Cutting-Edge Carbon Fiber Composites with MWCNT Reinforcement for UAV Rotodynamic Components

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**Abstract.** Durability is a critical factor in the design and load-bearing performance of components used in demanding real-time applications across aerospace, automotive, and marine industries. Drone components, in particular, are prone to fractures due to their complex geometries and suboptimal aerodynamic stability. Reducing the likelihood of structural failure is essential to expand their applicability, necessitating in-depth investigations into the underlying causes of material degradation. This study explores the frictional behavior of carbon fiber composites reinforced with multi-walled carbon nanotubes (MWCNTs) using a pin-on-disc test configuration, operating at a maximum disc rotation speed of 700 RPM. The pin specimens are modeled and analyzed using ANSYS ACP, a versatile tool for composite fabrication. A combination of experimental testing and advanced computational techniques is employed for structural optimization. The study focuses on MWCNT-enhanced polymer matrix composites, incorporating eight different carbon fiber types: AS-CFRP, CFRP-UD-O, CFRP-UD-230W, CFRP-Wn-FABRIC-O, CFRP-Wn-230P, CFRP-Wn-230W, CFRP-UD-230P, and HMS Carbon. Discretization and composite generation are carried out using ANSYS Mesh Tool and ANSYS ACP. Finally, comparative structural analyses are performed using ANSYS Structural to identify the optimal composite configuration. Results confirm that integrating MWCNTs significantly improves the mechanical and frictional performance of carbon fiber composites, making them ideal for high-stress, real-time operational environments.

# INTRODUCTION

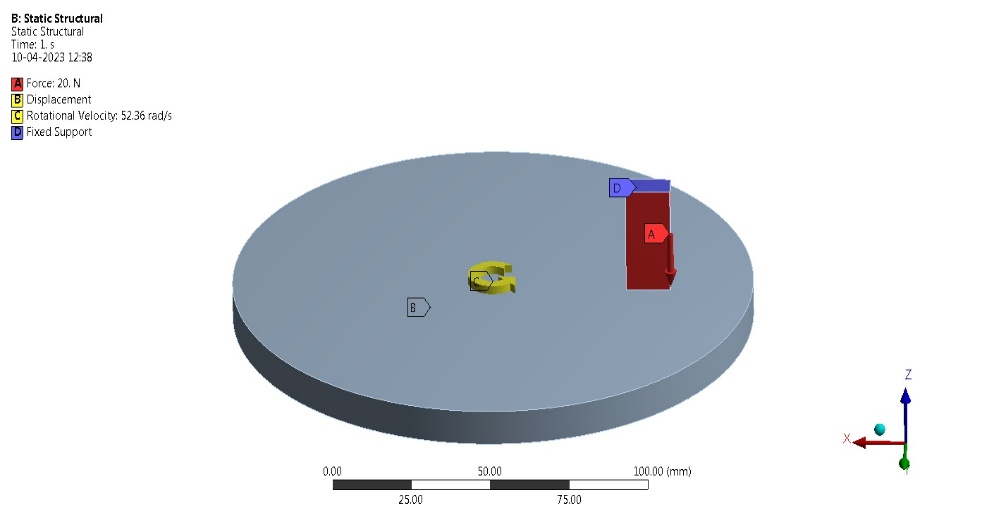
Carbon Nanotubes (CNTs) are cylindrical carbon-based nanostructures with diameters measured at the nanoscale. To enhance the mechanical performance of composite materials, Multi-Walled Carbon Nanotubes (MWCNTs) are incorporated into AS Carbon and HMS Carbon Epoxy, both part of the Carbon Fiber Reinforced Polymer (CFRP) family. In this study, epoxy resin is modified with a 5% MWCNT addition, and specimens are fabricated following standardized testing protocols. The composite system comprises 60% carbon fiber as the primary reinforcement and 40% epoxy resin with hardener as the matrix. During the fabrication process, the carbon fiber piles are placed onto a foil base, impregnated with resin, and layered continuously to form the composite structure. The Pin-on-Disc (POD) test, a widely recognized method in engineering, is used to evaluate the frictional behavior and wear rate of the materials. In the POD setup, standardized specimens are mounted in a pin holder, subjected to an applied load through the testing machine’s loading arm, and tested against a rotating disc at 700 RPM. The wear rate and friction coefficient are quantified using load cells and strain gauges. Specimens are designed according to ASTM G99 standards, with typical dimensions being 10 mm in diameter and 30 mm in length, although variations such as 6 mm by 10 mm have also been analyzed [1–3].

Material performance is highly influenced by the composition of its core components. This study employs carbon fiber and epoxy resin as the reinforcement and matrix, respectively. Both Single-Walled Carbon Nanotubes (SWCNTs) and MWCNTs are used in comparative analyses, with compositional variation introduced at the mixing stage. Eight different reinforcement volume fractions are analyzed to evaluate the mechanical response of MWCNTs. Fibers play a vital role in bearing loads in composite materials, contributing significantly to their high stiffness-to-weight ratios. Accurate assessment of fiber orientation—whether unidirectional, bidirectional, or multidirectional—is essential for understanding mechanical behavior [4–6]. Fiber materials can vary and include carbon, glass, and boron. The matrix’s primary role is to prevent delamination and to ensure mechanical bonding. The longevity and structural efficiency of composite laminates depend on the chemical interaction between the fibers and the matrix. Therefore, selecting a matrix that complements the reinforcement is crucial [4–6]. Among available matrices, epoxy resin stands out due to its superior compatibility and reliability across all fiber types, making it the preferred choice.

Finite Element Analysis (FEA) is utilized to simulate the mechanical behavior of CNT-reinforced polymer composites. The current study’s FEA framework, including material property definitions, mesh configurations, and composite element details, is thoroughly validated [6]. A hybrid laminate comprising MWCNTs, epoxy resin, carbon fiber, and Kevlar fiber is also evaluated. Both FEA and experimental testing are conducted to examine the structural performance of the hybrid configuration [7]. MWCNTs serve as the focal point of this comparative analysis. The study explores their integration into composites, associated modeling techniques, and their mechanical contributions. It also addresses challenges in nanocomposite fabrication, particularly issues related to load transfer and dispersion. The impact of MWCNT content, matrix selection, manufacturing methods, and environmental conditions is extensively analyzed [7–9]. Moreover, the effect of CNT agglomeration on the reinforcement-matrix interface and the associated degradation in material properties is investigated [10–12]. In addition to composite analysis, the author conducted a finite element investigation into the mechanical performance of six different composite disc specimens under rotational loading [2, 53-65]. A novel disc brake system tailored for long-range Unmanned Aerial Vehicles (UAVs) was also proposed, demonstrating the potential of CNT-reinforced composites in aerospace applications [13–15].

## IMPOSED METHODOLOGY – COMPUTATIONAL APPROACH

To conduct the wear test, a pin is pressed against a rotating disc, and the resulting frictional forces generated between the contact surfaces are measured [16–18]. In this study, appropriate boundary conditions have been applied to the simulation model, including the assignment of a rotational speed of 700 RPM to the disc under an applied normal load of 20 N [19–21]. The disc is fixed to rotate against the stationary pin, simulating the typical POD wear testing setup. Figure 1 illustrates the computational model along with the corresponding loading conditions [22–26]. For accurate numerical simulation in ANSYS, a three-dimensional model of the POD test setup must be constructed. The precision of the results significantly depends on the correct selection of element types and the mesh density [27-31]. Figure 2 presents the discretized geometry of the wear test specimens [66-71].



1. Boundary condition of pin on disc test

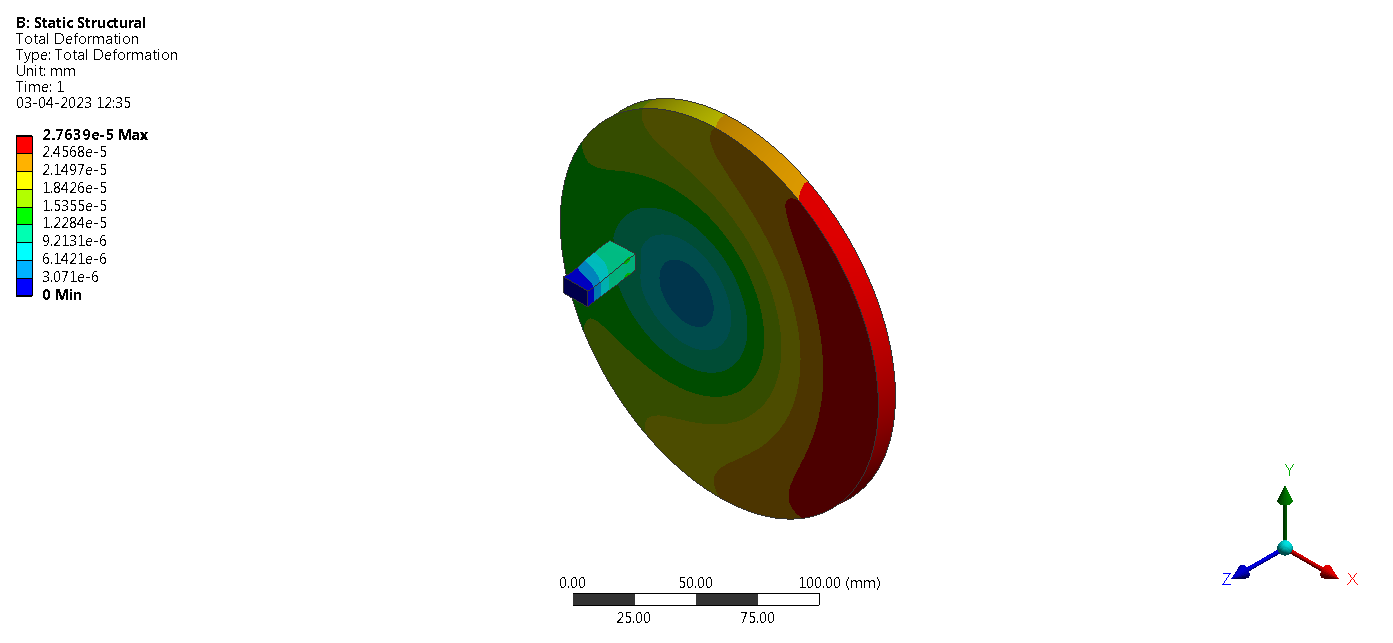
A close-up of a fingerprint

Description automatically generated

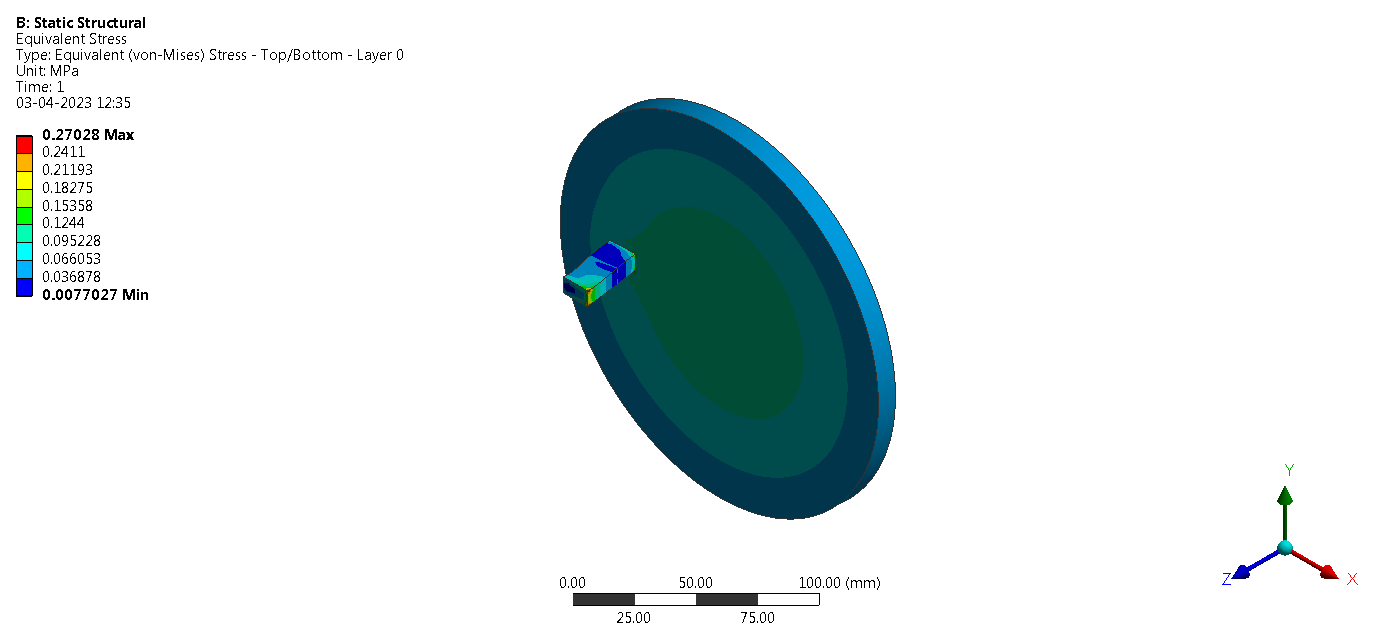
1. Discretization image of pin on disc test

## RESULTS AND DISCUSSIONS

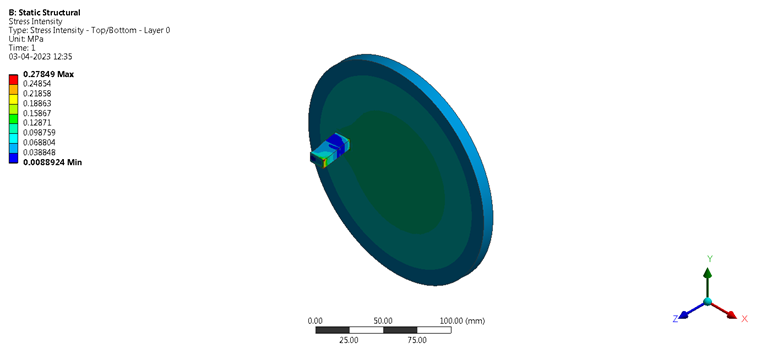
Figure 3 illustrates the total deformation in AS Carbon Epoxy integrated with MWCNTs under a frictional load at 700 RPM.



1. Computational analysis of Total deformation of AS Carbon Epoxy material



1. Computational analysis of equivalent stress of AS Carbon Epoxy material



1. Computational analysis of stress intensity of AS Carbon Epoxy material

Figures 4 and 5 demonstrate that the AS carbon composite exhibits the lowest equivalent stress and minimal stress intensity among the materials tested [30-39]. Further analysis, as shown in Figures 6 to 8, reveals that AS carbon epoxy material withstands higher frictional loads at a rotational speed of 700 RPM compared to other carbon fiber-reinforced composites under identical conditions [40-52].

1. Comprehensive report of total deformation of various carbon fibre composites in 700 RPM associated with MWCNTs
2. Comprehensive report of equivalent stress of various carbon fibre composites in 700 RPM associated with MWCNTs
3. Comprehensive report of stress intensity of various carbon fibre composites in 700 RPM associated with MWCNTs

## CONCLUSION

The essential requirements for this evaluation are equivalent stress, total deformation and stress intensity, which guided the material selection process. The validation indicates that the AS Carbon with MWCNTs employed in this study is more suitable and dependable for addressing friction-based composite issues. Various nanocomposites are evaluated by a pin-on-disc friction test, and it yields 25% for equivalent stress, 87% for total deformation, and 33% for stress intensity less when compared to other carbon fiber materials. The various types of composites containing MWCNTs are evaluated at 700 RPM with a load of 20 N. Among these various composites, AS Carbon Epoxy combined with MWCNTs exhibited the lowest wear rate.

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