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Influence of Fiber Orientation on the Properties of Composites

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ABSTRACT

The influence of fiber orientation on the properties of composite materials is a critical aspect in engineering design and manufacturing. This study investigates how varying fiber orientations affect the mechanical, thermal, and structural properties of composites using SolidWorks and ANSYS software. Finite element analysis (FEA) simulations were conducted to analyze the behavior of composites with different fiber orientations under various loading conditions. The results demonstrate that fiber orientation significantly impacts the stiffness, strength, and fracture resistance of composites, as observed through SolidWorks simulations. Additionally, ANSYS simulations provided insights into the thermal conductivity and electrical properties affected by fiber alignment. Understanding these influences is crucial for optimizing composite material performance and designing components with enhanced durability and functionality across a wide range of applications, including aerospace, automotive, and construction industries.

KEYWORDS: Fiber orientation, composite materials, mechanical properties, thermal properties, structural properties, SolidWorks, ANSYS, finite element analysis (FEA).

1. INTRODUCTION

Natural fibres being abundant in nature are available in large amount at negligible cost in raw state when compared synthetic alternatives also they have very low processing and production cost and are thus very cost efficient. Natural plant fibres are high strength, high stiffness, lightweight, non-corrosive materials, and flame-retardant materials hence they are very useful for mechanical and tribological applications. Natural Fiber Reinforced Composites (NFRCs) find themselves in a large scope of applications ranging from household utilities to aeronautical and aerospace applications accrediting to their light weight and low-cost characteristics. Natural fiber reinforced composites consist to two main components, i.e., the fiber and the resin or matrix. The fiber or natural fiber have a wide variety of exploration and discovery, fibers discovered from various plants or trees are named accordingly, Banana, Coir, Hemp, Flax, Jute, Hemp and sisal are common fibers to name a few. The fibers derived from different plants. have different organic structure and thus possess different type intermolecular structures and bonds thus each fiber has a unique set of physical, chemical and mechanical properties.

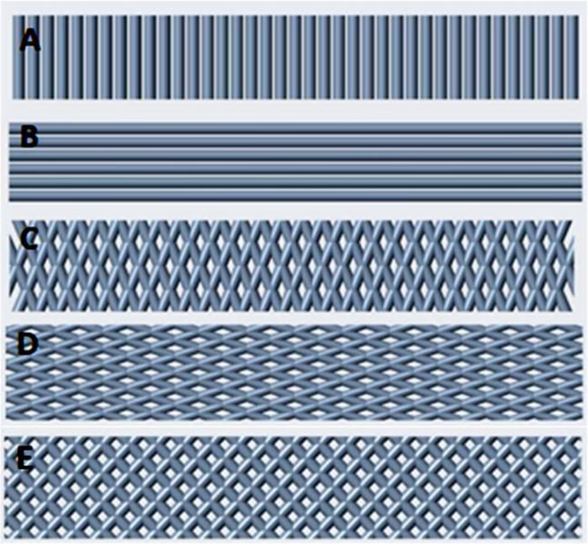


Fig. 1. Specimen with different fiber orientation (angle measured from horizontal) (a) 0_ specimen (b) 90_ specimen (c) 22.5_/_22.5_ specimen (d) 67.5_/_67.5_ specimen (e) 45_/_45_ specimen.

2. METHODOLOGY

The steps are mentioned below.

- SELECTION OF MATERIALS: The first step involved selecting three different materials for the study: structural steel, magnesium alloy, and aluminum. These materials were chosen based on their common use in engineering applications and their distinct mechanical properties.
- CREATION OF 3D-MODELS: Using SolidWorks software, detailed 3D models of the specimens were created. The dimensions and geometry of each specimen were standardized to ensure consistency across the experiments.
- MESH GENERATION: Finite element analysis (FEA) requires a meshed model for accurate simulations. The 3D models were meshed using appropriate meshing techniques to ensure a balance between accuracy and computational efficiency.
- MATERIAL PROPERTIES ASSIGNMENTS: Material properties such as Young's modulus, Poisson's ratio, and yield strength were assigned to each material in the SolidWorks simulation environment. These properties were obtained from literature sources and material databases.
- APPLICATION OF LOADS: Load scenarios were defined for each material specimen to simulate real-world operating conditions. The loads included tensile, compressive, and bending loads to assess the mechanical behavior of materials under states.
- FIBER ORIENTATION AND SIMULATION: For composites, fiber orientation plays a crucial role in determining mechanical properties. An additional simulation was conducted to analyze the effects of fiber orientation on composite behavior using ANSYS software. Different fiber orientations were modeled and analyzed to understand their impact on stiffness, strength, and deformation.
- ANALYSIS AND INTERPRETATION: After completing the simulations, the results were analyzed to evaluate the deformation, stress distribution, strain, and topology optimization (if applicable) for each material specimen and composite with varying fiber orientations. Graphical representations and numerical data were used to interpret the findings and draw conclusions.
- VALIDATION: To validate the simulation results, experimental tests may be conducted on physical specimens to compare with the simulated data. This step helps ensure the accuracy and reliability of the simulation methodology.

3. MODELING OF THE OBJECT

BASIC ASSEMBLY MATES:

- Coincident – place two flat surfaces in the same Plane
- Parallel – define two flat surfaces as parallel
- Perpendicular – define two lines or planes as perpendicular to one another
- Tangent – defines a cylindrical feature as tangent to a line or plane
- Concentric – align the centerlines of two cylindrical features
- Distance – make two surfaces parallel, with a specified distance between them

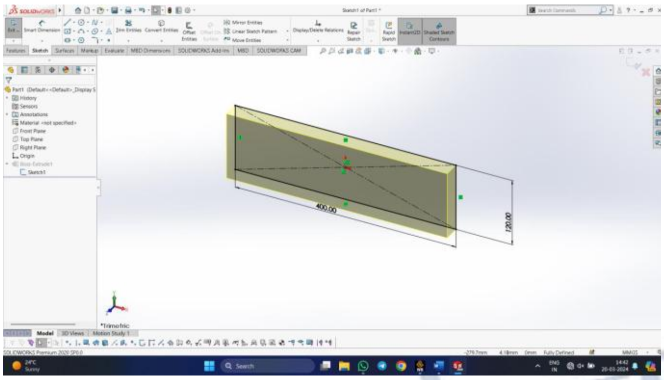


Fig 2: RECTANGULAR FRAME

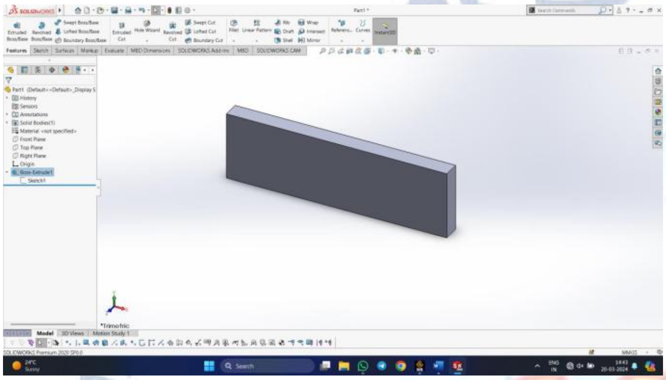


Fig 3: FINAL DESIGN

4. RESULT AND ANALYSIS

The steps needed to perform an analysis depend on the study type. You complete a study by performing the following steps:

Create a study defining its analysis type and options. If needed, define parameters of your study. A parameter can be a model dimension, material property, force value, or any other input.

- Define material properties.
- Specify restraints and loads.
- The program automatically creates a mixed mesh when different geometries (solid, shell, structural members etc.) exist in the model.
- Define component contact and contact sets.
- Mesh the model to divide the model into many small pieces called elements. Fatigue and optimization studies use the meshes in referenced studies.
- Run the study.

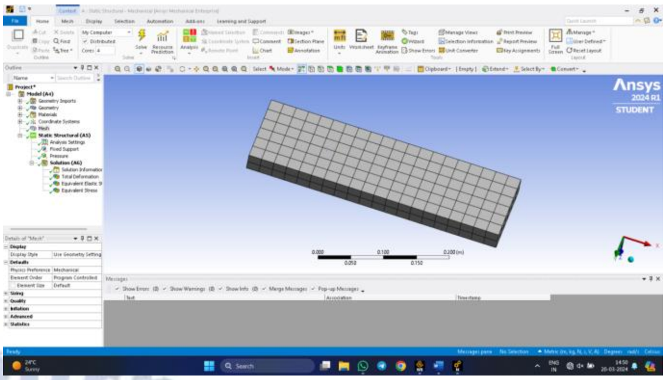


Fig 4: MESHING THE MODEL

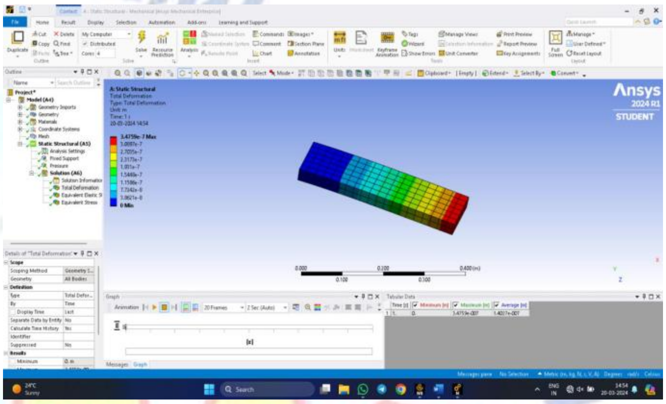


Fig: 5: TOTAL DEFORMATION OF 230 GPA

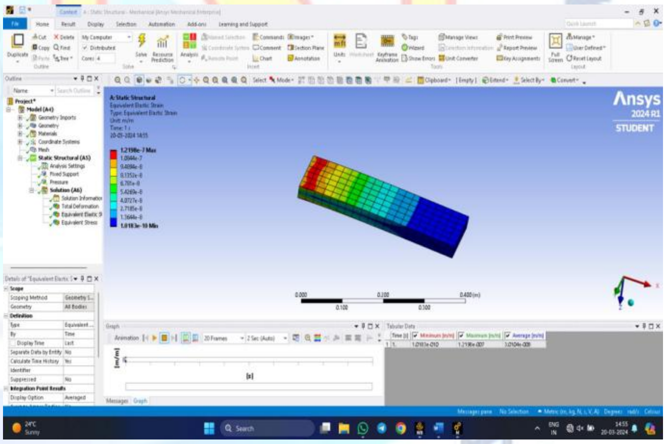


Fig6: ELASTIC STRAIN OF 230 GPA

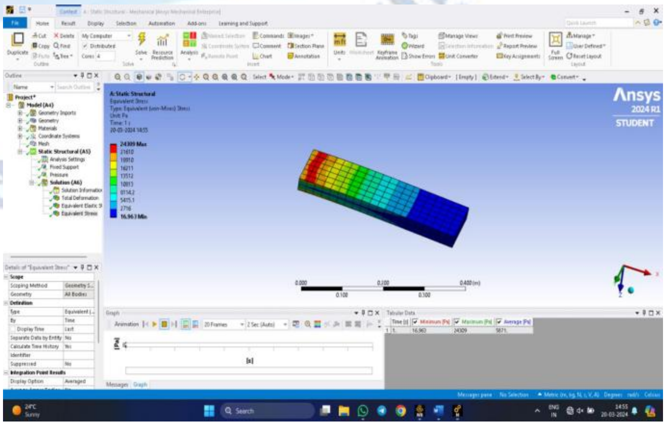
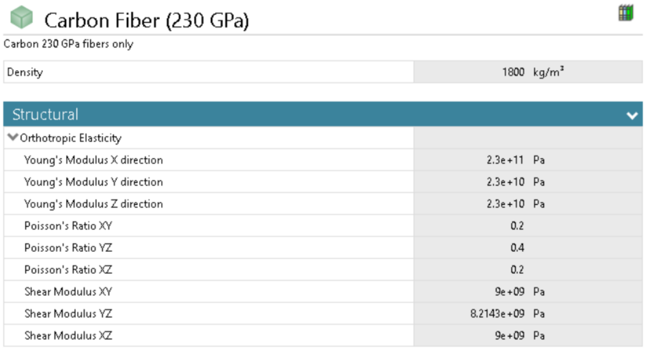


Fig7: STRESS OF 230 GPA

TABLE 1: CARBON FIBER 230 GPA

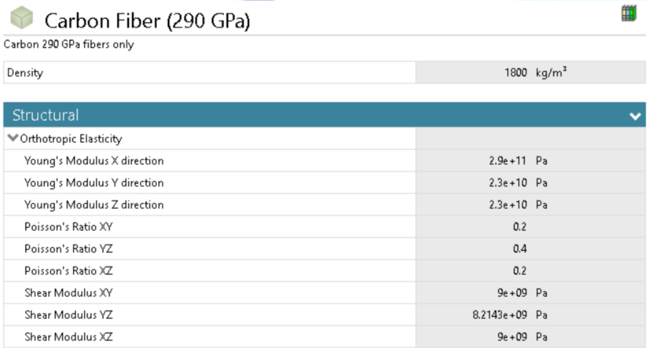


Carbon Fiber (230 GPa)

Carbon 230 GPa fibers only

Density	1800 kg/m³
Structural	
Orthotropic Elasticity	
Young's Modulus X direction	2.3e+11 Pa
Young's Modulus Y direction	2.3e+10 Pa
Young's Modulus Z direction	2.3e+10 Pa
Poisson's Ratio XY	0.2
Poisson's Ratio YZ	0.4
Poisson's Ratio XZ	0.2
Shear Modulus XY	9e+09 Pa
Shear Modulus YZ	8.2143e+09 Pa
Shear Modulus XZ	9e+09 Pa

TABLE 5.3: CARBON FIBER 290 GPA

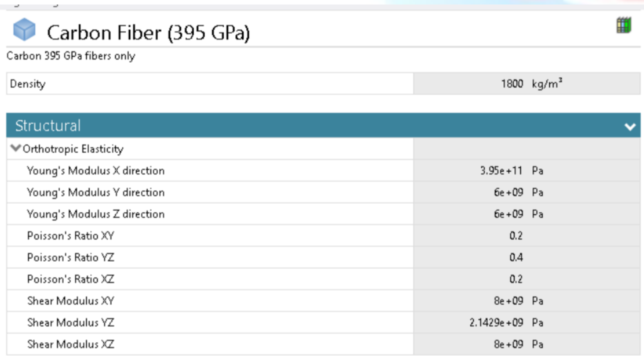


Carbon Fiber (290 GPa)

Carbon 290 GPa fibers only

Density	1800 kg/m³
Structural	
Orthotropic Elasticity	
Young's Modulus X direction	2.9e+11 Pa
Young's Modulus Y direction	2.3e+10 Pa
Young's Modulus Z direction	2.3e+10 Pa
Poisson's Ratio XY	0.2
Poisson's Ratio YZ	0.4
Poisson's Ratio XZ	0.2
Shear Modulus XY	9e+09 Pa
Shear Modulus YZ	8.2143e+09 Pa
Shear Modulus XZ	9e+09 Pa

TABLE 5.4: CARBON FIBER 395 GPA



Carbon Fiber (395 GPa)

Carbon 395 GPa fibers only

Density	1800 kg/m³
Structural	
Orthotropic Elasticity	
Young's Modulus X direction	3.95e+11 Pa
Young's Modulus Y direction	6e+09 Pa
Young's Modulus Z direction	6e+09 Pa
Poisson's Ratio XY	0.2
Poisson's Ratio YZ	0.4
Poisson's Ratio XZ	0.2
Shear Modulus XY	8e+09 Pa
Shear Modulus YZ	2.1429e+09 Pa
Shear Modulus XZ	8e+09 Pa

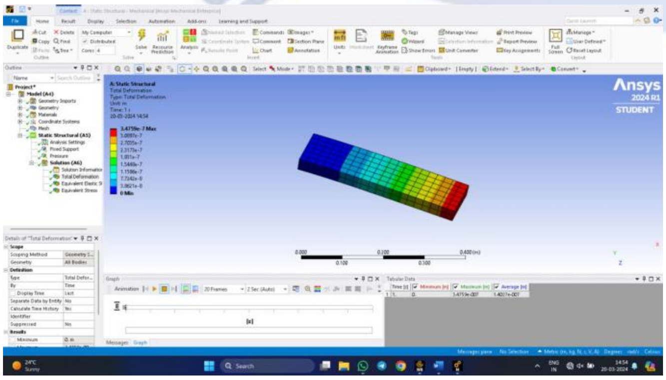


Fig 8: TOTAL DEFORMATION OF 395 GPA

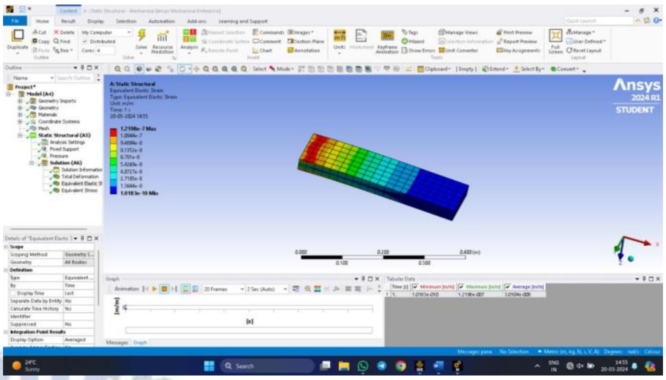


Fig 9: STRAIN OF 395 GPA

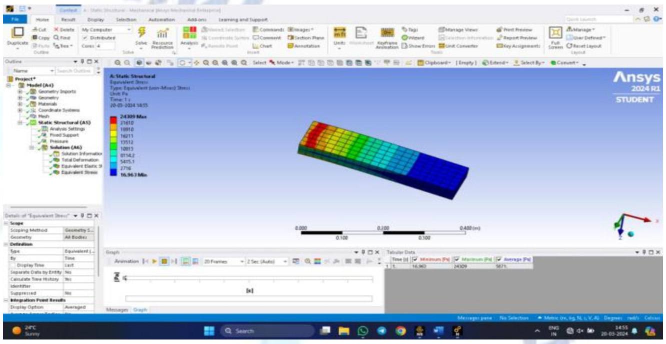


Fig 10: STRESS OF 395 GPA

5. CONCLUSION

The study's comprehensive analysis of Carbon Fiber (395 GPa), Carbon Fiber (230GPa), Carbon Fiber (290GPa) , alongside simulations of composite materials with varying fiber orientations, provides valuable insights into their mechanical behaviour and performance characteristics. The simulations revealed that magnesium alloy exhibited the highest deformation, indicating potential susceptibility to deformation under applied loads. Conversely, structural steel demonstrated comparatively lower deformation, showcasing its ability to withstand higher loads before reaching yield or failure. The stress distribution analysis further supported these findings, with structural steel exhibiting the highest stress levels, magnesium alloy and aluminum showing lower stress levels, highlighting their respective strengths and limitations under different loading conditions. Moreover, strain behavior analysis showcased magnesium alloy's higher strain, aluminum's moderate strain, and structural steel's least strain, reflecting their unique stiffness and resistance to deformation properties.

Additionally, topology optimization simulations for aluminum resulted in an optimal range of 0.4-0.6, indicating efficient design with balanced strength and material usage. The study also emphasized the impact of composite fiber orientation on mechanical properties such as stiffness, strength, and deformation, offering critical insights for optimizing composite designs tailored to specific applications. Overall, these findings contribute to informed material selection, design optimization, and engineering decision-making processes across industries, ensuring enhanced performance, durability, and efficiency in structural designs and applications. Future research may further explore advanced simulation techniques and material formulations to continue improving understanding and utilization of fiber orientation in engineering materials and composites.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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