Investigation of the Effects of Drilling on Mechanical Joints in Composite Structures

Pourya Fathi 1*, Amin Moslemi Petrudi 1, Ionut Cristian Scurtu 2

1 Department of Mechanical Engineering, Tehran University, Iran
2 Mircea cel Batran Naval Academy, Constanta, Romania

Email: Pr.Fathi@gmail.com

Abstract: The use of a variety of composites due to their superior properties, which include low weight, high strength, and high corrosion resistance, which are generally many applications in the aerospace, automotive, and marine structures have increased significantly. Fiberglass reinforced composites have several industrial applications due to their suitable mechanical and physical properties. Drilling is one of the common methods for connecting structures made of reinforced materials with fibers. Composite structures usually result from the joining of members to transmit and tolerate incoming forces. One of the methods of connecting the members, due to the ease of maintenance and repair, is the mechanical connection through screws or rivets, which inevitably must create holes in these members. Composites as materials that are difficult to machining, drilling these materials can lead to delamination and, in some cases, degradation. In this paper, the effects of drilling on mechanical joints in composite structures and solutions to prevent damage to them due to drilling are investigated.

Keywords: Mechanical joints, Drilling, Lamination, Composite structures.

1. Introduction

The use of mechanical joints in large composite structures is mandatory due to the constraints on the dimensions of the components, in terms of the manufacturing process and basic needs such as inspection, accessibility, repair, and maintenance. Composites have been widely used in various industries due to their strength to weight ratio and high stiffness, high buckling strength, fatigue, and many other desirable properties [1]. Mechanical joints are frequently used in structures, especially aerial structures, and are among the critical points of structures. Therefore, the design and construction of these joints are very important and the improper manufacturing process of these joints leads to the creation of defective structures [2]. Due to the increasing development of composite materials in various industries, especially the aerospace industry, and the use of these materials in various parts of the aircraft structure, the issue of connecting these materials with other metal or composite parts of the structure is of particular importance. Mechanical joints are widely used in industry, especially in aerial structures, and are critical points in composite structures. Therefore, the design and manufacturing process of joints in these structures is very important and designers have long paid special attention to it [3,4]. Fiber-reinforced composite layers are damaged by lamination in machining operations, especially in drilling operations that are subject to stress concentrations. The phenomenon of delamination is strongly influenced by factors such as the material and geometry of tools and machining parameters. Increasing the shear velocity and decreasing the advancing velocity reduces the damage of the laminate and improves the quality of the holes shown in Figure 1 [5].
Composite parts are mainly produced close to the final form to avoid machining on them, which increases production costs. However, in modern industries, the need for higher surface smoothness and higher dimensional accuracy, which cannot be achieved with the primary production methods of composites, have made secondary machining on these materials inevitable, which are shown in Figure 2 [6].

Drilling is the most important operation performed on these materials and drilling of these materials is associated with problems due to the tendency of this type of material to separate their layers under shear forces (axial force and torque). On the other hand, in industry, drilling is the last stage of the production and assembly process of parts, and creating a defect in this stage causes the part to be lost and imposes heavy costs, which are shown in Figure 3 [7].

Drilling operations are one of the traditional machining processes of materials that usually have defects such as cracking, cracking of the matrix, uncut fibers, and in addition to these when machining composites. These defects have a significant impact on the quality and strength of the final piece; It is increasingly felt that perforation and
hole diameter are the most important defects that occur when perforating fiber-reinforced composites and reduce the efficiency of the composite structure. In the following, the types of drilling methods will be briefly introduced and a common and widely used method called drilling will be described. Given that the drilling process will lead to damage to the components, solutions to reduce and eliminate the destructive effects of drilling will be considered [8].

2. Types of drilling methods in composites

Different drilling methods are used to make holes on these materials, the most important of which are ultrasonic drilling, electric discharge drilling, laser drilling, water jet drilling, and traditional drilling, which according to the required costs and quality, one These methods are used; However, due to the economics and availability of the drilling method, this drilling process is known as the most common method, which is shown in Figure 4 [9].

3. Injuries due to drilling

Damage caused by drilling can cause stress in the hole area, fatigue, and, most importantly, lamination of composite sheets. Laminating is the most important defect that occurs during the drilling of reinforced polymers and generally in multilayer composites. This defect has a very destructive effect on the part. This defect, in addition to reducing the quality of the part, causes a weakness in the assembly tolerance and has the potential to damage the part in the long run. The mechanism of these two defects is completely different [10]. The inlet occurs due to the pull-out mechanism while cracking at the output occurs due to pushing. A crack occurs at the inlet when the drill enters the workpiece. When the cutting edges of the drill engage with the workpiece, the shear force acting in the peripheral direction acts as the extruding force by applying axial force from the drill, causing cracking. This force creates an extraction force in the axial direction towards the slope of the drill groove, which causes the layers to separate from each other and creates a layering layer at the inlet surface of the hole [11]. The pushing mechanism occurs when the drill reaches the outlet of the workpiece. At this point, the resistance of the remaining layers of the workpiece, which have not yet been drilled, gradually decreases until these layers can no longer tolerate, the axial force exerted by the drill. It is at this point that the remaining layers separate and cause laminating at the outlet of the hole. Various factors affect the lamination of composites during drilling, including the rate of advance, drill rotation speed, material, and geometry of the drill [12].
3.1 Progress rate

Based on the results of research, it has been observed that at all cutting speeds, regardless of the material and angle of the drill, with increasing the progress rate, the amount of composite plate layering increases as shown in Figure 5.

![Diagram of the relationship between progress rate and delamination.](image)

3.2 Cutting speed

During the results, two different relationships were observed in different conditions between cutting speed and lamination. As shown in the figure below, in some composite sheets (CFRP fibers) the rate of lamination increases with increasing cutting speed, but in other conditions (GFRP woven fibers) the rate of lamination decreases with increasing cutting speed. Shown in Figure 6 [13].

![Diagram of the relationship between cut speed and delamination.](image)

Research also shows that lamination occurs even at the slowest cutting speeds.

3.3 Drilling geometry

One of the important parameters in the study of layering damage is drilling geometry. In general, drilling drills are divided into six different groups: 1- Wood drill 2- Stair drill 3- Spiral drill 4- Round drill 5- Straight drill 6- Cutting drill which is several common drills used in various industries in Figure 7 are shown. [14].
Research shows that in CFRP composite panels, in both traditional drilling methods and high-speed drilling, the layering increases with increasing head angle. However, the results of reducing the lamination by increasing the head angle in GFRP composite plates are available, the diagram of the relationship between the drill head angle and the lamination is shown in Figure 8 and the finite element model CFRP in Figure 9 [15].
4. Solutions to reduce damage caused by drilling

In general, to prevent the laminating of composite plates in drilling, a controlled advance rate should be followed, which is a function of the properties of the composite multilayers and the drill parameters and plate thickness, although the advance rate also depends on the drilling conditions [16].

4.1 Use of support

Studies and research show that the use of this support reduces the layering shown in Figure 10. The reason for using the support is to prevent the flexibility of the part or to reduce its dynamic movement, shown in Figure 11 [17].

4.2 Use of special drills

In the study of the types of drills mentioned above, the use of straight flute, step, core, step-core drills in comparison with the twist drill due to having a special geometry reduces the layering at any given progress rate [18].

4.3 Multi-stage drilling

Research has shown that the use of pre-drilling in composite multilayer drilling reduces the adverse effect of lamination. According to the results of research, it has been observed that at low speeds 40% and high speeds 60% of the total forward force is lost at the head of shear drills. Therefore, by creating a hole craft, this power can be prevented from being lost. As a result, pre-drilling, especially at high forward speeds, can be a good way to reduce stratification [19-20].

5. Conclusion

Mechanical and physical properties such as the high ratio of strength to weight and hardness to weight, make them superior to the use of composite layers in various applications. Multi-layer composite drilling differs significantly from traditional drilling of metals and other alloys in many respects. In the present paper, recent research on composite multilayer drilling processes, drilling drill geometry, and drilling-induced lamination are reviewed. Fiberglass reinforced composites have several industrial applications due to their suitable mechanical and physical properties. Drilling is one of the common methods for connecting structures made of reinforced materials with fibers. Composite structures usually result from the joining of members to transmit and tolerate incoming forces. One of the methods of connecting the members, due to the ease of maintenance and repair, is the mechanical connection through screws or rivets, which inevitably must create holes in these members. Composites as materials that are difficult to machine, drilling these materials can lead to stratification and, in some cases, degradation. There are generally four main methods used to drill composites: traditional drilling, grinding drilling, vibration drilling, and high-speed drilling. Most traditional drills are widely used, but to achieve higher drilling performance, grinding, vibration, and high speed gives us better quality for drilled holes. Composite multilayer drilling requires special requirements regarding the geometry of the drilling rig. In addition to helical drilling drills, other special
types of drills, including stair, wood, shear, and straight drilling drills, have been developed to reduce the layering caused by drilling. These special types of drills can apply a higher rate of advancement without lamination than spiral drills. Considerable efforts have been made to better understand the factors involved in composite multilayer lamination. The use of special drilling rigs, use of abutment, initial hole drilling, vibration drilling, and high-speed drilling significantly increase the quality of drilled holes. Research has shown that the rate of progression plays the most fundamental role in stratification. In general, the use of low advancement rate and high sheer speed makes it the least layered.

6. References

[1] Liu, DeFu, A review of mechanical drilling for composite laminates, 2011
[2] Lau WS, Wang M, Lee WB. Electrical discharge machining of carbon fibre composite materials. Int J Mach Tools Manuf; 30:297–308, 1990.
[3] Mathew J, Goswami GL, Ramakrishnan N, Naik NK. Parametric studies on pulsed Nd: YAG laser cutting of carbon fibre reinforced plastic composites. J Mater Process Technol; 89–90:198–203, 1999.
[4] Shanmugam DK, Nguyen T, Wang J. A study of delamination on graphite/ epoxy composites in abrasive water jet machining. Composites: Part A; 39:923–9, 2008.
[5] Davim JP, Reis P, Antonio CC. Experimental study of drilling glass fiber reinforced plastics (GFRP) manufactured by hand lay-up. Compos Sci Technol; 64:289–97, 2004.
[6] Kilickap E. Optimization of cutting parameters on delamination based on Taguchi method during drilling of GFRP composite. Expert Syst Appli; 37:6116–22, 2010.
[7] Tsao CC. Prediction of thrust force of step drill in drilling composite materials by Taguchi method and radial basis function network. Int J Adv Manuf Technol; 36:11–8, 2008.
[8] Fernandes M, Cook C. Drilling of carbon composites using a one shot drill bit. Part I. Fiver stage representation of drilling and factors affecting maximum force and torque. Int J Mach Tools Manuf; 46:70, 2006.
[9] Karnik SR, Gaitonde VN, Campos Rubio J, Esteves Correia A, Abrao AM, Davim JP. Delamination analysis in high speed drilling of carbon fiber reinforced plastics (CFRP) using artificial neural network model. Mater Des; 29:1768–76, 2008.
[10] Kilickap E. Optimization of cutting parameters on delamination based on Taguchi method during drilling of GFRP composite. Expert Syst Appli; 37:6116–22, 2010.
[11] Hocheng H. The path towards delamination-free drilling of materials. Process Technol; 167:251–64, 2005.
[12] Tsao CC, Hocheng H. Effects of exit back-up on delamination in drilling composite materials using a saw drill and a core drill. Int J Mach Tools Manuf; 45:1261–70, 2005.
[13] Fernandes M, Cook C. Drilling of carbon composites using a one shot drill bit. Part II. Empirical modeling of maximum thrust force. Int J Mach Tools Manuf; 46:76–9, 2006.
[14] Hocheng H, Tsao CC. Comprehensive analysis of delamination in drilling of composite materials with various drill bits. J Mater Process Technol; 140:335–9, 2003.
[15] Jain S, Yang DCH. Delamination-free drilling of composite laminates. ASME; 116:475, 1994.
[16] Won MS, Dharan CKH. Chisel edge and pilot hole effects in drilling composite laminates. J Manuf Sci Eng; 124(2):242–7, 2002.
[17] Tsao CC, Hocheng H. The effect of chisel length and associated pilot hole on delamination when drilling composite materials. Int J Mach Tools Manuf; 43:1087–92, 2003.
[18] Tsao CC. The effect of pilot hole on delamination when core drill drilling composite materials. Int J Mach Tools Manuf; 46:1653–61, 2006.
[19] A. Moslemi Petrudi, K. Vahedi, M. Rahmani, and M. Moslemi Petrudi, “Numerical and analytical simulation of ballistic projectile penetration due to high velocity impact on ceramic target”, Fra & Int Strut, vol. 14, no. 54, pp. 226-248, Sep. 2020.
[20] P. Fathi, A. Naddaf Oskouei, K. Vahedi, and A. Moslemi Petrudi, “Numerical and Experimental Analysis of Stacking Sequences Effects in Composite Mechanical Joints under Impact Loadings”, Fra & Int Strut, vol. 14, no. 53, pp. 457-473, Jul. 2020.