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Experimental Investigation of Delamination on Functionalized Nano Tubes Reinforced Carbon/Epoxy Composites During Varied Drilling Point Angles and Its Study by Comparing Infrared Thermography and Digital Microscope

Bhanu Murthy Soppari[1,2*], Kishore Nath Nayani[3] and Ramesh Babu Poosa[1]

[1]*Department of Mechanical Engineering, Osmania University, Hyderabad, Telangana, India*
[2]*Department of Mechanical Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, Telangana, India*
[3]*Advanced Systems Laboratory, DRDO, Hyderabad, Telangana, India*

***Correspondence to:**
Bhanu Murthy Soppari
Department of Mechanical Engineering,
Osmania University,
Hyderabad, Telangana, India.

Department of Mechanical Engineering,
VNR Vignana Jyothi Institute of
Engineering and Technology,
Hyderabad, Telangana, India.
E-mail: sopparibhanumurthy@gmail.com

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Abstract

The delamination at hole entrance surface has a significant impact on the strength and stiffness property of material on delamination factor calculation methods used by Chenand Davim. Delamination frequently happens around the holes in drilling even though interlaminar strength is good. In this study, the drilling of functionalised amine based multi-wall carbon nano tubes (MWCNTs) carbon fiber laminate composite was examined for hole quality by three different point angles as one major parameter. Numerous drilling operations need to performfor assembly of carbon-fiber-reinforced-plastic (CFRP) in aircraft parts. Drilling carried out with Design-of-Experiment (DOE) from Taguchi based on the feeding rate, cutting parameter, and point angle as L_{27} Orthogonal array. The impact of machining quality on stiffness degradation was further examinedby NDT (Non-Destructive Testing) i.e., infrared thermography and digital microscope in which cutting speed 1000 rpm, feed rate 20 mm/sand point angle 118º interpreted the values as minimum delamination in both the NDT observations and are plotted the same using Python programming.

Keywords

Functionalized amine multi-wall carbon nano tubes, Carbon fiber, Drilling, Delamination, Infrared thermography, Digital microscope, Python

Introduction

Mainly focused on Infrared thermography to evaluate composite materials are being employed more and more in the aerospace, marine, automotive, and other industries since they have high specific strengths and stiffness. Multiple forms of defects, including voids, inclusions, delamination's, dis-bonds, resin-rich, resin-starved zones, etc., may be present in the finished product due to the inherent complexity of manufacturing composite structures [1]. CFRP is frequently employed in airplane constructions to reduce fuel consumption, CO_2 emissions and due to its light weight, strong and resistant to corrosion. Even though CFRP's large-scale components are made. An enormous amount of drilling is done during assembly operation to meet the required dimensional tolerance [2]. It has been suggested to utilize a varying feed drilling technique to reduce delamination, which is a result of the negative force when drilling CFRP on back (supporting) of workpiece plate. To adjust the feed there are two stages that must be taken: first, a low or regular feed rate must be used. Second, is increased greater than previous by speeding up drill until it produces a negative thrust and cuts with lips at a significant explicit rake angle as it departs the workpiece plate. When it comes to production management, high feed-rate encourages the machining [3]. A new delamination measurement technique was created using the idea of image

differentiation. The approach is properly laid out, making it possible to use it immediately and post-process it for different situations. Contrary to CT- or X-ray-based technologies, the proposed method does not call for complicated equipment, making it simple and affordable to apply in the business [4]. To evaluate the viability of defect detection using thermography and PET NDT techniques, a variety of faults were inserted into the laminate. It was shown that some faults could be found using either technique, but others were missed by both. There were several flaws that only one technique could discover. Both procedures are proven to be equally effective for clear air defects [5]. The uncoated tool produced the least delamination damage when drilling CARALL composite when the coating qualities were investigated; nevertheless, as the feed rate and force rose, the degree of delamination increased. The delamination factor showed no linear relationship with cutting speed [6]. To check for hole entry damages in drilling, drilled hole quality evaluation based on 2D digital image processing with segmentation extended feature identification is assessed. Results from a 3D microscope are evaluated using a robustness camera. The evaluation procedure altered the duration by a factor of 60 with at least 67% of a 3D measuring correctness [7, 8]. Investigated delamination of composite laminate with various cutting parameters under varying percentage of MWCNTs designed for DOE L_{27} orthogonal array in ANOVA extended the machining process further for hole quality inspection using thermography technique concluded with the delamination reduces with proper interlaminar bonding between the lamina to lamina (ply to ply) at the reinforcement process [9]. To achieve a very high machining rate with no delamination, a novel drilling technique was proposed. The torques, tensions, and friction along the uncut chip were measured using orthogonal drilling procedures. Even at the 100th drilling, compared to constant feed drilling, summed variable feed in drilling unexpectedly controls the delamination factor [10].

Drilling CFRP laminate, there are changes in the thrust along with torque at entrance and exit. Average thrust force and delamination factor is also examined while drilling multidirectional and unidirectional laminates using high-speed steel and carbide drills. Parts used in aeroplane fabricated using composites are shown in figure 1. Unidirectional CFRP composite laminates can be drilled with a carbide drill [11, 12].

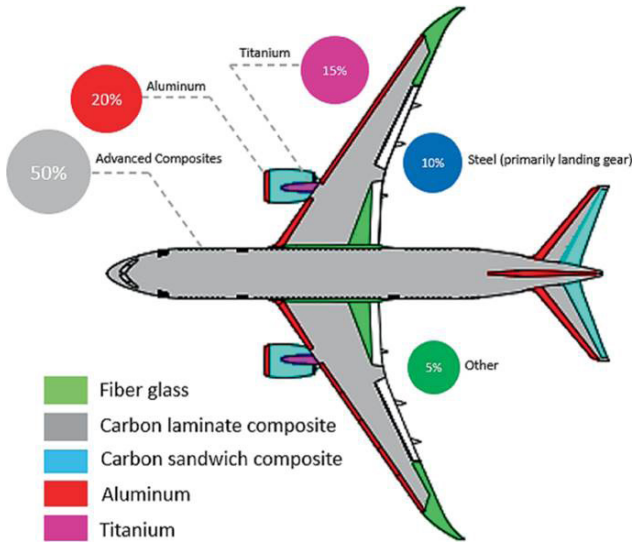


Figure 1: Composite parts in aeroplane [12].

Experimentation

Materials

The T700SC-12K-50C carbon fiber no twist is bought from "Toray Advanced Materials Korea Inc." "Amine [NH_2] functionalized MWCNTs" group is bought from Ad-Nano Technologies Private Limited (Karnataka, India), which is produced through "Chemical-Vapor-Deposition" technique functionalized. Araldite® LY-556 is an epoxy resin and hardener HY-951 hardener HY-951:1 from Huntsman Advanced Material (Mumbai, India). The properties tabulated in table 1 and the methodology of fabrication is shown in figure 2.

Delamination

CFRP composites were damaged during drilling in the form of pushing (exit side) and peeling (entrance side) respectively during of the hole are shown in figure 3.

Table 1: Material properties.

Product	Properties	Make
Materials - Carbon fiber	Tensile strength - 5150 MPa	Toray Advanced Materials Korea Inc.
	Elongation % - 2.2	
	Density (10^3 kg/m^3) - 1.79	
	Twist - No twist	
	Tensile modulus (GPa) - 234	
Araldite® LY 556	Viscosity at 25 °C - 80 - 125 (mPa.s)	Huntsman Advanced Materials, Mumbai.
	Density at 25 °C - 0.99 - 1.02 (g/cm^3)	
Hardener HY 951	Density = 0.95 gm/cm^3	
	Melting point = 120 C (lit.)	
	Boiling point = 266 - 267 °C (lit.)	
Amine [NH_2] group functionalized multi-wall carbon nanotubes. (ADMWCNT-NH_2)	Diameter ~5 - 15 nm	Ad Nano Technologies Shimoga, Karnataka, India
	Length ~10 µm	
	NH_2 ratio ~2-5%	
	Purity ~99%	

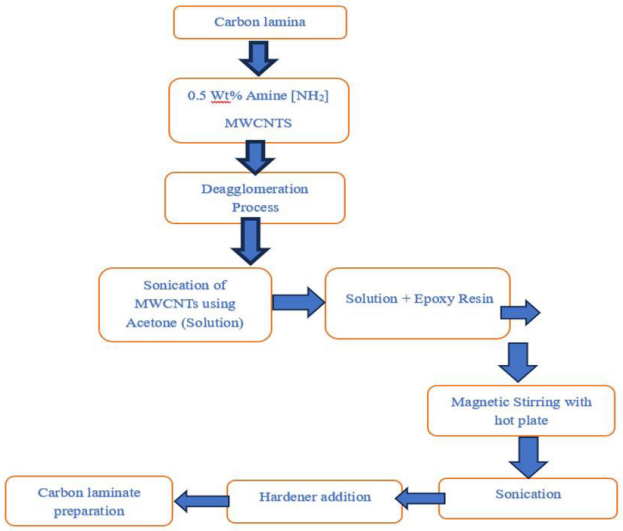


Figure 2: Flow chart preparation process of carbon fiber laminates.

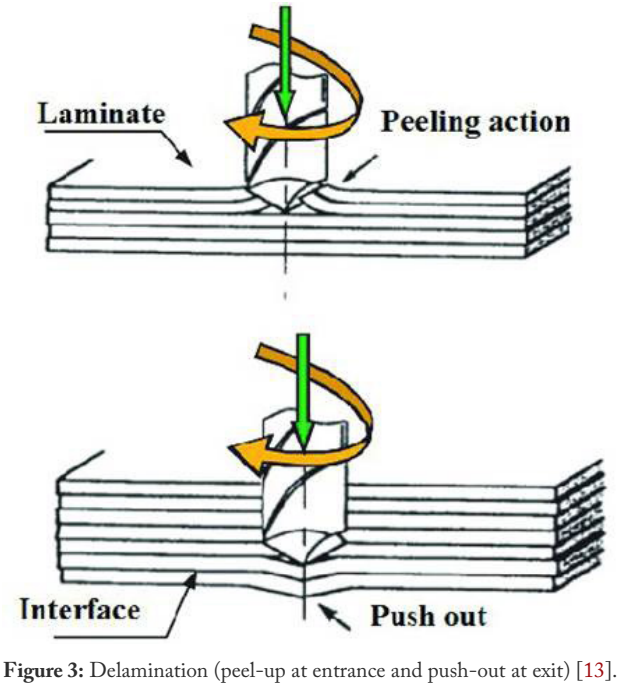


Figure 3: Delamination (peel-up at entrance and push-out at exit) [13].

Peel-up

As drill reaches the laminate, peel-up delamination begins to happen. Due to the cutting force occurring in the perimeter once the drills cutting-edge contacts the laminate, a peel-up delamination happens. Friction between the tool and the work piece as well as the tool's form, determine the peeling force.

Push-out

As the drill enters the material's exit side, delamination that pushes out takes place. The thickness that is still uncut and the resistance to deformation both decline as the drill nears its conclusion.

The tool finally pushes through the exit side, and as it does, an exit delamination zone forms because the thrust force is greater than the inter-laminar bond strength. This occurs shortly before the drill completely penetrates the lamination.

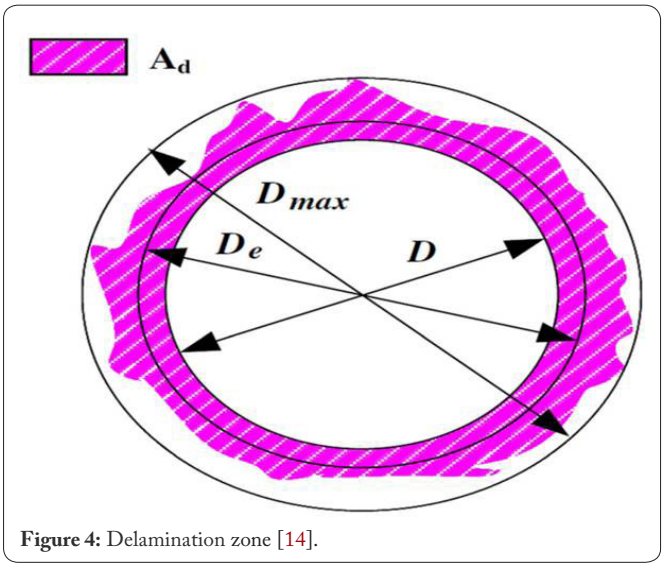


Figure 4: Delamination zone [14].

The thrust force can be reduced using a variety of drill geometries and cutting conditions to reduce push-out delamination. The absolute hole diameter in the damage zone can be used to calculate the degree of delamination. Delamination factor is provided to assess, and it is simple to compare the delamination degree with varied cutting circumstances and workpiece materials. The delamination factor (Fa) is defined as follows.

$$F_a = \frac{D_{\max}}{D} \quad (1)$$

Where, D_{max} is the absolute diameter of drilledzone, D is nominal diameter; F_a is delamination-factor [13].

The delamination factor (F_{da}) shown in figure 4, a unique method developed and is suggested to quantify the delamination factor. The conventional F_d, in equation 2's first half stands for the second section, it appears how much the damage area and the size of the crack affected.

$$F_{da} = F_d + \frac{A_d}{A_{\max} - A_0}\left(F_d^2 - F_d\right) \quad (2)$$

i.e., A_{max} is maximum diameter of delamination zone (D_{max}). A_0 is nominal hole (D_0).

Drilling

Drilling setup for CFRP-Amine (0.5 wt.%) laminate employed vertical machining centre (VMC) machine shown in figure 5 and critical parameters considered are tabulated in table 2. L_{27} holes are drilled according to the DO) shown in table 3 while maintaining the fiber orientation. Solid carbide twist drills with various point angles (85°, 118°, and 135°) of diameter 6 mm are employed during dry environment throughout the process. Repeatability of VMC has 0.012 mm.

Results and Discussion

Drilling operation performed on 0.5 wt.% Amine based carbon laminate using (DOE) L_{27} developed in Taguchi and the circularity of nominal diameter has verified using NDT techniques (Infrared thermography and digital microscope).

Using an external energy source and an infrared detector, infrared thermography is 2D, non-contact method that enables surface temperature mapping by producing colourful images that are simple to understand. In this work, the benefit of active thermographyfor the non-destructive assessment of drilled material investigates and compares the same by digital microscope of 50x using Dewinter-Biowizard 4.5 version software to analyse hole diameter with standard (base diameter) photographs (drilled holes) with a G2 mark "RE-50X" microscope images shown in figure 6 and figure 7, respectively. The output values of both NDT are considered as the input for Python for developing the interpretation of F_d vs all other critical parameters like (cutting speed, feed rate, and point angle) and are as shown in figure 8. The values obtained from thermography and microscope are evaluated for as per the delamination factor with cutting speed, feed rate, and point angle which in turn cleared showed the values approximately with slight deviation and are shown in figure 9, figure 10, and figure 11, respectively.

Conclusions

Delamination analysis of 0.5 wt.% functionalized amine MWCNTs reinforced carbon fiber laminate used for drilling operation to evaluate the effect of delamination and its responses based on varying point angles along with critical parameters considered to be and investigated for the delam-



Figure 5: VMC (BMV60 + TC24 (mm).

Table 2: Experimental parameters.

Experiment	Cutting speed (rpm)	Feed rate (mm/s)	Point angle (°)
1	500	10	85
2	500	10	85
3	500	10	85
4	500	15	118
5	500	15	118
6	500	15	118
7	500	20	135
8	500	20	135
9	500	20	135
10	750	10	118
11	750	10	118
12	750	10	118
13	750	15	135
14	750	15	135
15	750	15	135
16	750	20	85
17	750	20	85
18	750	20	85
19	1000	10	135
20	1000	10	135
21	1000	10	135
22	1000	15	85
23	1000	15	85
24	1000	15	85
25	1000	20	118
26	1000	20	118
27	1000	20	118

Table 3: DOE (L_{27}) Orthogonal array.

Factor	Level 1	Level 2	Level 3
Cutting speed (rpm)	500	750	1000
Feed rate (mm/s)	10	15	20
Point angle (°)	85	118	135
Tool	Solid carbide twist drill		



Figure 6: Delamination at peeling (entrance) microscope image.

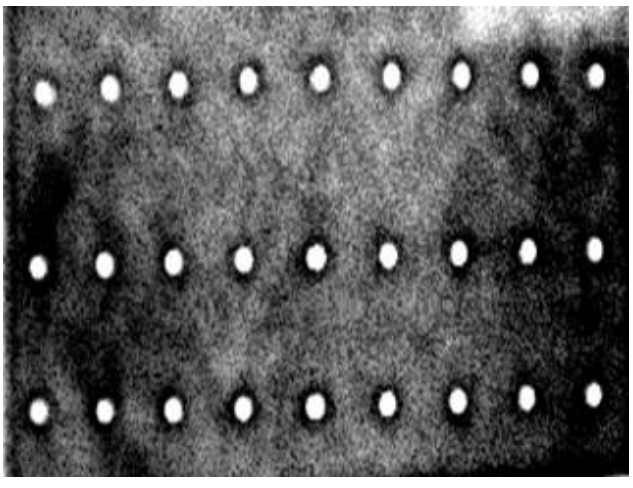


Figure 7: Delamination at peeling (entrance) thermography image.

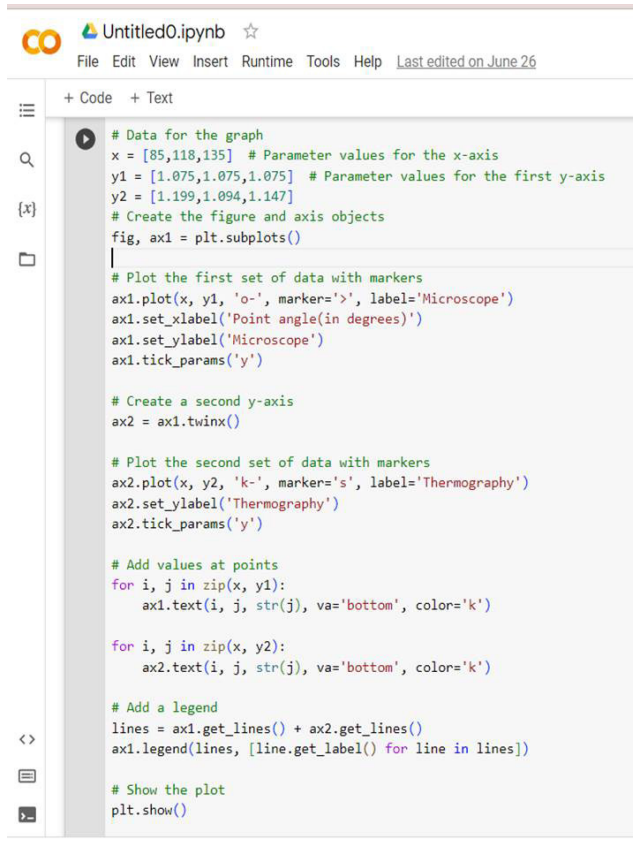


Figure 8: Code for interpretation of delamination factor vs critical parameters.

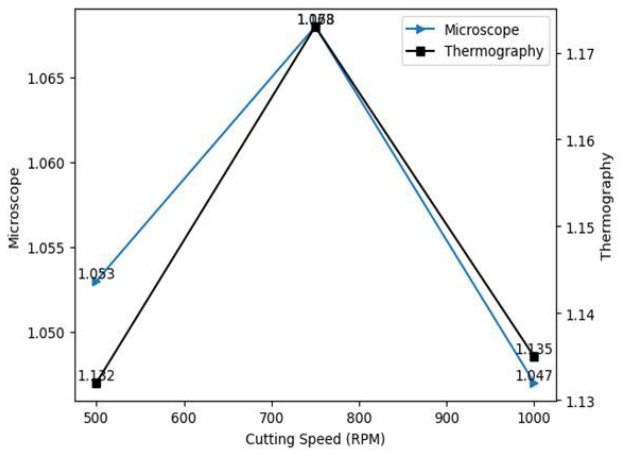


Figure 9: Delamination factor vs cutting speed.

ination factor f_d and are as follows:

- It was found that some faults were found by both. There were several flaws that only one technique could discover.
- From the results based on digital microscope the smallest delamination factor F_d is shown at cutting speeds of 1000 rpm, 20 mm/s, and a drill with a 118° tip angle.
- From thermographic based analysis it clearly shows the minimum delamination at 500 rpm, 10 mm/s and 118° @ cutting speed, feed rate and tip angle, respectively.
- Based on the comparison of drilled laminate inspected by two different NDT techniques it is evident that digital microscope has limitation compared to infrared thermography and digital microscope has its own advantages like inspecting surface area and so, but interlaminar defects may be done accurately using infrared thermography according to his work as per the results.

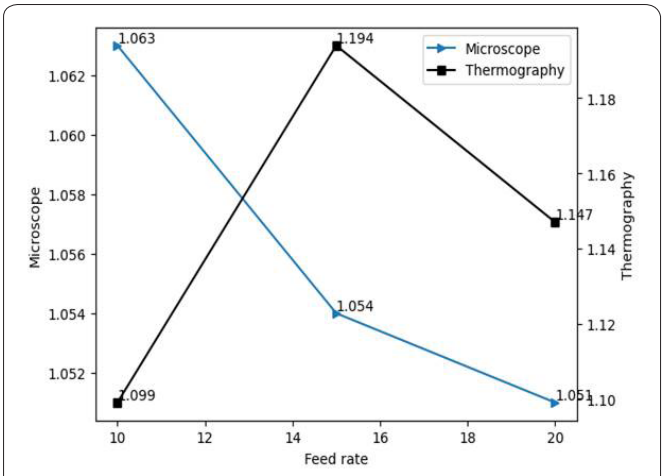


Figure 10: Delamination factor vs feed rate.

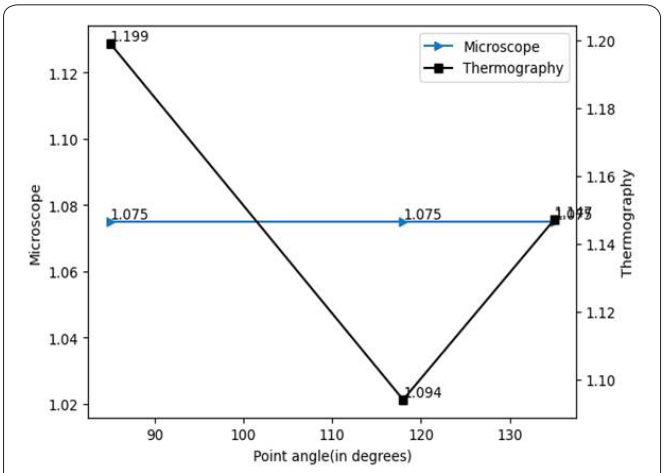


Figure 11: Delamination factor vs point angle.

Acknowledgements

None.

Conflict of Interest

None.

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