Structural Investigations on Various Carbon and Glass Fibre Reinforced Polymers added with Single-Walled Carbon Nanotubes Under Flexural Loading Conditions

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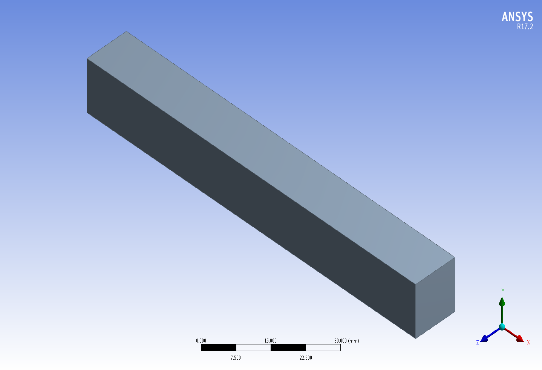
**Abstract.** In aerospace, drone, and marine sectors, a material’s ability to withstand mechanical loads is critical for ensuring structural integrity and operational reliability. Components of unmanned aerial vehicles (UAVs), such as propellers, fuselage, wings, connecting arms, empennage, and landing gear, often exhibit significant flexural demands due to complex geometries and limited aerodynamic efficiency. This study focuses on developing robust, lightweight materials through a combination of experimental and computational methodologies. The structural behavior of CF-GY-70 epoxy, integrated with single-walled carbon nanotubes (SWCNTs), is examined alongside various E-glass fiber-reinforced polymer (GFRP) composites—namely E-GFRP, E-GFRP-FABRIC-O, E-GFRP-UD-O, E-GFRP-Polyester, and E-GFRP-W. These composites are designed to enhance flexural strength while maintaining weight efficiency. Specimens are modeled according to ASTM D7264 standards using ANSYS Build Modeler, with ANSYS Mesh Tool and ANSYS ACP employed for mesh generation and composite layering. Structural performance is validated through advanced simulations in ANSYS Structural. Comparative analysis reveals the most effective filler combinations for enhancing durability and load-bearing capabilities. The results highlight the potential of SWCNT-enhanced composites in meeting the rigorous demands of next-generation UAV and marine applications.

# INTRODUCTION

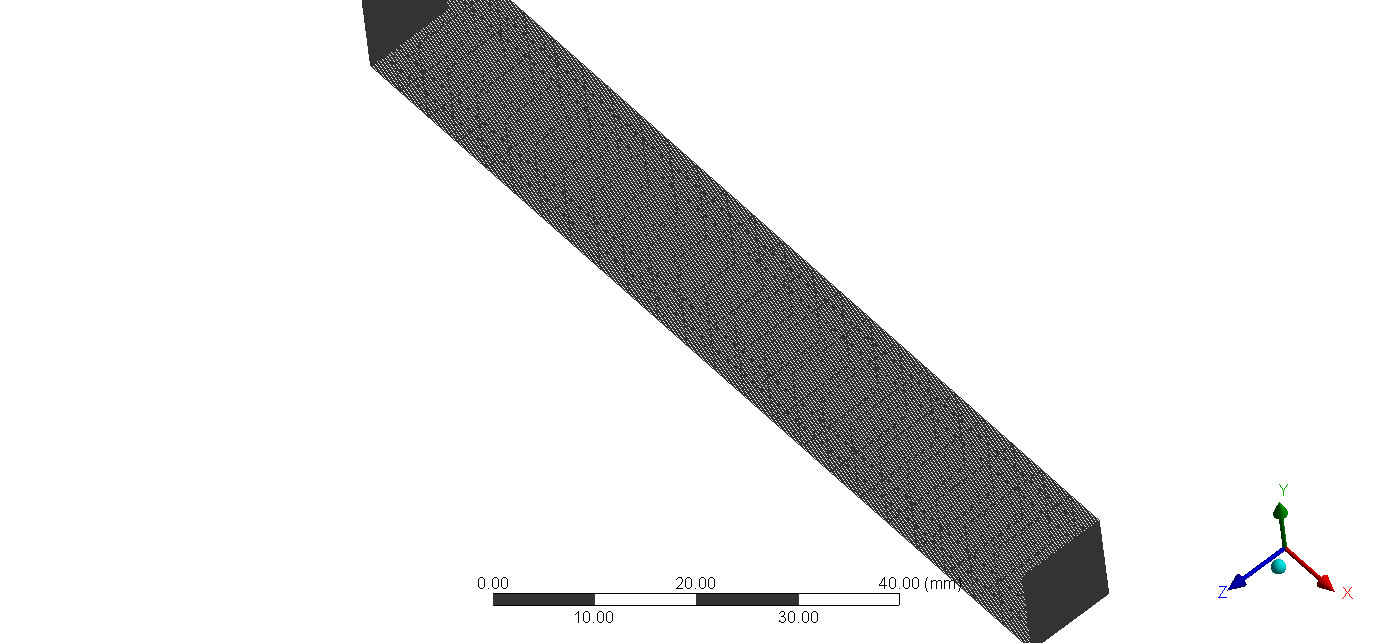
To enhance the material strength property, single-walled carbon nanotubes (SWCNTs) are combined with CF-GY-70 and the E-Glass Fiber Reinforced Polymer (E-GFRP) family. Epoxy is supplemented with a 5 percent addition of SWCNT, and normal specimen testing protocols are adhered to. The specimen dimensions, as per ASTM Standard D-7264, are 100 mm, 20 mm, and 7 mm. In carbon nanotubes (CNTs), the matrix consists of 60% carbon fiber as reinforcement and 40% epoxy resin with a hardener. The flexural test is a fundamental engineering assessment that quantifies a material's resistance to bending and its stiffness. In flexural testing, a standard ASTM specimen with specified parameters is supported by two pins and positioned horizontally until failure occurs. The applied axial stress and elongation are utilized to ascertain the material's stiffness. The composition of core materials greatly influences property estimations. This research uses numerical modelling grounded in finite element analysis (FEA) to examine the flexural characteristics of nanocomposites. This structural simulation employs glass fiber, CF-GY-70 fiber, and epoxy resin as reinforcement and additives. SWCNTs and multi-walled carbon nanotubes (MWCNTs) are employed in comparative structural study due to a modification at the mixing level. Aerospace applications, such as flight control systems, empennage, and aircraft surfaces, significantly benefit from the use of CFRP (Carbon Fiber Reinforced Polymer) composite materials. The matrix enhances the properties of composite materials. The matrix not only stores fibers but also binds them with mixes to enhance the material's reinforcing properties. To examine the mechanical characteristics of SWCNTs, six distinct quantities of reinforcement are utilized. In composite materials, fibers are crucial for load-bearing capacity. The fibers are accountable for the laminate's rigidity, resulting in composites possessing a significantly high stiffness-to-weight ratio. The allocation of loads among fibers influences load-bearing capacity [1-3]. An accurate evaluation of fiber orientation is necessary as a result [4]. Three distinct forms of fiber can be utilized to fabricate composites: unidirectional, bidirectional, and multidirectional. Fibres can be produced from several materials, including carbon, glass, and boron [5]. An elevated efficiency in composite laminates is attained through the inclusion of a secondary component that facilitates both direct and indirect reinforcement [9]. The primary function of the matrix is to resist delamination [6-8]. The author conducted FEA computations on polymer composites using CNTs. The finite element analysis framework, material mechanical properties, mesh types utilized, and composite elemental data in the present work were all well substantiated [10]. Although assessed the bending behavior of nanocomposites, fundamental theoretical knowledge, computational tools, and mechanical properties of nanocomposites were employed to achieve preliminary insights [11]. The reliability of ANSYS has facilitated the researcher's analysis of nanocomposite materials at present. The provided source offers a comprehensive understanding of computational structural methods; hence, this study employed ANSYS Workbench to examine the flexural behavior of nanocomposites. In conclusion, the performance of CNT-reinforced polymer composites has been thoroughly evaluated based on several critical factors, including CNT weight percentage, matrix selection, manufacturing techniques, and environmental conditions. This comprehensive review takes into account both the advantages and limitations of these variables. It presents detailed insights into optimal filler loadings, advanced fabrication methods for high-performance nanocomposites, and the selection of suitable matrix materials. The study also includes a detailed fracture analysis of nanocomposites incorporating various types of CNTs. A key focus of the current work is the comparative evaluation of flexural strengths between SWCNTs and MWCNTs, offering foundational data for future composite development [12,13]. Additionally, the effects of CNT agglomeration in reinforced composites are examined, shedding light on their structural characteristics and the adverse impacts on both the reinforcement phase and matrix integrity [14–16].

## IMPOSED METHODOLOGY – COMPUTATIONAL APPROACH

Computational structural analysis in this study is performed using Finite Element Analysis (FEA), a powerful method that relies on pre-programmed numerical algorithms for accurate simulation results [17–19]. The formulation of the flexural study involves several critical steps: constructing the computational model, developing the finite element mesh, establishing the justification for applied analysis methods [20–22], and defining appropriate boundary conditions [17–19]. These foundational stages are essential before obtaining reliable computational outputs [20–22]. This research investigates the flexural behavior of composite materials across multiple engineering disciplines [34-39]. The simulation adheres to ASTM D7264 standards, using a test specimen with dimensions of 100 mm span, 20 mm width, and 7 mm thickness, subjected to a loading force of 3791.3 N [23–27]. Figure 1 presents the 3D computational model of the test specimen. For meshing, three-dimensional brick elements are employed, ensuring a high-quality discretization with mesh quality exceeding 90%. The detailed mesh structure of the discretized model is shown in Figure 2 [28-32].



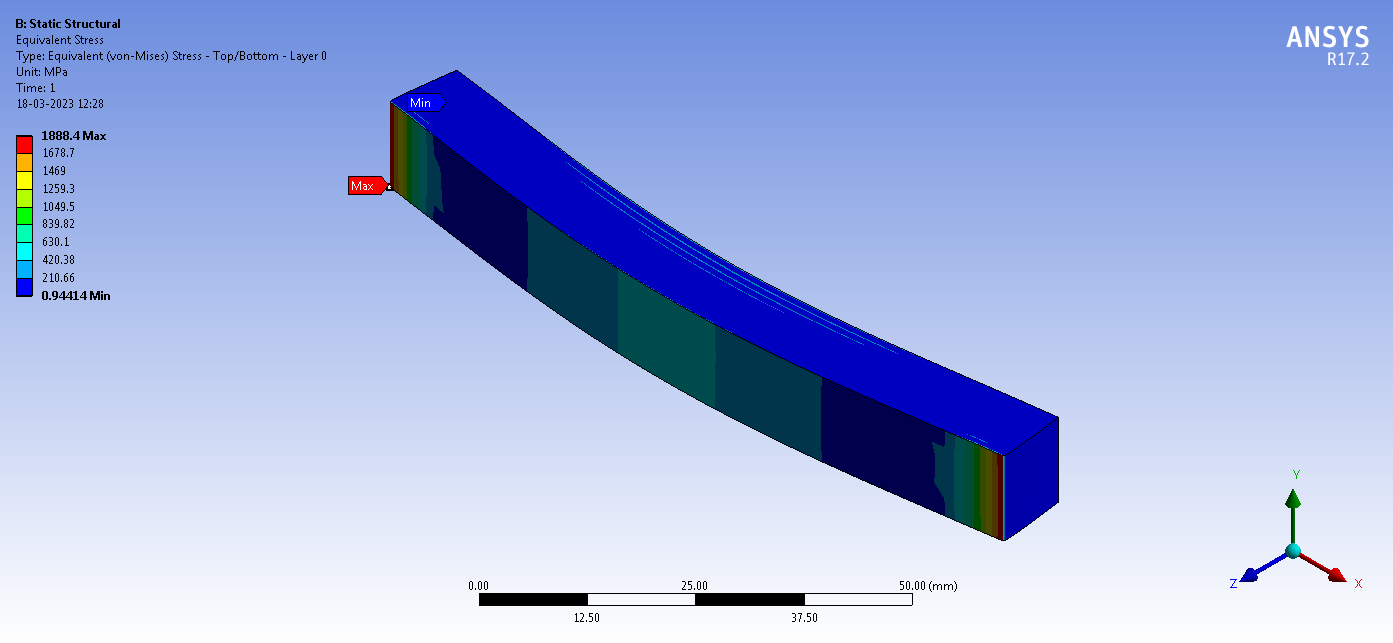
1. Computational model of flexural test specimen



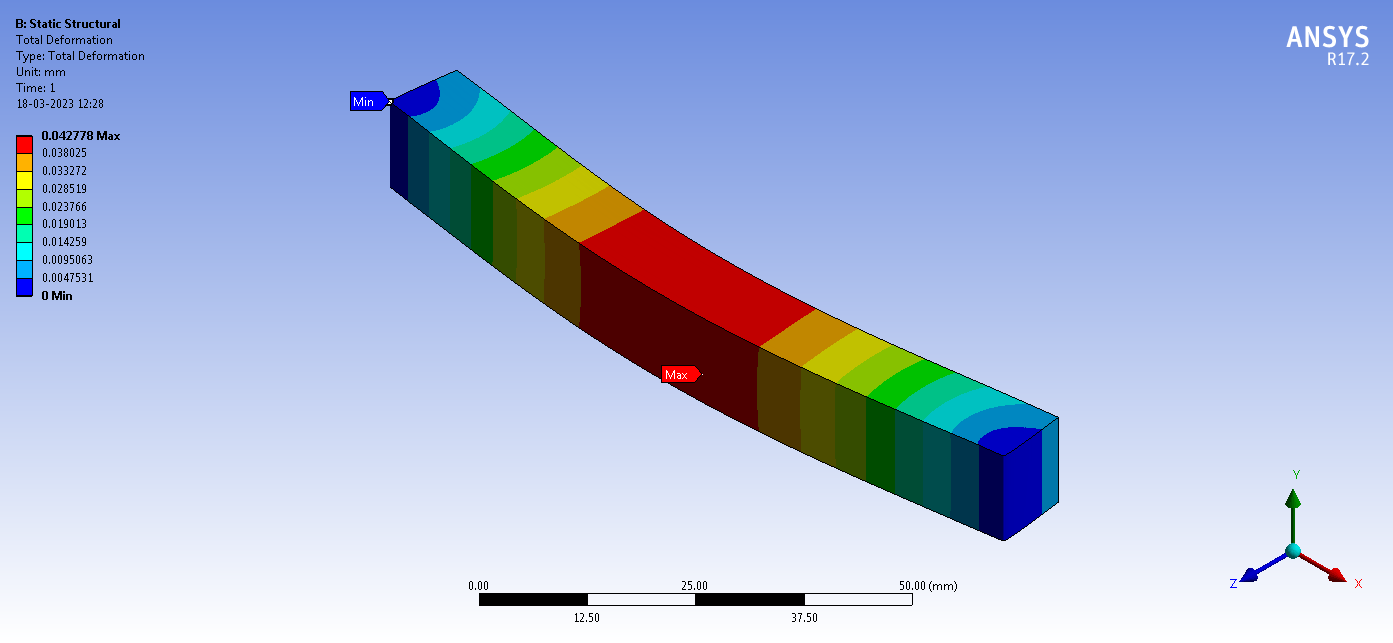
1. Discretization image of the flexural test specimen.

## RESULTS AND DISCUSSIONS

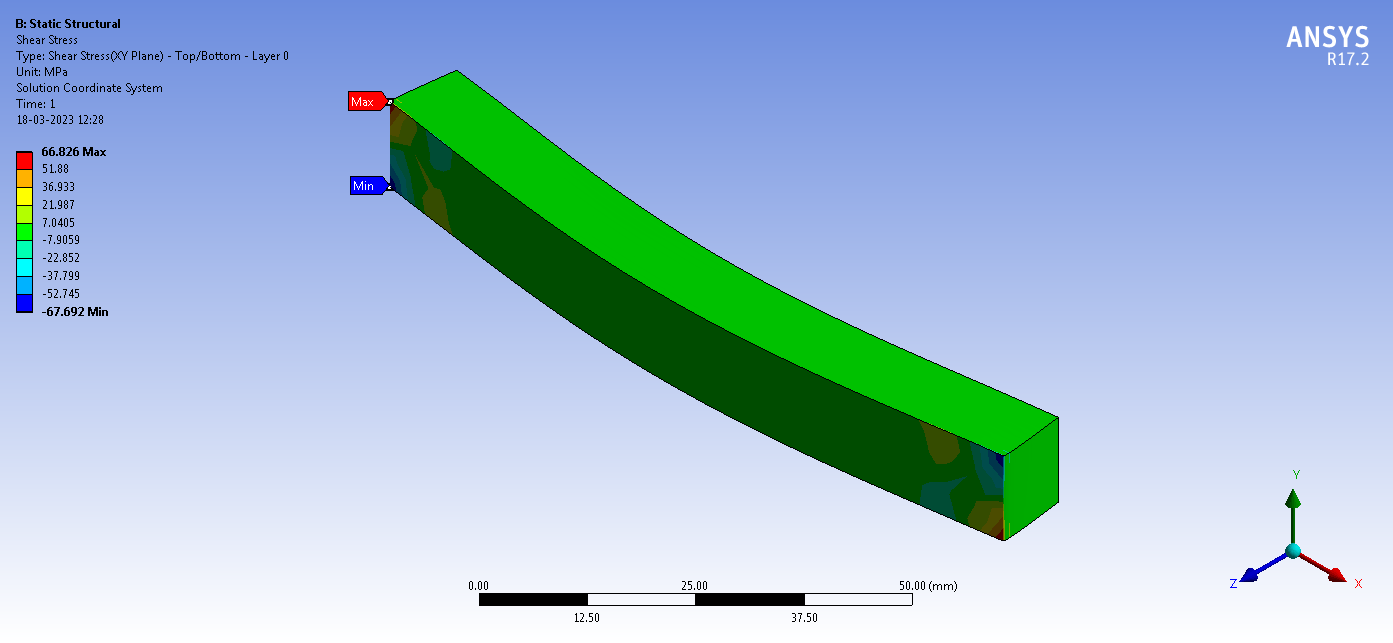
Figures 3 to 5 present the comprehensive structural analysis of the CF-GY-70-epoxy composite reinforced with SWCNTs under flexural loading conditions. Specifically, Figure 3 illustrates the distribution of equivalent (von Mises) stress [40-49], Figure 4 displays the total deformation of the material, and Figure 5 highlights the shear stress response.



1. Equivalent stress of SWCNTs associated test specimen



1. Total deformation outcomes of SWCNTs associated test specimen



1. Shear stress outcomes of SWCNTs associated test specimen

Figures 6 to 8 reveal that the CF-GY-70-epoxy composite demonstrates the lowest values of deflection, equivalent stress, and shear stress, respectively. The detailed analysis of these figures confirms that the CF-GY-70-epoxy material reinforced with SWCNTs sustains higher flexural loads compared to other E-GFRP composites incorporating SWCNTs [50-59]. Key parameters such as total deformation and equivalent stress are crucial in this assessment, as they support stiffness-based material selection and performance evaluation [60-72].

1. Comprehensive report of total deformation of various composites associated with SWCNTs
2. Comprehensive report of equivalent stress of various composites associated with SWCNTs

1. Comprehensive report of shear stress of various composites associated with SWCNTs

## CONCLUSION

All critical input data including three-dimensional geometry, mechanical properties of the materials used, boundary conditions, and the selection of primary and secondary constituents for the nanocomposite are obtained through an extensive literature review. During the flexural testing phase, carbon fiber composites are evaluated under an applied load of 3791.3 N. Among the tested configurations, the CF-GY-70-epoxy combined with SWCNTs exhibited the lowest deflection.

A comparative analysis between CF-GY-70-epoxy and various E-GFRP composites, all infused with SWCNTs, demonstrated that the CF-GY-70-SWCNT combination outperformed others. Specifically, it achieved a 72% reduction in total deformation and a 22% improvement in equivalent stress, confirming its superior mechanical performance under flexural loading.

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