Delamination Analysis in Composite Drilling Using CAD/CAM Simulation

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***Abstract*—Glass Fiber Reinforced Polymer (GFRP) composites are widely used in aerospace, automotive, marine, and structural applications due to their high strength-to-weight ratio, corrosion resistance, and excellent mechanical properties. However, drilling operations often cause defects such as delamination, fiber pull-out, and matrix cracking, which reduce component quality and performance. This study investigates delamination behavior during drilling of an 8-ply GFRP laminate using CAD/CAM simulation and Finite Element Analysis (FEA). A 2 mm thick laminate with [0/90/0/90] s fiber orientation was modeled and drilled using a 6 mm solid carbide twist drill. The effects of spindle speed (1000–3000 rpm) and feed rate (0.05–0.15 mm/rev) on thrust force, stress distribution, deformation, and delamination were analyzed using ANSYS Explicit Dynamics. Results indicate that higher feed rates increase thrust force and delamination, while suitable spindle speeds improve hole quality. The study identifies optimal drilling parameters for minimizing damage and enhancing machining performance in GFRP composites.**

***Index Terms*—GFRP Composite, Delamination, Composite Drilling, CAD/CAM Simulation, Finite Element Analysis, ANSYS Explicit Dynamics, Spindle Speed, Feed Rate, Hole Quality, Twist Drill.**

I. INTRODUCTION

Composite materials are widely used in aerospace, automotive, marine, and structural applications because of their high strength-to-weight ratio, corrosion resistance, and durability [7]. Drilling is one of the most common machining operations performed on composite laminates for assembly purposes [3]. However, drilling often causes defects such as delamination, fiber pull-out, and matrix cracking, which reduce the mechanical performance and service life of composite structures [8]. Delamination is considered the most critical damage during drilling. Therefore, understanding and minimizing drilling-induced delamination is essential [1]. CAD/CAM modeling and Finite Element Analysis (FEA) provide effective tools for analyzing drilling behavior and optimizing machining parameters [10].

II. REVIEW OF LITERATURE

Geier et al. (2017) presented a detailed review of finite element methods (FEM) for machining composite materials. The study focused on the application of FEM in drilling, milling, trimming, and turning operations of composite laminates. The authors reported that finite element simulations provide valuable insights into stress distribution, crack initiation, and delamination propagation during drilling.

Liu et al. (2019) reviewed the mechanisms, evaluation methods, and suppression strategies of drilling-induced delamination in composite laminates. The study examined various factors influencing delamination, including drill geometry, feed rate, spindle speed, and material properties. The authors highlighted that advanced CAD/CAM simulation techniques enable virtual analysis of drilling processes and help identify optimal drilling conditions before manufacturing.

Patel and Chaudhary (2021) conducted a comprehensive review on delamination evaluation in drilling of composite materials. The study highlighted that drilling-induced delamination is one of the most critical defects affecting the structural integrity of Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) composites.

III. METHODOLOGY

3.1 Introduction

In this chapter, we describe the materials, laminate design, drill tool specs, machining parameters, CAD/CAM modeling technique, and finite element methods that were used for delamination analysis in drilling of GFRP composites.

Table 3.1 Mechanical and Physical Properties of GFRP Composite

Property	Typical Value
Density	1.8–2.0 g/cm³
Tensile Strength	300–900 MPa
Compressive Strength	250–600 MPa
Flexural Strength	400–1000 MPa
Elastic Modulus	20–45 GPa
Poisson's Ratio	0.22–0.30
Interlaminar Shear Strength	20–50 MPa

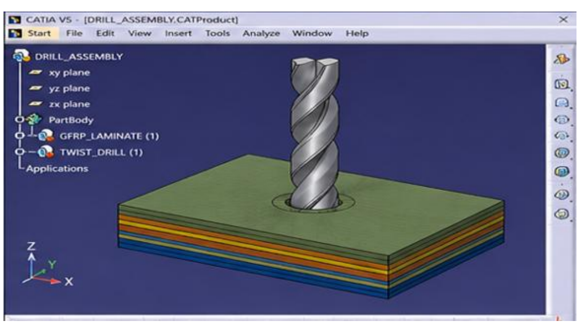

Figure 3.1: Isometric View of Drill and GFRP Laminate Assembly in CATIA V5

The figure 3.1 shows the CATIA V5 assembly model of a solid carbide twist drill positioned on a GFRP laminate workpiece. The model represents the drilling setup used for machining studies, where the drill interacts with the composite laminate to create holes. This assembly is utilized for analyzing drilling performance, tool behavior, and damage characteristics in GFRP composite materials.

IV. FINITE ELEMENT MODELING AND ANALYSIS

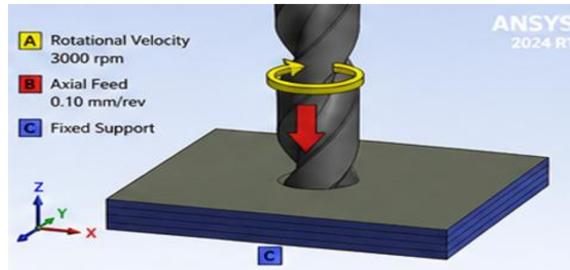

Figure 4.1: Boundary Conditions and Loading Applied to the Drill and GFRP Laminate in ANSYS

The figure 4.1 illustrates the boundary conditions and loading applied during the finite element simulation of drilling a GFRP (Glass Fiber Reinforced Polymer) laminate in ANSYS 2024 R1.

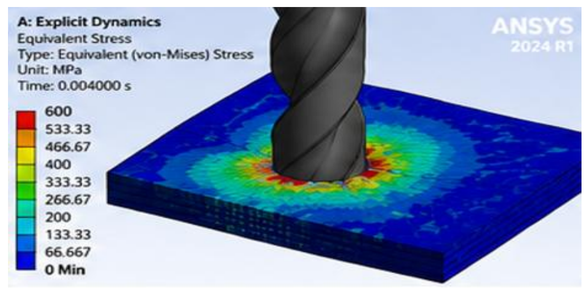

Figure 4.2: Von-Mises Stress Distribution in GFRP Laminate During Drilling Simulation

The figure4.2 shows the equivalent (von-Mises) stress distribution in the GFRP laminate during the drilling process obtained through ANSYS Explicit Dynamics analysis. The maximum stress is concentrated around the drill–workpiece contact region, reaching values up to 600 MPa, while the stress decreases away from the hole area. This result helps evaluate the material response, damage initiation, and structural integrity of the composite laminate during drilling.

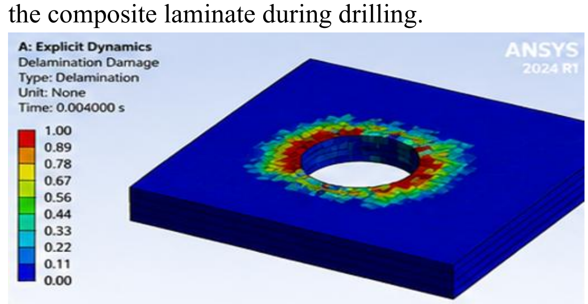

Figure 4.3: Delamination Damage Distribution in GFRP Laminate During Drilling Simulation Showing Peel-up and Push-out Delamination in ANSYS 2024 R1.

The figure 4.3 shows the delamination damage distribution in the GFRP laminate after the drilling operation obtained from ANSYS Explicit Dynamics analysis. Higher delamination damage is observed around the hole boundary, with damage values approaching 1.0, indicating severe interlayer separation in that region. This result is used to evaluate hole quality and the extent of drilling-induced damage in the composite laminate.

V. RESULTS AND DISCUSSION

This section details the results of the ANSYS Explicit Dynamics finite element model of drilling Glass Fiber Reinforced Polymer (GFRP) laminates. An extensive analysis is conducted into the relationship between spindle speed and feed rate and thrust force, stress distribution, deformation, and delamination behavior. A 6 mm solid carbide twist drill was used to conduct the drilling simulations under different machining conditions. Researching the relationship between cutting parameters and drilling-induced damage in composite laminates may be aided by the results of simulations.

Table 5 Simulation Parameters

Parameter	Value
Composite Material	GFRP
Laminate Thickness	2 mm
Number of Plies	8
Drill Diameter	6 mm
Drill Material	Solid Carbide
Point Angle	118°
Helix Angle	30°
Cooling Condition	Dry Drilling
Analysis Type	Explicit Dynamic

VI. CONCLUSION

- This study analyzed delamination in GFRP composite drilling using CAD/CAM modeling and Finite Element Analysis (FEA).
- The results showed that feed rate and spindle speed significantly influence thrust force, stress distribution, deformation, and delamination.
- Higher feed rates increased thrust force and drilling damage, while appropriate spindle speeds improved hole quality and reduced delamination.
- The simulation successfully predicted drilling behavior and helped identify optimal machining conditions.
- The best results were obtained at a spindle speed of 3000 rpm and a feed rate of 0.05 mm/rev using a 6 mm solid carbide drill.
- These parameters minimized delamination and improved hole quality. Overall, CAD/CAM simulation proved to be an effective and economical tool for analyzing composite drilling operations.

FUTURE SCOPE

Future research can focus on the drilling analysis of different composite materials such as CFRP and hybrid composites.
Advanced damage models and Artificial Intelligence techniques can be integrated with FEA to improve delamination prediction accuracy.
Experimental validation of simulation results can also be carried out for better reliability. Further studies may investigate the effects of different drill geometries, cooling techniques, and machining conditions to achieve higher drilling performance and reduced composite damage.

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