

Multi Objective Optimisation in Drilling of Composites

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Abstract— Composite laminates (CFRP, GFRP, and fiber metal composite laminates) are attractive for many applications (such as aerospace and aircraft structural components) due to their superior properties. Usually, mechanical drilling operation is an important final machining process for components made of composite laminates. However, composite laminates are regarded as hard-to-machine materials, which results in low drilling efficiency and undesirable drilling-induced delamination. Therefore, it is desirable to improve the cost-effectiveness of currently-available drilling processes and to develop more advanced drilling processes for composite laminates. Such improvement and development will benefit from a comprehensive literature review on drilling of composite laminates. This review paper summarizes the progress in mechanical drilling of composite laminates reported in the literature. It covers drilling operations in conventional drilling and high speed drilling, drill bit geometry and materials, drilling-induced delamination and its suppressing approaches, thrust force, and tool wear. It is intended to select appropriate parameters for the experimentation on CFRP using conventional drilling method, to reduce delamination effect and for multi-objective optimization using ANN.

Keywords—CFRP, Delamination, prepreg, conventional drilling, carbide drill tool.

I. INTRODUCTION

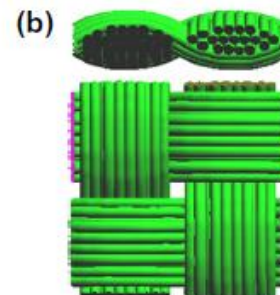
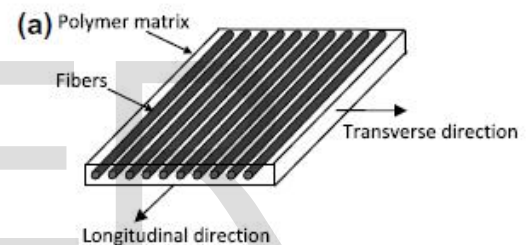
There is an increasing demand in a variety of industries such as aircraft, spacecraft, automobile, marine, chemical processing equipment, and sporting goods for high-performance, lightweight structures which has stimulated a strong expanding development of fiber reinforced polymer composite laminates. Fiber reinforced composite laminates commonly used in industries mainly include CFRP (Carbon Fiber Reinforced Polymer) composite, GFRP (Glass Fiber Reinforced Polymer) composite, and fiber metal composite laminates (FMLs). Owing to their considerable advantages, they are being used to replace conventional metallic materials in a wide range of industries including aerospace, aircraft, and defense, which require structural materials with superior properties such as high strength-to-weight and stiffness-to-weight ratios.

A. Characteristics and applications of composite laminates

CFRP and GFRP composite laminates are by far the most commonly fiber reinforced composite materials used in many industries in view of their high mechanical properties. They are formed by the combination of fibers (carbon or glass) and polymer matrix.

Fibers are lightweight, stiff, and strong, which provide most of stiffness and strength of the composite laminates. The

polymer matrix binds the fibers together thus transferring load to reinforced fibers, and providing protection from environmental attack to fibers. Thermoset and thermoplastic are two kind of polymer matrix materials used most commonly. Thermoplastic polymers, however, are available which combine better mechanical properties, environmental resistance, temperature performance and process ability. Fibers are often used as continuous reinforcements in unidirectional (UD) or bidirectional (woven) forms by aligning a large number of them in a thin plate, called prepreg ply, which thickness is about 0.15 mm. A unidirectional fiber orientation prepreg ply (UD-ply, shown in Fig. 1a) has maximum stiffness and strength along the fiber direction and minimum properties in a direction perpendicular to fibers, called anisotropic material. However, a



Ply No.	Orientation angle
1-6	0
7-12	45
13-18	90
19-24	-45
25-30	-45
31-36	90
37-42	45
43-48	0

Fig. 2. A typical quasi-isotropic laying-up sequence of a unidirectional-ply FRP composite laminate (after [11,12]).

bidirectional fiber orientations prepreg ply (woven-ply, shown in Fig. 1b) almost has maximum stiffness and strength along every direction. A fiber reinforced polymer composite laminate is usually made by bonding many prepreg plies together to obtain excellent properties.

Consequently, UD-plyies are laid-up at different fiber orientations (cross-ply) to manufacture quasi-isotropic composite laminate Fig. 2 shows a typical quasi-isotropic laying-up sequence of a FRP composite laminate made up of a number of identical UD-plyies.

B. Carbon Fibre Reinforced Plastic

CFRPs are composite materials. In this case the composite consists of two parts: a matrix and a reinforcement. In CFRP the reinforcement is carbon fiber, which provides the strength. The matrix is usually a polymer resin, such as epoxy, to bind the reinforcements together. The reinforcement will give the CFRP its strength and rigidity; measured by stress and elastic modulus respectively. Unlike isotropic materials like steel and aluminum, CFRP has directional strength properties. The properties of CFRP depend on the layouts of the carbon fiber and the proportion of the carbon fibers relative to the polymer. There is no technology that can help automakers reach their lightweight goals faster than carbon fiber-reinforced plastics. Long used in Formula 1 racing and other extreme sports, carbon composites are unparalleled in their ability to reduce mass, facilitate sleek, aerodynamic shapes, reduce tooling investment, eliminate corrosion and denting, improve sound damping and vibration, and protect occupants even in high-speed crashes. Carbon fiber's main attraction is its strength-to-weight ratio, which is 20 percent the mass of steel yet equally stiff and strong. Replacing today's steel body-in-white (BIW) with an integrated carbon-composite structure could net up to a 60 percent mass reduction, boosting fuel efficiency by as much as 30 percent via mass decompounding: A lighter vehicle body makes it possible to reduce the cost and robustness of everything from hardware to brakes to engines with no loss in performance. Safety is clearly a concern, especially in small cars. Composites offer the highest specific-energy absorption of all major structural materials. CFRP crush cones and similar energy-absorbing structures can absorb ~120 kJ/kg of energy if made with a thermoset matrix (e.g., epoxy) or ~250 kJ/kg in a thermoplastic matrix vs. ~20 kJ/kg for steel. Although CFRP can offer 50 to 60 percent mass reduction vs. similar components in steel, the cost is 2 to 10 times higher when both materials and processing costs are considered. Glass-reinforced composites reduce mass by 25 to 35 percent at costs on par with or slightly higher (1.5 times) than steel: magnesium offers a 60 to 75 percent mass reduction at 1.5 to 2.5 times greater cost and aluminum reduces mass by 40 to 60 percent at 1.3 to 2 times higher cost. These are not inconsequential differences. Unfortunately, 51 percent of the cost of carbon fiber is directly tied to the cost of polyacrylonitrile (PAN), rayon, and petroleum pitch precursors. That, in turn, is tied to the cost of oil.

For building components joining composite laminates to other metal materials structures is necessary, and this can be done only by means of bolted and riveted joints. Bolt joining

efficiency and quality depend critically on the quality of machined holes. Various drilling processes are extensively used for producing riveted and bolted joints during assembly operation of composite laminates with other components. For rivets and bolted joints, damaged-free and precise holes must be drilled in the components to ensure high joint strength and precision. However, some special characteristics of composite laminates such as non-homogeneous, anisotropic, and highly abrasive and hard reinforced fibers, result in them difficult to machine. Several undesirable damages (such as delamination, and fiber pull-out) induced by drilling drastically reduce strength against fatigue, thus degrading the long-term performance of composite laminate.

Delamination is considered the major damage. Therefore, any drilling-induced delamination that results in the components rejected represents an expensive loss since drilling is often a final machining operation during assembly of components made of composite laminates. To increase drilling efficiency of composite laminates with the least waste and damages, it is essential to understand the drilling behavior by conducting largenumber of drilling experiments and by establishing of drilling models of composite laminates.

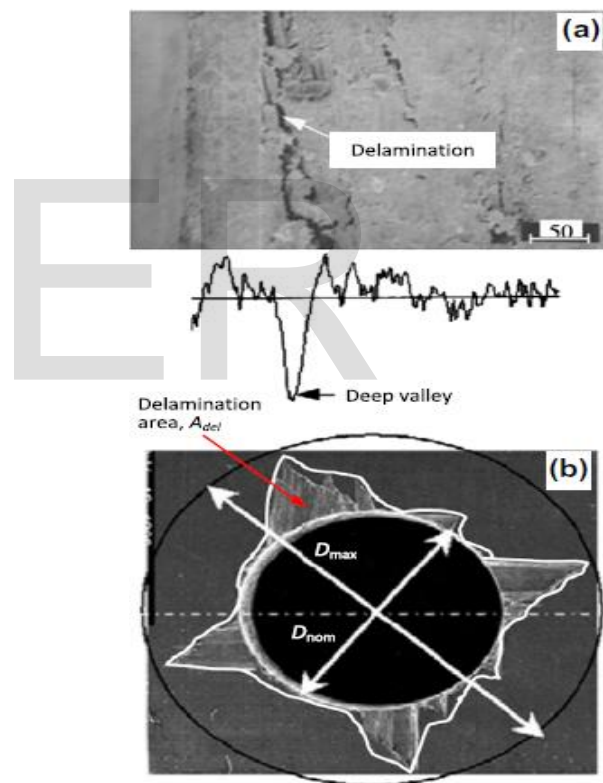


Fig. 3: SEM images of delamination (a) intersection image of GFRP; and (b) surface image of CFRP

C. Drilling-induced delamination

Delamination is an inter-ply failure phenomenon induced by drilling, which is a highly undesirable problem and has been recognized as a major damage encountered when drilling

composite laminates. Fig.3 shows several SEM images of delamination damage. Delamination not only reduces drastically assembly tolerance and bearing strength, but also has the potential for long term performance deterioration under fatigue loads.

The present work is a summarized literature review on different research and review projects done up to date on the drilling of fibre reinforced composites. The aim is to select optimal drilling parameters to reduce the overall delamination effect working with CFRP 200 GSM 2*2 twill fabric, 4 mm thick plates. Drilling type is conventional drilling, drill tool diameter 8 mm.

II. LITERATURE SURVEY

Devised Analysis of 25 review papers is as follows

Vaibhav A. Phadnis[1], studied FEA model of drill workpiece interface. Experimental quantification of drilling-induced damage is performed by means of X-ray micro computed tomography, the model is used to predict optimal drilling parameters. Sanjay Rawat[2] showed that the effect of tool wear on the quality maps can be established through the changes in the thrust and cutting forces. J.P. Davim[3] established a correlation between cutting velocity and feed rate with the delamination in a CFRP laminate. [4] DeFuLiu, YongJun Tang, W.L. Cong. Have given a comprehensive review of mechanical drilling for composite laminates. They have collected data about all drilling methods & machining parameters. Mr. A.M. Abrao.[5] worked on the damage on High-speed steel (HSS) (using parameters such as damage width, delaminated area or delamination factor). Another point of agreement among the authors is the need of developing devices and/or procedures in order to allow the reduction of the damaged area without the need of a backing material, which makes the drilling operation longer and dearer.

Islam Shyha et al. [6] achieved a longest tool life when drilling woven MTM44-1/HTS OC at a feed rate of 0.4 mm/rev (3750 holes). The drilled hole diameter was found to be undersize for all conditions tested by 36 μ m (~2.5%) to 73 μ m (~5%) at the end of tool life. In 2010, E. Kilickap [7] presented an application of the Taguchi method for investigating the effects of cutting parameters and point angles on the delamination factor in dry drilling of CFRP composites. The level of the best of the cutting parameters and point angles on the damage is determined by using ANOVA. In 2011, K. Palanikumar[8] used Taguchi's method with grey relational analysis and found that the largest value of the Grey relational grade for the spindle speed of 2500 rpm and feed rate of 100 mm/min. It is the recommended levels of the controllable parameters of the drilling operations as the minimization of the thrust force, surface roughness and delamination factor are simultaneously considered. U.A. Khashaba[9] observed that at minimum cutting variables the thrust force of continuous winding, woven/epoxy and chopped composites were suddenly dropped from the maximum value to zero at the drill exit with significant push-out delamination by variable feed technique. Carlos Santiuste et al. [10] observed the effect of bending moment (involving both cracking and crushing damage) for fiber

orientations close to the cutting speed direction in CFRPs. The increment of angle orientation led to increased crushing damage beneath the machined surface.

In 2010, while drilling CFRP/Al stacks, Vijayan Krishnaraj [11] investigated that the magnitude of thrust force and torque during drilling of Al compared to CFRP is double at low feed rate (0.05 mm/rev) where as at 0.1 mm/rev and at 0.15 mm/rev it is approximately three times higher. C.C. Tsao n, Y.C. Chiu D[12] considered Evaluation of drilling parameters to develop a new device and to solve the problems of relative motion and chip removal between the outer and inner drills in drilling CFRP composite laminates. In Delamination in drilling of composite materials with various drill bits by H. Hocheng, C.C. Tsao [13] to get the critical thrust force at the onset of delamination is predicted and compared with the twist drill using work material like saw drill, candle stick drill, core drill and step drill. Edoardo Capello[14] work on Workpiece damping and its effect on delamination damage in 5 June 2003 using Damage free machining to analyze the differences in delamination mechanisms when drilling with and without a support placed under the workpiece. In 22 October 2007, V.N. Gaitonde, S.R. Karnik, J. Campos Rubio, A. Esteves Correia, A.M. Abrao, J. Paulo Davim, [15] work on high-speed drilling of carbon fiber reinforced plastic composites to get details of model development and model adequacy test by analysis of variance (ANOVA).

Yigit Karpata [16] investigated the Drilling thick fabric woven CFRP laminates with double point angle drills in 25 May 2012 using diamond coated carbide to get the influence of double point angle drill geometry on drilling performance through an experimental approach. Vijayan Krishnaraj [17], work on Optimization of machining parameters at high speed drilling of CFRP laminates using work material like K20 carbide drill to get full factorial design performed on thin CFRP laminates using K20 carbide drill by varying the drilling parameters such as spindle speed and feed rate to determine optimum cutting conditions. T.J. Grilo[18] work on delamination analyses of CFRPs using different drill geometries to get the influence of three distinct drill geometries and cutting parameters (feed rate and spindle speed) in the delamination was assessed through two delamination factors. Sanjay Rawat, Helmi Attia[19] analyzed the effect of speeds and feed rates on the damage mechanisms, namely, delamination, surface roughness, fiber pullout, thermal damage, hole circularity and hole diameter error were established using a newly introduced concept of Machinability Maps. R. Janssen [20] presented concerning the realization of economical drilling processes of multi-layer materials.

H. Hocheng [21] Compared to sharp drill, the worn twist drill allows for lower feed rate below which the delamination damage can be avoided. T. Branson, D. Kim [22] observed that dissimilar mechanical and thermal properties affected the tool life and allowed for increased matrix degradation regardless the cutting tool material. Pedro Reis [23] presented a new comprehensive approach to select cutting parameters for damage-free drilling in carbon fiber reinforced epoxy composite material. The approach is based on a

combination of Taguchi's techniques and on the analysis of variance (ANOVA), Dave (Dae-Wook) Kimb,[24]analysed Higher torque and thrust values were observed at the higher spindle speeds which caused a significant increase in tool wear due to the higher temperature generated. ChinmayaR.Dandekar [25] studied molecular dynamic simulations, 2-D and 3-D finite element models and the emerging field of multi- scale models.

From studying all this we found a considerable gap in analysis of conventional drilling methods on CFRP material. Also artificial neural network optimization is not yet used in this field.

III. PROBLEM DEFINATION

1. CFRP composites have large range of application in aircraft industries. The CFRP composites are joined together by bolting hence drilling operation is required for the same which induces delamination in drilled hole.
2. Holes with high delamination, if used for bolting the laminates, it may fail to its earliest due to initiation of cracks from delaminated areas.
3. Minimization of delamination factor will increase the life of the material especially when used in fluctuating stresses applications.

IV. OBJECTIVES

- To Maximize Material Removal Rate and to Minimize Delamination simultaneously using multi objective optimization techniques
- To Compare the optimization techniques like fuzzy logic and grey relational analysis in drilling of CFRP composite.
- To obtain optimum process parameters in drilling of CFRP composites.

V. METHODOLOGY

The Experimentation involves Drilling of CFRP Composite on Conventional drilling machine. The levels of process parameters will be set by various test runs. Input variables like Cutting speed, feed rate & drill tool type will be considered. Then, according to Taguchi L27 Orthogonal array 27 cuts will be taken corresponding to the various setting. The output responses like roughness, cutting forces and material removal rate will be done equipment's and mathematical models available. The optimization will be done after experimentation by integrating Grey relational analysis and fuzzy logic. Further, the confirmation test will be done followed by ANN and Conclusion.

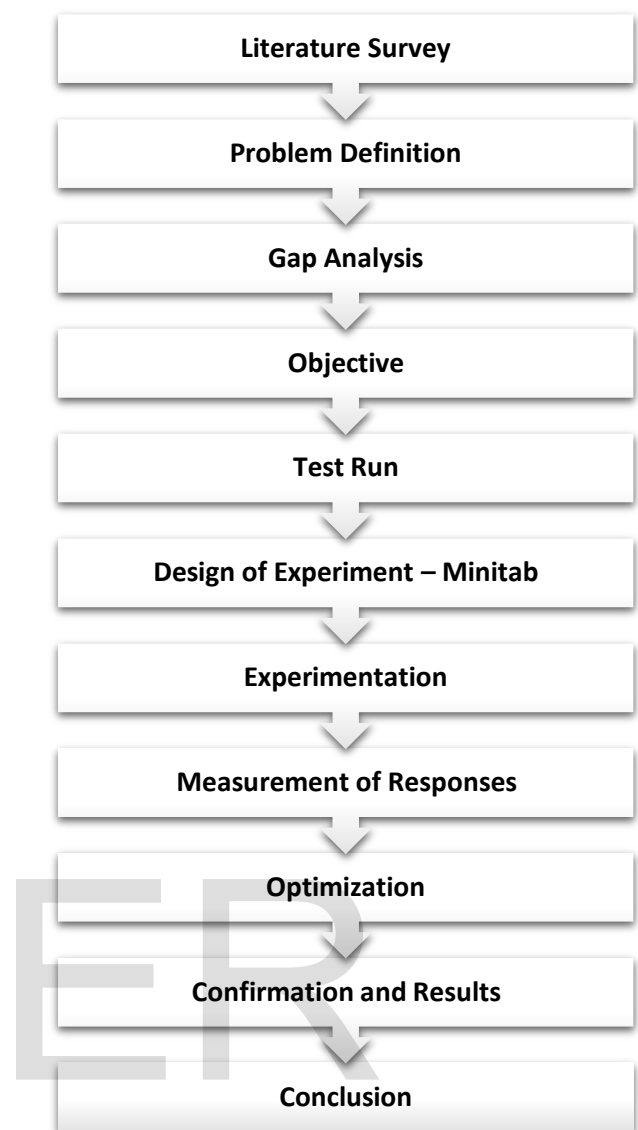


Fig.4 Flow Chart of Methodology

VI . REFERENCES

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