99-112, January 2025

Original Article

Optimization of Layered Hybrid Laminates Using ANSYS for Enhanced Tensile Properties and Performance Analysis

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Received: 17 November 2024 Revised: 25 December 2024 Accepted: 13 January 2025 Published: 25 January 2025

Abstract *- This study examines the tensile properties of hybrid laminates through modelling analysis, focusing on Carbon Epoxy, Glass Epoxy, and Kevlar Epoxy composites. The laminates, each tested with a thickness of 2.5 mm for Carbon and Glass Epoxy and 2.5 mm for Kevlar Epoxy, were evaluated under a load of 100,000 Newtons using ANSYS 2024 R1 simulation software. The results obtained suggest that the Kevlar Epoxy possesses the highest degree of stiffness compared to the others. Then, a global comparative analysis of total strain, equivalent stress, normal stress, shear stress, equivalent elastic strain, normal elastic strain, and shear elastic strain is performed for Kevlar-reinforced carbon, glass, and aluminum composites. The result showed that aluminum-glass had the lowest deformations overall, and its value was* $3.6849\times10^{-4}m$*, which was the greatest stiffness and minimum deformation under load. For equivalent stress, the Aluminum-Kevlar composite has the maximum stress or 1.62E+09 Pa, showing high durability. The maximum normal stress (9.22E+08Pa) together with maximum shear stress (2.27E+08Pa) capacity was found in the aluminium-glass composite which further proved resistance to both normal and tangential forces. The aluminum-carbon composite presents the maximum amount of elastic strain, meaning it has the largest deformation due to stress. Such significant work contributes greatly to understanding hybrid laminate mechanical performance: such knowledge about the material is important for selecting an appropriate material in engineering applications.*

Keywords *- Hybrid laminates, Tensile properties, Total deformation, Equivalent stress, Elastic strain, Normal stress, Carbon epoxy, Kevlar-epoxy.*

1. Introduction

A multiphase composite comprising reinforcement and matrix phases that provide exceptional mechanical properties makes up a sizable portion of the materials science repertoire [1]. Therefore, the reinforcing phase, which consists of fibers, particles, or flakes, can be used to give the composite the necessary strength and stiffness. The matrix phase facilitates the easier transfer of loads throughout the material by connecting these reinforcements. Composites can be broadly categorized based on the matrix material employed, including PMC (Polymer Matrix Composites), MMC (Metal Matrix Composites), and Ceramic Matrix Composites [2]. Due to operational requirements and environmental conditions, each variety will have its own benefits and uses. The fact that polymer matrix composites are widely used in high-performance sectors, including the automotive, marine, and aerospace industries, is an important consideration. The high strength-to-weight ratio, superior wear and corrosion resistance, and the possibility of creating intricately designed molded products are the primary factors behind PMCs' broad appeal [3]. In the marine environment, for instance, where corrosion resistance against seawater is crucial, PMCs are widely employed for applications. They are also utilized for airplane components, where weight reduction is crucial. Their affordability and adaptability provide more proof that PMCs may be used to create big parts; in fact, boat hulls can be produced in a single piece without joints. MMCs are utilized in components that are subjected to high temperatures and severe thermal stresses, including those seen in the automotive and aerospace industries. Similar to this, CMCs are employed in applications such as heat shields and turbine blades where the matrix materials must withstand extremely high temperatures and sour chemical conditions [4].

The evolution of composite materials is very rapid, given a number of factors, including large-scale manufacture of the fibers and developed advanced fabrication procedures [5]. Due to these developments, the cost of composite materials has dramatically fallen and become competitive alternatives to traditional metals in applications, including steel and aluminum, in industrial ventures. Because composites are incredibly light and bring much cost savings during production and shipment, switching to composites is considered performance but also economic efficiency. Hybrid laminates—a specialized group of composite material—use several types of fiber or matrix to optimize the performance qualities for specific applications. These laminates achieve a balanced performance profile by taking the best attributes of several materials[6]. Understanding the tensile characteristics of hybrid laminates is essential for comprehending how they behave mechanically under various loading scenarios, which has a direct bearing on their applicability for a range of applications.

A fundamental experimental method for evaluating mechanical properties such as strength, stiffness, and ductility of composite materials is the tensile test, in which a specimen is subjected to a uniaxial tensile load, and the elongation and stress response are measured. The findings offer important information on how the material behaves under tensile pressures, which is crucial for creating and refining parts that can tolerate particular loading scenarios. Tensile testing can show how the mix of various fibers and matrices impacts the material's overall performance in the context of hybrid laminates[7].

For instance, hybrid laminates are likely to have better tensile strength and toughness than single-material composites because of the synergistic effects of the combined components. Through experiments conducted to explore the tensile properties of hybrid laminates, researchers can better determine which material and configuration combinations will enhance performance for a particular application.

Hybrid laminates have a considerable variation in tensile characteristics, and the design of test specimens, conducting testing techniques, and materials selection were key factors in experimental investigation. Choosing the right reinforcing fibers, matrix materials, and stacking order for hybrid laminates can have a significant impact on their tensile properties. In addition, to obtain accurate and reproducible values, test specimen preparation and conditioning should be followed closely[8].

1.1. Importance of Studying Tensile Properties in Hybrid Laminates

Hybrid laminates exhibit a behavior under different loads. Hence, tensile properties should be investigated in detail[9]. Tensile tests are still the primary means of determining composite material's mechanical reactivity. Being an important step in material qualification, tensile tests provide data on the critical mechanical properties, such as strain-to-failure, ultimate tensile strength and Young's modulus, which are indispensable to predicting the behavior of materials under operating pressure. Yet, it still has some problems, particularly at low temperatures, when specimen sliding and sensitivity to temperature cause abnormal strength ratings in the composites of the polymer matrix. At lower temperatures, the hybrid laminates' polymer matrix becomes more brittle and might possess early failure during testing[10]. It might also become difficult to accurately quantify the tensile quality of such a material due to this brittleness since failure may occur before it attains its full strength. On the other hand, the slippage could impair further results obtained from experimental work because the fixtures used in tensile testing may not be rigid enough to keep the specimens firm. All these difficulties require great consideration of the test settings and setup, along with some modifications in testing tools and processes.

Tensile characteristics aid engineers in predicting the behavior of these materials when put to actual use, and hence, it provides crucial information about the material's performance[11]. This knowledge is essential for the design of components that must withstand certain stress conditions without failing. Therefore, in aircraft applications, tensile stresses are quite extreme, so reliability and good performance of the material are very important. Using proper tensile property data, engineers would be capable of designing safer and more efficient structures by selecting the optimal hybrid laminate configuration that may satisfy the desired performance criteria. A number of parameters have been attributed as being capable of influencing tensile properties, and some examples mentioned in a multitude of previous studies include but not be limited to: the matrix material, the stacking sequence of the laminate, and the types of fibers used[12]. For example, glass fibers can withstand superior flexibility and toughness against impact, but carbon fibers are very known for their tensile strength and stiffness. A material that combines the best characteristics of each type of fiber can be generated by using several types of fibers to form a hybrid laminate. While carbon fibers can provide the laminate with sufficient tensile strength and stiffness, glass fibers can enhance the overall toughness and impact resistance of the laminate.

1.2. Challenges and Innovations in Testing and Analysis

Hybrid laminates are very challenging to be tested in terms of tensile testing, especially when accurate and consistent results are desired at low temperatures where the behavior of polymer matrices changes[13]. Some of the difficulties associated with the hybrid laminate material combination are slippage of the test specimen from the testing fixtures and brittleness of the polymers at reduced temperatures, which affects measurements for tensile strength and modulus. Such challenges need innovative test methodologies and modification of equipment to improve the accuracy and reliability of results obtained. Consequently, researchers are coming up with new testing methods and changing setups of equipment in a bid to overcome the existing problems. Modifications may range from minimal specimen slippages while grips are being improved or even by exchanging advanced clamping mechanisms. More importantly, new technologies, such as cryogenic testing chambers, are employed to control the temperature environment more subtly. So, in order to test accurately even at low temperatures at which polymers tend to become brittle, researchers continue to improve testing protocols and equipment to minimize the problems associated with the tensile testing of hybrid laminates [14].

In addition, innovation can also be found on the analytical side through the integration of finite element analysis with experimental test protocols. FEA is also a powerful tool that validates experimental results and predicts the behavior of hybrid laminates under several loading conditions and, indeed, provides a complete understanding of the stress distribution and failure points within the structure of the laminate due to the simulation of complex interactions between different materials and structural elements[15]. This computational approach not only supports experimental testing but offers insights to laminate behavior perhaps not attainable through experiment alone.

Iterative comparison between FEA predictions and experimental data helps refine models with an increase in the accuracy of predictions and achieves optimized laminate design for specific applications. Fractographic analysis also constitutes an important technique in studying hybrid laminate failure mechanisms. The researchers attain insight into interfacial properties and failure modes through investigating failure in the fracture surfaces of failed specimens. From this, weak points in the laminate structure can be identified[16]. This knowledge is used to enhance material design itself to improve the overall performances and reliabilities of hybrid laminates ultimately. In summary, the problems associated with testing and analyzing hybrid laminates should be solved using more than one methodology, which includes new testing methodologies, computational analysis techniques such as FEA, and detailed fractographic analyses. Through combining experimental insight with computational simulation and failure analysis, the tensile properties of hybrid laminates can be optimized and must be suitable for various real-world applications[17].

2. Related Work

M. Damghani and associates (2024) Low Velocity Impact (LVI) effects the mechanical properties of the Carbon Fibre Reinforced Polymer (CFRP) components at different stages of manufacturing or in service, especially in repaired areas. The study contrasts impact-damaged repaired CFRP (5 J energy), virgin CFRP and repaired CFRP (stepped scarf). The findings indicate that small and medium repairs have substantial delamination but only little surface damage. Retention of strength: small (71%), medium (83%), and big (almost full). The stiffness increased with repair size; LVI had no effect on the load-bearing capacity of bug fixes. Maximum stresses for minor, medium, and major repairs are 67%, 77%, and 85% pristine, respectively[18]. Singh Kishan Pal et al. (2021) This study delves into the effects of impact damage and post-effect tension strength on hybrid woven carbon and glass composite laminates. It focuses on the performance and sequencing of laminate stacking in three different configurations. Low temperatures present difficulties for tensile testing, which is frequently used to describe mechanical reactivity. This results in inconsistent strength ratings and testing problems[19]. Mahdi Damghani and associates' (2023) Effects of hybrid carbon and glass fiber reinforced polymers on composite performance under low energy impacts (≤10J) are investigated in this work. It analyzes four laminate types, including pure carbon and hybrid carbon-glass layups, to assess impact damage and residual tensile strength. The results demonstrate how damage and tensile strength are influenced by the distribution of glass plies[20]. Dias Thaís da Costa et al. (2022) Because of their renewability and other advantages, natural fibers are partially replacing synthetic fibers in composites. This study examines the effects of hybridization and stacking on the mechanical and physical characteristics of glass/jute laminates. Density, volume fraction, and mechanical strength tests were performed on glass, pure jute, and hybrids. When compared to pure materials, hybrids displayed intermediate qualities[21]. Al Khaddour, Samer, et al. (2021) In this work, carbon, glass, and Kevlar textiles were combined with epoxy resin to generate composite materials. For tensile qualities, the ideal epoxy ratios were 30%wt for carbon fiber, 3%wt for glass, and 45%wt for Kevlar. To identify the ideal preparation conditions, the impacts of stacking sequences and fabric content on tensile qualities were examined.

Guangyong Sun et al. (2018) Basalt fiber is being investigated as a reinforcing material because of its great heat resistance, ductility, and affordability when compared to carbon fiber. This work uses computational, analytical, and experimental techniques to investigate epoxy composites reinforced with carbon/basalt fiber. Tensile and bending loads were applied to seven laminates with various hybrid ratios and sequences. The results show that whereas tensile modulus is less affected by stacking sequences, strength and flexural modulus are. Analytical models are in good agreement with tensile characteristics. ABAQUS/Explicit Finite Element Analysis (FEA) demonstrated a strong connection with experimental results. Flexural strength is reliably predicted by modified analytical models. Basalt fibers improve fracture resistance and change failure modes, according to SEM data [22]. Satish, K. G. et al. (2022) Hybrid composite specimens under in-plane compressive and tensile stress were investigated experimentally. In accordance with ASTM guidelines, laminated specimens were constructed using 40% polyester reinforcements made of steel and nylon mesh. The findings demonstrated that specimens with a larger steel content were able to handle heavier loads and that superior strength was provided by 0° and 90° orientations [23]. Song Jun Hee et al. (2015) Using varied lamination structures, paired hybrid materials were combined to make a variety of lightweight, high-performance polymeric composites. Six carbon/glass and carbon/aramid hybrid composites were created[24]. Lamination pairing affected mechanical qualities, with tensile strength being impacted by carbon fiber supremacy. For the best tensile and bending qualities, lamination positions have to be effective. Aabdul Khalil, H.P.S. et al. (2008) The study looked at vinyl ester composites reinforced with glass fibers (CSM) and the Empty Fruit Bunch (EFB) of oil palm fibers in different layer configurations. The composites were cured at 50°C with a 50/50 EFB/CSM ratio. When compared to control fibers, hybrid composites demonstrated better density, water absorption, and mechanical qualities. The best tensile and flexural qualities were found in composites having glass fibers on the outer layer[25]. Murugan, R. et al. (2014) Because of their mechanical qualities, glass woven fabric composites are utilized in civil constructions and airplanes. Interlaid layers of high-modulus carbon cloth increase strength without adding weight. The mechanical characteristics of four-layered glass/carbon hybrids and speciality laminates were examined. The findings revealed different bonding qualities and static and dynamic strengths[26].

3. Material and Method

3.1. Selection of Materials

The materials chosen for composite fabrication significantly impact the final product's properties and performance. Fibers, like long fibers for strength and short fibers for impact resistance, and resin matrices, which bind the materials and enhance strength, are crucial elements. Polymer matrices, categorized into thermoplastics and thermosetting plastics, play a vital role in inter-laminar adhesion and mechanical properties. While plastic materials offer various advantages, their disposal presents environmental challenges, necessitating recycling and hybridization for sustainability. Researchers explore methods like Nano clay and fiber reinforcement to enhance composite properties, leading to improved mechanical, thermal, and flame-retardant characteristics.

Table. 1 Composite laminate dimension

Fibre orientation	Width (mm)	Overall length (mm)	Thickness (mm)	Tab Thickness (mm)	Tab length (mm)
0°	25	250	2.5	1.5	25
90°	25	250	2.5	1.5	25

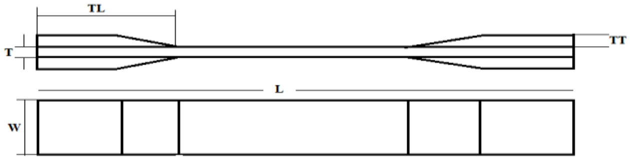

Fig. 1 Tensile test specimen

3.1.1. Aluminum Laminate Material

Aluminum, the 13th element in the periodic table, is prized for its versatility and widespread use across industries. Aluminum extracted from bauxite ore has remarkable strength even though it is very light. It is naturally resistant to corrosion, and aluminum is a good conductor of electricity. Both these aspects make it suitable for applications involving high-performance material requirements at relatively lower costs. Since it can be molded into any desired shape, aluminum finds wide use in products that constitute laminates formed with other materials. Its primary properties - malleability and high thermal conductivity-make its application exclusive to heat dissipation purposes.

Table 2. General properties of aluminium

Serial Number	Characteristics of Aluminium	Corresponding Value
1	Atomic Number	13
2	Atomic Weight	26.98 g/mol
3	Valance of Electron	3
4	Melting Point Temperature	660°C
5	Boiling Point Temperature	2480°C
6	Crystal Structure	FCC
7	Thermal Conductivity	0.6 Cal/Cms °C
8	Electrical Resistivity	2.69(Ωm) at 20°C
9	Density	2.7 g/m3
10	Elastic modulus	69 GPa
11	Poisson’s ratio	0.34

Since one can form an alloy and composite, the possible applications of aluminum are expanded and bring in innovation, including its use in the construction, automotive, aviation, energy, and food processing industries. With different grades of aluminum, a number of high-strength, corrosion-resistant, and ductility requirements can be approached. For example, Grade 1100-H14 is highly ductile but ideal for very lightweight equipment, while Grade 6061-T6 maintains structural strength, making it suitable for aerospace applications.

3.1.2. Glass Fibre Reinforced Laminate Material

The study focuses on evaluating the tensile properties of hybrid laminates, specifically incorporating Glass Fibre Reinforced Laminate (GFRL) materials. GFRL materials exhibit distinctive properties crucial for assessing their performance in various applications. The density of the glass fibre is 2.55 g/cm³, which contributes to its overall weight and structural characteristics. With a filament strength of 3500 MPa, the glass fibre demonstrates significant resistance to breaking under tensile stress. The tensile modulus, recorded at 80 GPa, indicates the material's rigidity and ability to maintain its shape under applied forces. Additionally, the strain-to-failure percentage of 1.6% highlights the extent to which the material can elongate before failure, providing insight into its ductility and resilience.

Fig. 2 Glass fibre reinforced laminate material

3.1.3. Carbon Fiber Laminate Material

The carbon fiber laminate material has varying mechanical properties necessary for its evaluation in hybrid laminates. The density of the material has been measured to be 1.8 g/cm³, whereby as a carbon fiber, it would inherently possess relatively lower mass compared to similar materials used in traditional laminates, thus giving the laminate generally lower mass.

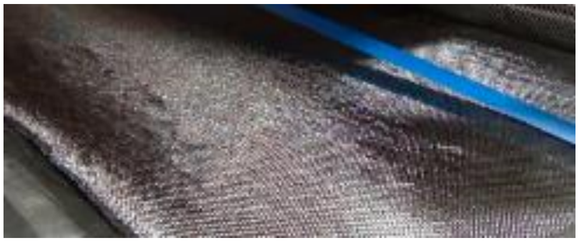

Fig. 3 Carbon fiber laminate material

The filament strength of the carbon is seen to be very high at 4000 MPa, thereby giving it great strength to stand loads and considerable robustness. 240 GPa in tensile modulus states the stiffness and resistance of deformation by material under tensile stress, while at 5% carbon fiber laminate had a strain-to-failure, which would, therefore, imply that it can take in much deformation before failure; hence, good durability and structural integrity in most applications.

3.1.4. Kevlar Fiber Laminate Material

Kevlar is one of the high-performance fibers that have been extensively utilised in composite laminates as a result of an attractive strength-to-weight ratio. The laminate of Kevlar fiber is quite lighter since its density is 1.4 g/cm³. Another significant advantage of the fiber is that its filament strength is as high as 3200 MPa, which contributes to solidity and durability. The tensile modulus for Kevlar is reported at 125 GPa, and this serves as another reason for its stiffness along with resistance to deformation under tension. Furthermore, Kevlar has a strain-to-failure of 2.6%, implying that it can undergo substantial elongation prior to breaking. On account of these properties, Kevlar is an appropriate material for hybrid laminates where strength and flexibility are utilized in an application.

Fig. 4 Kevlar fiber laminate material

Table 3. Properties of Fibre

Sl. No	Property	Glass	Carbon	Kevlar
1	Density (g/cm³)	2.55	1.8	1.4
2	Filament Strength (MPa)	3500	4000	3200
3	Tensile Modulus (GPa)	80	240	125
4	Strain-to-Failure (%)	1.6	5	2.6

The chosen matrix material for the epoxy resin is characterized by excellent mechanical strength and is very easy to process with the effectiveness of impregnation of fibers, making it suitable for high-performance composites. In the beginning of the chemical reaction, the resin is mixed up with the curing agent (hardener) in a 10:1 weight ratio.

The resin and hardener were procured from CMC Corporation, which is the local distributor for Pune. Table 2 summarises the specifications of the resin provided by the supplier.

3.2. Method

In order to understand the tensile property performance of hybrid laminates in various engineering applications, it becomes essential to study the tensile properties of hybrid laminates. For the current research study, different hybrid laminate configurations were analyzed for their tensile behavior using ANSYS software that simulates and then evaluates its respective mechanical characteristics. The laminates examined here include Carbon Epoxy at a thickness of 2.5 mm, Glass Epoxy at 2.5 mm, and Kevlar Epoxy at a thickness of 2.5 mm. The stress-strain responses and failure behaviors of these laminates under applied loads were evaluated by simulating tensile tests using ANSYS. The process involved generating finite element models of the laminates, appropriate boundary conditions, and several loading scenarios as well as analysis of resulting stress distributions and deformation patterns. This study aimed to compare the tensile strength, stiffness, and ductility of various laminate types as a function of individual properties contributing to hybrid material performances. The simulation data from these studies are useful for understanding designing and optimization criteria for composite laminates in engineering applications.

4. Modelling

In this experimental study, aluminum glass epoxy and kevlar epoxy-reinforced hybrid epoxy composites were fabricated, as well as the mechanical characteristics of the composites were evaluated and compared with values obtained through the use of ANSYS 12.0.

4.1. Aluminium + Carbon Total Deformation

Figure 5 shows Total deformation of the composite beam made of aluminum-carbon materials under applied stress using ANSYS 16.0. This uses a color gradient from blue to red to indicate the different levels of deformation, where the maximum of 0.0014819 meters is illustrated in the central section in red. This area has the maximum applied stress and, therefore, considerable bending.

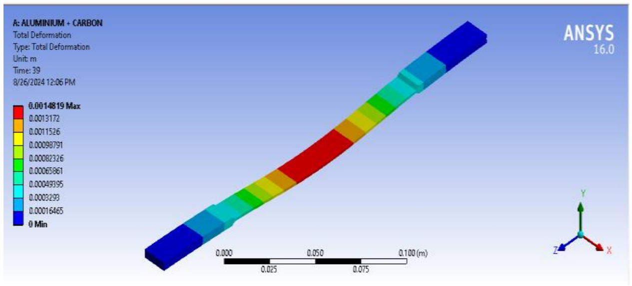

Fig. 5 Total deformation

As we move toward the end of the beam, deformation slowly decreases; this is seen in the blue color, indicating minimal displacement. Analysis: The nature of the beam at the central point has emphasized the necessity of optimization in its design so that under operational loads, it can withstand deformation.

4.1.1. Equivalent Stress

Figure 6 shows the equivalent (von-Mises) stress distribution in an aluminum-carbon composite beam, simulated in ANSYS 16.0. The stress levels range from a minimum of 2.0524e6 Pa (dark blue) to a maximum of 5.598e8 Pa (red). The highest stress concentrations appear at the central region and near the fixed supports, marked in red and yellow, indicating zones of potential failure under load. The rest of the beam exhibits lower stress levels, with the majority of the structure in blue and green, indicating a more uniform and lower stress distribution. This analysis is crucial for identifying areas where the material might yield and ensuring structural integrity under loading conditions.

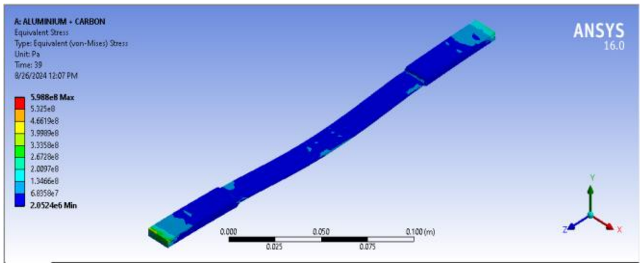

Fig. 6 Equivalent stress

4.1.2. Normal Stress

Figure 7 presents the normal stress distribution along the X-axis in an aluminum-carbon composite beam, as analyzed in ANSYS 16.0. The stress ranges from a minimum of -1.711e8 Pa (dark blue) to a maximum of 9.2233e7 Pa (red). The central region of the beam, particularly where bending occurs, shows the highest tensile stresses, indicated by the transition from green to red. Compressive stresses are found near the fixed supports, marked in blue.

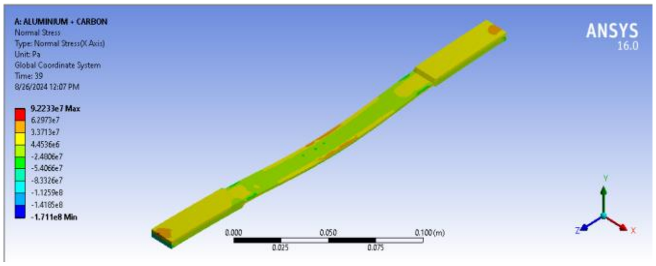

Fig. 7 Normal stress

Figure 8 displays a shear stress distribution analysis of an aluminum-carbon composite structure using ANSYS 16.0. The shear stress ranges from a maximum of approximately 7.3332×1077.3332 \times 10^77.3332×107 Pa (indicated in red) to a minimum of −7.4256×107-7.4256 \times 10^7−7.4256×107 Pa (indicated in blue). The structure shows a non-uniform distribution of shear stress along its length, with higher stress concentrations observed near the extremities. The central region, predominantly in green, exhibits moderate stress levels, while areas in yellow and light blue indicate regions with lower stress.

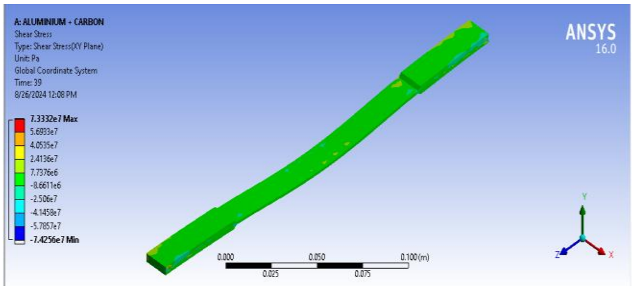

Fig. 8 Shear stress

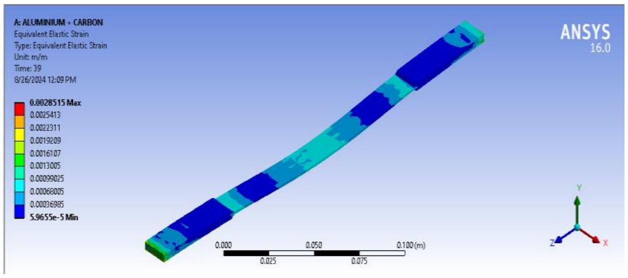

Fig. 9 Equivalent elastic strain

Figure 9 depicts an equivalent elastic strain distribution for an aluminum-carbon composite structure analyzed using ANSYS 16.0. The strain values range from a maximum of approximately 0.00285150.00285150.0028515 m/m (shown in red) to a minimum of 5.9655×10−55.9655 \times 10^{-5}5.9655×10−5 m/m (shown in dark blue). The strain is concentrated primarily at the ends of the structure, where the highest strain occurs, indicating significant deformation under the applied load. The central region shows relatively lower strain values, with a gradient from light blue to green, suggesting less deformation.

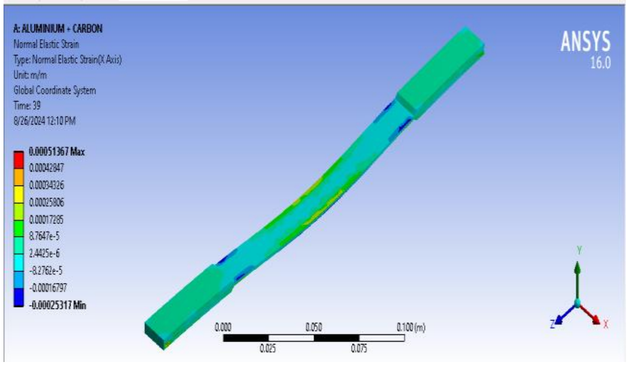

Fig. 10 Normal elastic strain

Figure 10 displays normal elastic strain distribution along the X-axis of a composite beam made of aluminum and carbon under loading conditions, as simulated in ANSYS 16.0. The strain ranges from a minimum value of approximately -0.00025317 m/m to a maximum value of 0.00051367 m/m. The color gradient, ranging from blue (indicating compression) to red (indicating tension), shows how the strain is distributed along the length of the beam. The strain concentration appears to be more significant in the central region, indicating that the middle section of the beam is experiencing higher deformation, likely due to bending or loading effects, with a more uniform strain distribution towards the ends.

4.1.3. Shear Elastic Strain

Figure 11 shows the shear elastic strain distribution in the XY plane of an aluminum-carbon composite beam, as simulated in ANSYS 16.0. The shear strain ranges from -0.0012121 m/m (indicated by dark blue) to 0.0014638 m/m (indicated by red). The distribution suggests that the beam is experiencing varying degrees of shear deformation along its length, with higher concentrations near the center and towards one end. This pattern may indicate regions where the composite material is undergoing significant internal sliding between the aluminum and carbon layers, possibly due to torsional effects or non-uniform loading.

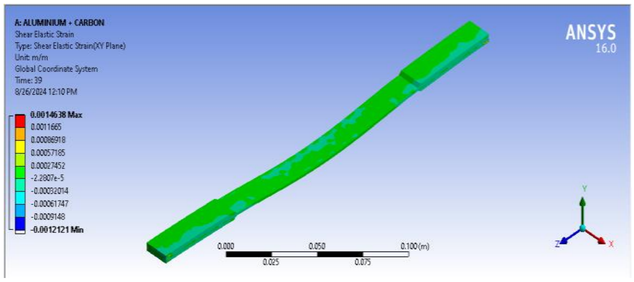

Fig. 11 Shear elastic strain

4.2. Aluminium + Glass

Figure 12 display Total Deformation Distribution of Aluminium Glass Composite Beam subjected to loads in ANSYS 16.0 Deformation range: from minimum, 0 m (dark blue) to maximum, 0.00036849 m (red). The deformation is most pronounced in the middle of the beam. It would appear that the maximum bending stress lies at the central section while there is minimal effect of deformation at the ends.

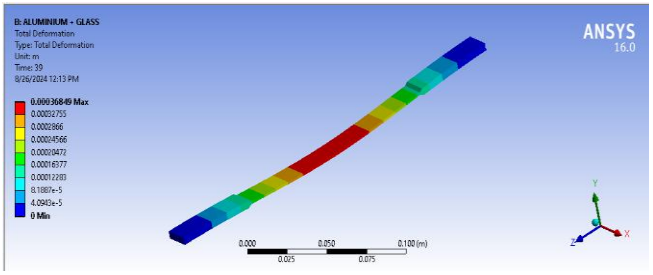

Fig. 12 Total deformation

This is characteristic of the behavior of a beam under bending, with maximum deformation at the middle, with relatively fixed or less affected ends.

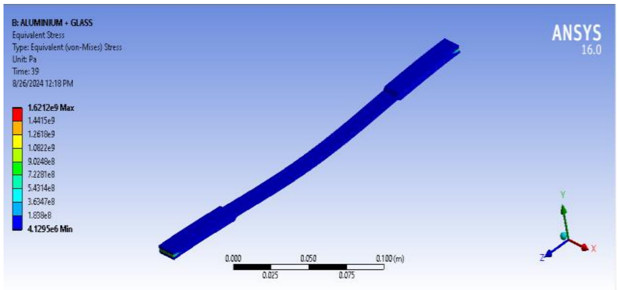

Fig. 13 Equivalent stress

Figure 13 displays Von-Mises stress in a composite structure made of aluminium and glass determined by finite-element analysis. The bending load of this structure is distributed between its two extremities in order to cause the largest stresses near them. The sufficient color-stress map is used for the determination of failure points, and it reflects blue areas of minimum stresses and red areas of maximum stresses. The analysis, therefore, hints that the structure, in such areas with high stress, may require strengthening or may have chances of failure in materials. Such an analysis would be critical to comprehend the structural integrity of the composite as well when subjected to applied loads.

Figure 14 displays Composite aluminum and glass structure in the context of FEA with normal stress along the X-axis. The stress range is from -477 MPa, shown in blue, to 531 MPa in red. The structure tends to bend downward with higher tensile stress concentrations on top and compressive stress at the bottom, corresponding to the color bands. The material is likely to fail at maximum stress near the ends of the structure.

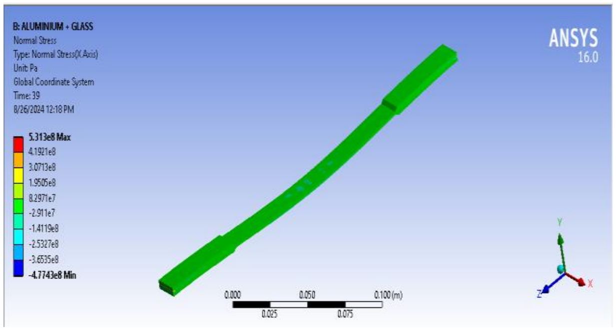

Fig. 14 Normal stress

Figure 15 displays a finite element analysis (FEA) of a composite structure made of aluminum and glass, illustrating the shear stress distribution in the XY plane. The shear stress ranges from -197 MPa (blue) to 227 MPa (red). The structure exhibits higher shear stress along its curved sections, especially near the ends where the maximum stress occurs. This suggests that these areas are more susceptible to shearing forces, which could lead to potential failure or delamination between the aluminum and glass layers.

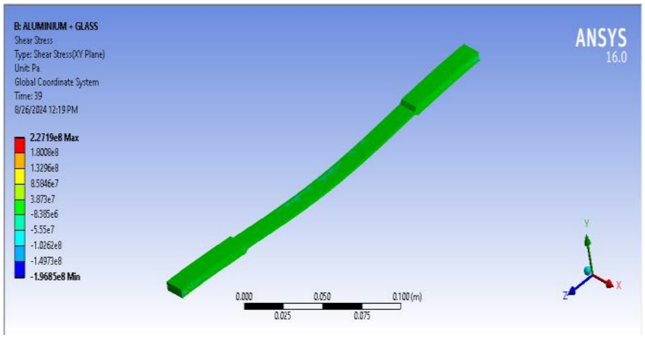

Fig. 15 Shear stress

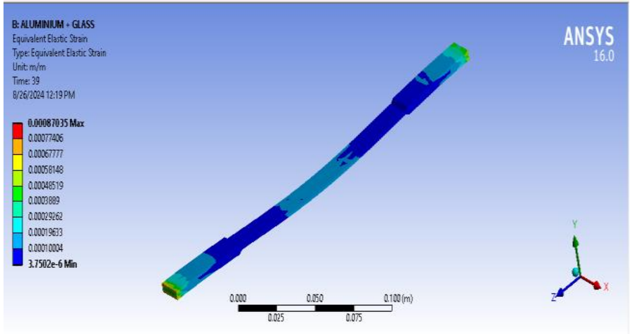

Fig. 16 Equivalent elastic strain

The figure 16 displays the equivalent elastic strain distribution in a composite material comprising aluminum and glass under loading conditions, as simulated using ANSYS 16.0. The strain values range from a minimum of approximately 3.75×10−63.75 \times 10^{-6}3.75×10−6 to a maximum of 8.70×10−48.70 \times 10^{-4}8.70×10−4 m/m. The strain distribution is uneven, with higher strain regions indicated in red and orange, particularly concentrated near the edges and at specific points along the length of the structure, suggesting potential areas of stress concentration. Lower strain areas, shown in blue, dominate most of the structure, indicating relatively stable regions with minimal deformation.

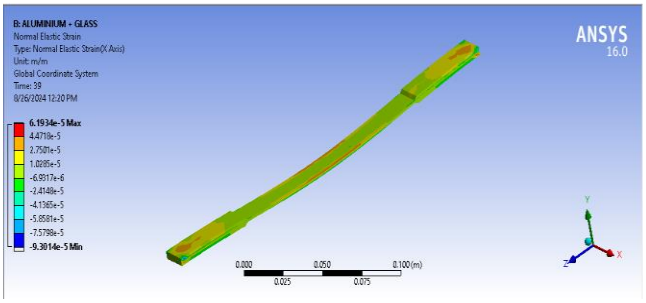

Fig. 17 Normal elastic strain

Figure 17 normal elastic strain distribution along the X-axis in a composite material made of aluminum and glass, analyzed using ANSYS 16.0. The strain values range from approximately −9.30×10−5-9.30 \times 10^{-5}−9.30×10−5 to 6.19×10−56.19 \times 10^{-5}6.19×10−5 m/m. Areas with positive strain (in red and orange) indicate tensile regions, while negative strain areas (in blue and green) indicate compression. The highest tensile strain occurs near the edges, while compression is more prominent in the middle sections of the structure.

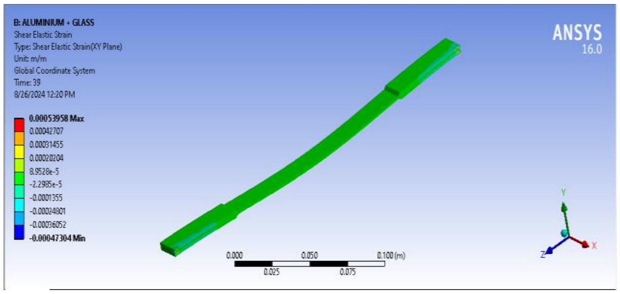

Fig. 18 Shear elastic strain

Figure 18 shows the shear elastic strain distribution in the XY plane for an aluminum and glass composite material, as analyzed using ANSYS 16.0. The strain values vary from approximately −0.000473-0.000473−0.000473 to 0.0005390.0005390.000539 m/m. The strain is concentrated at the ends of the structure, with the maximum shear strain observed near the edges (indicated in red). The central region exhibits minimal shear strain, shown in green, suggesting that the material experiences shear primarily at its extremities.

4.3. *Aluminium + kelvar*

Figure 19 represents a finite element analysis (FEA) of total deformation in a composite beam made of aluminum and Kevlar using ANSYS 16.0 software. The beam appears to be under a bending load, as indicated by the deformation pattern. The deformation is color-coded, with blue indicating minimal displacement and red indicating the maximum deformation of 0.00112554 meters. The deformation increases gradually from the ends of the beam towards the center, with the most significant displacement occurring in the middle, suggesting that the beam's central region experiences the highest stress concentration due to bending.

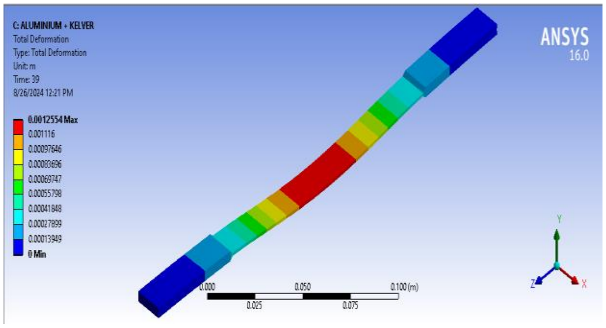

Fig. 19 Total deformation

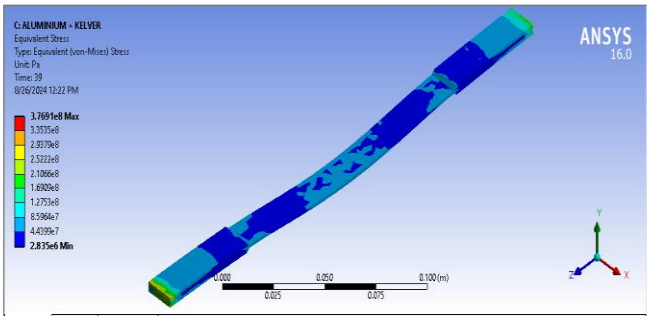

Fig. 20 Equivalent stress

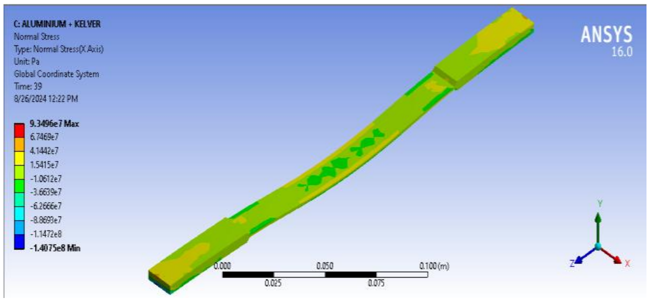

Fig. 21 Normal stress

Figure 20 shows a Finite Element Analysis (FEA) of equivalent (von-Mises) stress distribution in a composite beam made of aluminum and Kevlar using ANSYS 16.0 software. The stress distribution is represented by a color scale, where blue indicates low stress and red represents the highest stress, peaking at 3.769e8 Pa. The maximum stress concentration occurs at the fixed ends of the beam, particularly at the corners, likely due to boundary constraints and load application points. The middle section of the beam shows lower stress levels, suggesting that while deformation occurs, the material is primarily stressed at the supports and edges, crucial for understanding potential failure points in the composite structure.

Figure 21 displays a finite element analysis (FEA) of normal stress in the X-axis direction within a composite beam made of aluminum and Kevlar, using ANSYS 16.0 software. The stress distribution is shown through a color gradient, with red indicating the highest normal stress (9.349e7 Pa) and blue indicating the lowest stress (-1.407e8 Pa). The highest tensile stresses are concentrated near the upper surface at the midpoint, whereas the highest compressive stresses are located at the lower surface, especially near the fixed ends. This pattern aligns with the expected stress distribution in a bending scenario, where the top fibers of the beam experience tension and the bottom fibers undergo compression.

Figure 22 displays The ANSYS simulation result visualizes the shear stress distribution within an Aluminum-Kevlar composite structure, specifically along the XY plane.

The color gradient, ranging from blue to red, represents shear stress values between -6.1231e7 Pa (minimum) and 5.2932e7 Pa (maximum). The red regions indicate areas subjected to the highest shear stress, around 52.932 MPa, which could be critical points for potential material failure or deformation under load. Conversely, the blue regions correspond to lower stress areas, with a minimum shear stress of -61.231 MPa, possibly indicating zones of compression or lower stress concentration.

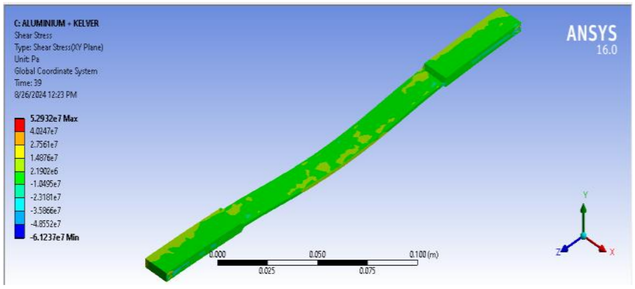

Fig. 22 Shear stress

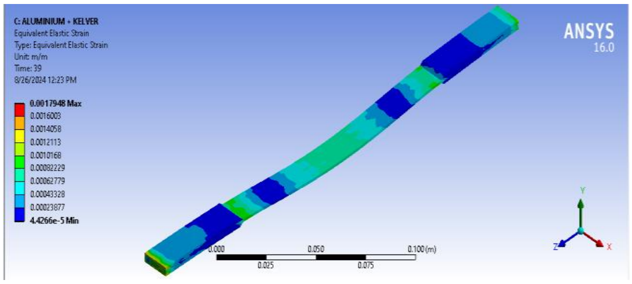

Fig. 23 Equivalent Elastic strain

Figure 23 shows the ANSYS simulation shows an equivalent elastic strain distribution in an Aluminum-Kevlar composite. Values ranging from 4.4266e-5 m/m to 0.0017948 m/m reflect the degree of deformation of materials due to loading. Regions of large strain are thus confined by the red regions, and those that have not experienced such considerable elastic deformation would be stiffer, represented by the color blue. This analysis is important for the overall understanding of the elastic behavior of the composite and its structural integrity and performance conditions under operational stresses.

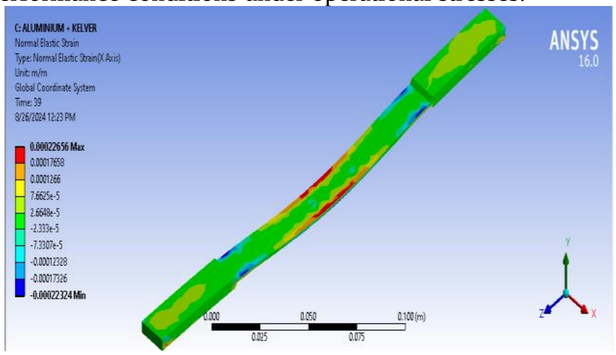

Fig. 24 Normal elastic strain

Figure 24 shows the ANSYS simulation results show the normal elastic strain distribution along the X-axis for an Aluminum-Kevlar composite. The strain values range from -0.00022324 m/m (blue) to 0.00022656 m/m (red). The red zones represent areas with the highest tensile strain, where the material experiences maximum elongation along the X-axis, potentially indicating critical regions prone to stretching under axial loads. In contrast, the blue regions indicate compressive strain, where the material is being compressed. This strain distribution is essential for evaluating the composite's behavior under axial stress, helping identify areas vulnerable to failure or deformation and guiding design optimizations.

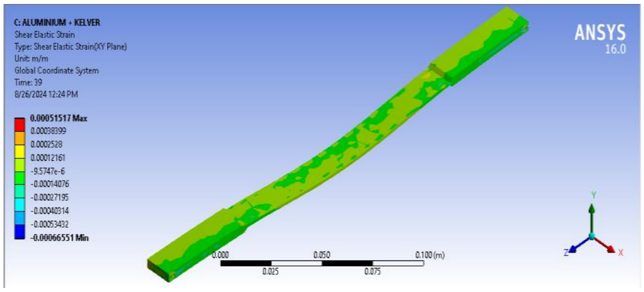

Fig. 25 Shear elastic strain

Figure 25 shows the interference pattern shows maximum intensity values of 150 units at x = 0.5 and x = 1.5, indicating regions of constructive interference. This is where the amplitudes reinforcing the wave will be at their maximum values. Minimum intensity values of 30 units, on the other hand, are found at x = 1.0 as an indication of destructive interference where the amplitudes of the wave cancel each other. This periodic character of the wave interactions is well demonstrated by this oscillatory pattern of peaks and troughs, wherein the intensity fluctuations do indeed contain information about the wavelength and phase differences of the interfering waves.

5. Results and Discussion

Table 4. Total deformation

Total Deformation in m		
Aluminium + carbon	**Aluminium +Glass**	**Aluminium + Kelvar**
0.0014819	0.00036849	0.0012554

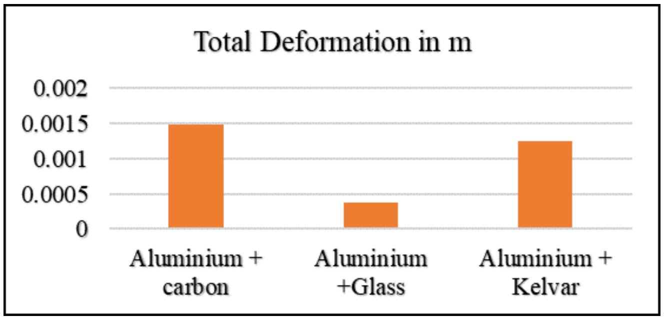

Fig. 26 Total deformation

The Figure 26 compares the total deformation of aluminum when combined with different composite materials—carbon, glass, and Kevlar. Aluminum combined with glass shows the least deformation (0.00036849 m), indicating higher stiffness and better resistance to deformation under load. In contrast, the aluminum-carbon combination has the highest deformation (0.0014819 m), followed closely by Aluminum-Kevlar (0.0012554 m). This suggests that while all combinations provide reinforcement, aluminum-glass composites offer superior rigidity compared to the other two combinations.

Table 5. Equivalent Stress in Pa

Equivalent stress in Pa		
Aluminium + carbon	**Aluminium +Glass**	**Aluminium + Kelvar**
5.99E+08	3.77E+08	1.62E+09

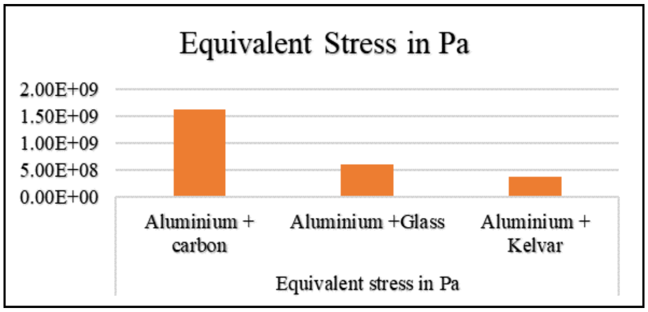

Fig. 27 Equivalent Stress in Pa

The Figure 27 presents the equivalent stress (in Pa) for aluminum when combined with different composite materials—carbon, glass, and Kevlar. The Aluminum-Kevlar combination experiences the highest stress (1.62E+09 Pa), indicating it bears the greatest load before deformation, making it highly durable under stress. Aluminum-carbon shows moderate stress levels (5.99E+08 Pa), while aluminum-glass has the lowest stress (3.77E+08 Pa), suggesting that it is the least resistant to applied forces.

Table 6. Normal stress

Normal Stress in Pa		
Aluminium + carbon	**Aluminium +Glass**	**Aluminium + Kelvar**
9.35 E+07	9.22 E+08	5.31 E+07

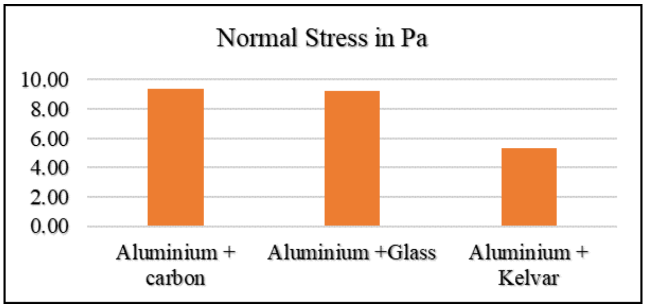

Fig. 28 Normal Stress

The Figure 28 presents the normal stress (in Pa) for aluminum combined with carbon, glass, and Kevlar. The aluminum-glass composite experiences the highest normal stress (922,000,000 Pa), indicating it can withstand the greatest load along the normal direction. The aluminum-carbon combination shows moderate stress levels (93,500,000 Pa), while the Aluminum-Kevlar composite has the lowest stress (53,100,000 Pa).

Table 7. Shear stress

Shear stress in Pa		
Aluminium + carbon	Aluminium +Glass	Aluminium + Kelvar
7.33E+07	2.27E+08	5.29E+07

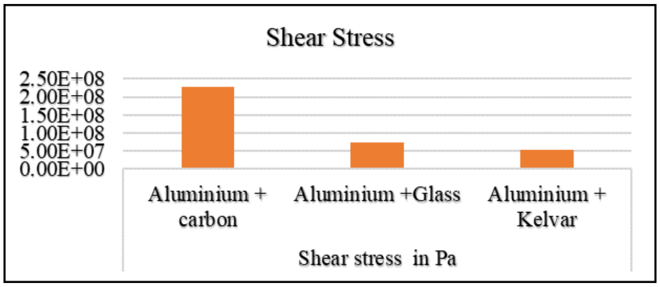

Fig. 29 Shear stress

The Figure 29 shows the shear stress (in Pa) for aluminum combined with carbon, glass, and Kevlar. The aluminum-glass combination exhibits the highest shear stress (2.27E+08 Pa), indicating it can withstand greater tangential forces before failure. In contrast, the Aluminum-Kevlar composite shows the lowest shear stress (5.29E+07 Pa), followed by aluminum-carbon (7.33E+07 Pa). This suggests that aluminum-glass is the most resistant to shear forces, while Aluminum-Kevlar is the least resistant in this context.

Table 8. Equivalent elastic strain

Equivalent Elastic strain in m/m		
Aluminium + carbon	**Aluminium +Glass**	**Aluminium + Kelvar**
0.0028515	0.0017948	0.00087035

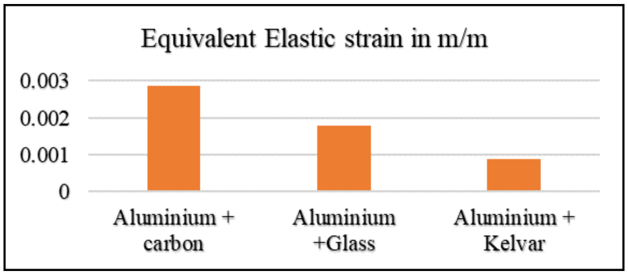

Fig. 30 Equivalent Elastic Strain

The Figure 30 shows the equivalent elastic strain (in m/m) for aluminum when combined with carbon, glass, and

Kevlar. The aluminum-carbon composite exhibits the highest elastic strain (0.0028515 m/m), indicating it undergoes the most deformation under stress, while the Aluminum-Kevlar combination shows the lowest strain (0.00087035 m/m), demonstrating greater stiffness and resistance to deformation. The aluminum-glass combination has a moderate strain value (0.0017948 m/m), balancing flexibility and rigidity.

Table 9. Normal elastic strain

Normal Elastic Strain in m/m		
Aluminium + carbon	**Aluminium +Glass**	**Aluminium + Kelvar**
6.19E-05	0.00051367	0.00022656

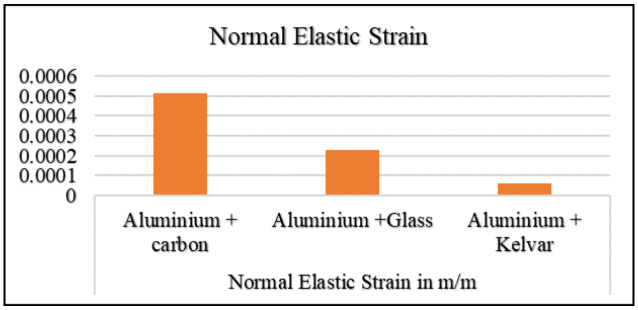

Fig. 31 Normal Elastic Strain

The Figure 31 presents the normal elastic strain (in m/m) for aluminum combined with carbon, glass, and Kevlar. The aluminum-glass composite shows the highest normal elastic strain (0.00051367 m/m), meaning it experiences the most deformation along the loading direction. The aluminum-carbon combination exhibits the lowest strain (6.19E-05 m/m), indicating it is the most resistant to deformation, while Aluminum-Kevlar has a moderate strain value (0.00022656 m/m).

Table 10. Share elastic strain

Shear Elastic Strain in m/m		
Aluminium + carbon	**Aluminium +Glass**	**Aluminium + Kelvar**
0.0014638	0.00053958	0.00051517

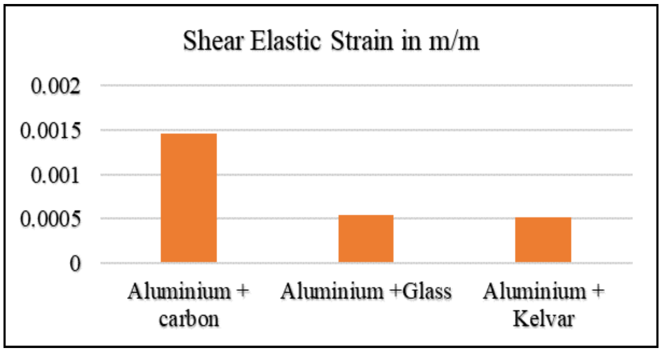

Fig. 32 Share elastic strain

The Figure 32 shows the shear elastic strain (in m/m) for aluminum combined with carbon, glass, and Kevlar. The aluminum-carbon composite exhibits the highest shear strain (0.0014638 m/m), indicating it undergoes the most deformation when subjected to shear forces. Both the aluminum-glass (0.00053958 m/m) and Aluminum-Kevlar (0.00051517 m/m) combinations have much lower shear strains, with Kevlar showing slightly better resistance.

6. Conclusion

This study examines the tensile characteristics of hybrid laminates, specifically concentrating on the performance of aluminum combined with various composite materials: Kevlar, glass, and carbon epoxy. The outcomes indicate that aluminum alloyed with glass fiber presents an excellent function in the sense of stiffness and elongation resistance. Specifically, the total elongation for Aluminum-Glass was at 0.00036849 m, and this was very minimal compared to that of 0.0014819 m recorded for Aluminium-Carbon and 0.0012554 m for Aluminium-Kevlar. This implies that Aluminum-Glass laminate has a better ability to hold its shape under applied loads, with a possible utilization in industries that demand lightweight strength materials. Moreover, based on the determination of equivalent stress in each composite, the aluminum-kevlar composite achieved the highest level of stress at 1.62E+09 Pa, meaning that it is capable of carrying high loads before getting deformed. Compared to Aluminum-Glass, the hybrid composed of aluminum-kevlar presents an equivalent stress of 3.77E+08 Pa, meaning, it has a lesser resistance to applied forces than the Aluminum-Kevlar hybrid. However, this characteristic does not somehow strip off the general usability of the Aluminum-Glass composite; rather, this further emphasizes its role in applications where flexibility and lower weight are advantageous.

The tests of normal and shear stresses were also conducted: normal stress was highest for the Aluminum-Glass combination (9.22E+08 Pa), followed by shear stress (2.27E+08 Pa), which in turn further established the strength of the combination in withstanding heavy loads and tangential forces. The aluminum-carbon composite showed a middle position for these values. At the same time, Aluminium-Kevlar exhibited the lowest value in both categories and thus hinted at the limitations of this composite in requiring more shear resistance. Lastly, in terms of strain measurement, the Aluminum-Glass composite had balanced elastic strain, which means flexible and does not lose rigidity.

The Aluminum-Carbon laminate had the highest elastic strain and, therefore, deformed most under stress. The Aluminium-Kevlar composite had the lowest elastic strain values, indicating rigidity in that composite. In conclusion, while all hybrid laminates analyzed prove useful in providing reinforcement, the Aluminum-Glass composite clearly represents the most promising option, with the best balance between stiffness, resistance to deformation, and general performance under tensile loads.

The importance of hybrid laminates, especially the Aluminum-Glass hybrid, for many applications running from automotive applications towards aerospace applications, where the service performance weighs in with concerns about weight, is generally emphasized by these results.

Future Scope

Long-term durability under cyclic loading and diverse environmental conditions could be established for the future in the foreseen research of these materials. Certain applications may also be optimized with respect to flexibility, strength, and weight by optimizing the laminate configuration and thicknesses for optimum performance. Advanced composites and hybrid materials with novel reinforcement techniques and manufacturing processes can also be studied for emerging industrial applications.

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