DESIGN OF A NEW ONE-SHOT TOOL WITH DOUBLE MARGINS STRUCTURE IN DRILLING TITANIUM/COMPOSITE STACKS

Chong Zhang[1], Zhenyuan Jia, Fuji Wang, Boyu Zhang, Guangjin Bi and Junwei Yin

1 The Key Laboratory for Precision and Nontraditional Machining Technology of Ministry of Education, Dalian University of Technology, Dalian 116024, China.
E-mail: wfjsll@dlut.edu.cn, web page: http://www.dlut.edu.cn

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ABSTRACT

Drilling pilot holes on Titanium/CFRP stacks components is inevitable for assembling process in manufacturing industries. However, drilling of such laminated composite is a challenging task to manufacturing engineers because of differential physical and mechanical properties and performance mutation at the interface. Therefore, it is important to choose the advisable variable machining parameters regarding the sequence of stacks and makes use of appropriate drill geometry in order to achieve low damage and precise holes. In the article, a novel step drill is proposed with special margins structure on its second stage. A contrast experiment of two different machining parameters in drilling the Ti/CFRP stacks is designed. The thrust force, delamination factor and the holes diameter are obtained, and the influence of step drill with different machining parameters is derived. It is found that in the Parameter A, the step drill has a better performs. The length of the First stage of the drill has an important influence on the quality of the processing and the choice of the process. The better processing quality can be obtained, when the length of the first stage of the drill is suitable.

1 INTRODUCTION

In aerospace structural applications, the hybrid structure of titanium (Ti) and carbon fiber reinforced plastic (CFRP) stacks is becoming widely utilized due to corrosion resistance, and the unique ability to withstand high stress in service while with high strength-to-weight ratio, low density, and excellent heat resistance[1,2]. Generally, the laminate structures are assembled by bolt and rivet joints and the assembly is the terminal process of the aircraft manufacturing, thus the drilling operation is the most essential process in the final production process [3]. However, in the aircraft industry, the concentricity of holes and position precision are significant and highly demanded. With the conventional processing method, these parts should be first rough machined respectively, and then be fine finished synchronously. This conventional technique not only is low efficient but can easily cause the deformation of parts and the accuracy out of tolerance, thereby invalidating the assembly and causing enormous economic losses. But drilling the stacks in assembly workplace at the same time is an effective way to avoid the above-mentioned problems. Therefore drilling the connecting holes of the Ti/CFRP laminate in one-shot processing has become the trend of aircraft industry [4].

However, drilling of such laminated composite is a challenging task to manufacturing engineers because of differential physical and mechanical properties and performance mutation at the interface. When drilling the stacks the one-shot drills wear rapidly since the shock and friction impact [5,6]. Since the unique manufacturing features of CFRP, it is easily produce delamination, burr, pore wall shrinkage and other defects when drilling process. And at same time, in the process of drilling titanium alloy, due to its high chemical activity, low thermal conductivity and other negative factors, there will be metal burrs, chip formation and other damage [7]. On the other side, although the titanium alloy chip can be quickly discharged and accelerated cooling, when the titanium alloy is at the top of the CFRP, but this stacking sequence results in large delamination at the outlet of the CFRP, accelerate tool wear, poor surface quality of the holes and produce holes outside the required holes size accuracy[5,8]. So that it is important to choose the advisable variable machining parameters regarding the sequence of stacks and makes use of appropriate drill geometry in order to achieve low damage and precise holes [9].

With respect to the current research advances, a large amount of experimental work has been performed in the past few decades in order to get optimal tool geometries or favorable cutting parameter [4,8,9]. Based on reported literature and also our extensive experimental work, when drilling the stacks very special tools must be used [3-5], thus increasing the undamaged cost. But sometimes, undamaged is not possible. So that drilling must be applied for burr minimization [10]. To minimize the burr size, a step drill is designed to separate the drilling into two steps. In this process, the burr formed after drilling with the front edge is removed and a smaller burr is formed in step cutting with the step edges. Therefore, with an optimal structure of the second step can be used to minimize the burr and the delamination [11,12].

The present article aims to figure out a new geometrical drill to through multilayer materials in only one shot, without any cooling. Furthermore， a novel step-structure with broaching part, special reaming part and cutting edge is presented and to make the modification of the one short drill. The effect of the reaming part structure on the damage reduction is presented geometrically. Meanwhile, it was verified experimentally that the novel drill was effective on reducing the drilling damage.

2 TOOL GEOMETRY DESIGN AND CUTTING PARAMETERS

Previous studies have presented various multi-stage drilling tools such as one shot drill, stepped drill [13,14]., etc. The thrust force was effectively reduced by the multi-stage drilling process and drill-exit quality was improved. Hence, this article employs the one type of the popular one short drilling tools, step drill, which is widely utilized in the industry, and makes geometric modifications on its cutting edges to accomplish a further improvement [15].

The one shot drill Fig. 1 normally has two stages, named as the First step and the second step with two different point angels. The drilling Ti/CFRP process of a step drill at the exit is divided into six stages as shown in Fig. 1. In stage I, the cutting edges of the First step drilling into the Ti plate. In the stage II, the margin edges of the First step cutting the Ti plate. In stage IV, the margin edges with a small point angle involve in the removal of material, and following that, in the bottom of the Ti, the secondary cutting edges gradually drill the CFRP, and the Second step begin to cut the CFRP until the hole is finished as stage VI. In terms of the above six drilling stages of the step drill, there is possibility that the damages are removed in the subsequent drilling stage if they are not so severe. However, the damages induced in Stage VI cannot be complete elimination, and become the final damages of the machined hole together with the residual damages in the Stage IV.

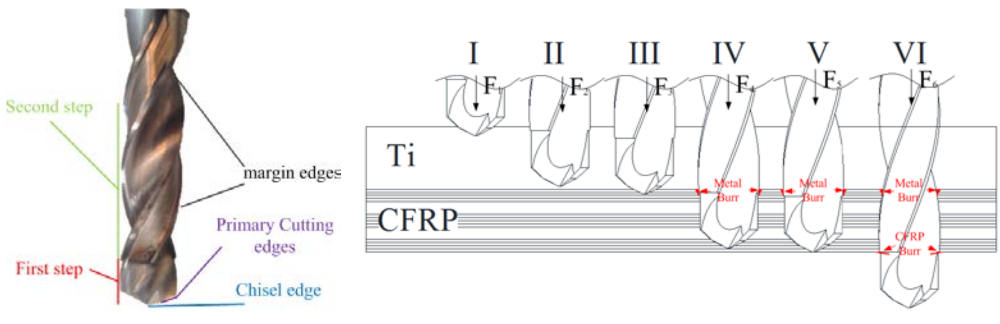


Figure 1. Step drill and the drilling process at the hole exit

2.1 Cutting edge and reaming structure on step drill

Reducing the final damages at the both plats exit is always the top priority in drilling laminates structure process, however, even if a step drill is applied, damages are inevitable. Based on analysis of the process of drilling stacks structure above, we change the cutting edges and reaming part of step drill in order to limit the damage at exit of the both plates. Drills are made of K44UF tungsten carbide without coating which have two primary cutting edges with different point angle, as shown in the Fig. 2. And in this way, the cutting force can be dispersed. There are three margin edges in reaming part of this step drill. The margin edges can reduce damages at the exit of the machined hole by removing residual material gradually. The width of each margin edge is designed to guarantees enough strength. In this way, the CFRP burr can be removed effectively, as shown in the Fig. 3.

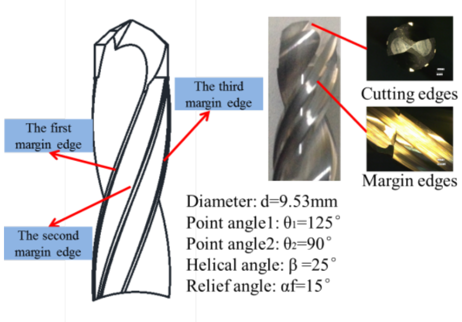
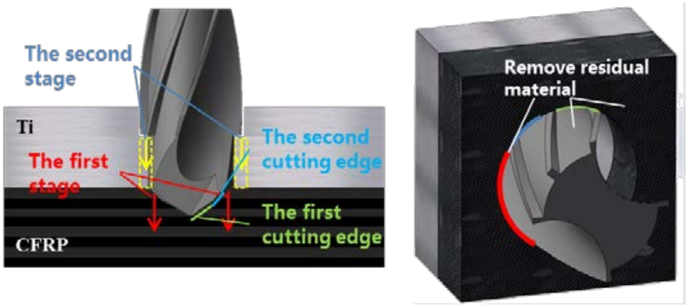


Figure 2. The novel step drill with margin edges structure



(a) (b)

Figure 3. Geometrical analysis of cutting process (a) Stage III, (b) Stage V

2.2 Selection of cutting parameters

A lot of literatures show that, in the machining of laminated materials, the composite part of the most suitable processing conditions is high speed and low feed, but when machining titanium alloy with low speed and low feed is more appropriate, and for thicker titanium alloy by pecking process has a positive effect on processing quality. Therefore, the choice of processing parameters also has a profound impact on the quality of processing, in addition, because of the machining of laminated materials; titanium alloy will lead to greater problems. Based on the above analysis, the selection of the stop position of the spike drilling process will have a great impact on the final processing effect. Therefore, the processing parameters of this experiment are shown in Table 1. Two processing methods are selected. The positions where the peck stop are the drill point out of the Ti layer (Parameter A) and the reaming part out of the Ti layer(Parameter B), respectively.

The drilling experiment is carried out under the condition of dry processing, and two kinds of picking drilling technology are selected. At the beginning of the machining, the Ti alloy was drilled with the cutting rates 300r/min and 30mm/min until the peck drill end, and then the drill changed the cutting speed to 4000 r/min and processed the CFRP layer with the cutting feed 35mm/min.

3 EXPERIMENTAL PROCEDURES AND EQUIPMENT

3.1 Ti/CFRP workpiece details

In order to guide drilling of aviation parts preferably, he workpiece used in this study was composed of a single layer of 6 mm thick, rolled annealed Ti-6Al-4V alloy (Ti), and multi-directional CFRP composites and laminated by 20 layers of P2352 prepreg in the fiber orientation of [(-45/0/45/90)2/0/0]s. The reinforced fiber is Toray-T800S and the fiber volume content is 60%. The mechanical properties of the composites and Ti are listed in Table 1 and Table 2. And both of materials are cut into the same size in order to clamping at same time.

Temperature[℃]	Yield Stress Rp0.2%[MPa]	Tensile Strength Rm[MPa]	Elongation A4[%]
20	990	1050	12

Table 1. Mechanical properties of Ti-6Al-4V

Longitudinal tensile strength (MPa)	Transverse compressive (MPa)	Longitudinal Young’s modulus (GPa)	Transverse Young’s modulus (GPa)	Poisson’s ration
2842	165.6	160	8.97	0.28

Table 2. Mechanical properties of composites

3.2 The equipment

A series of drilling operations were carried out on the GONA 5-axis machining center. The basic device of the drilling experiment is shown in Fig 4. During the drilling process, the test sample was clamping by a self-made fixture, and the drill bit was drilled from the top of the workpiece. In order to observe conveniently, a Kistler force sensor, 9257B dynamometer, was fixed on the platform of the machining center to support the clamping system and measure the thrust force during drilling. The Kistler amplifier and data acquisition were employed to read and save data from the force sensor in a sampling frequency of 3 KHz. After the drilling experiment, the machined holes were observed on Keyence digital microscope to measure the final exit quality.

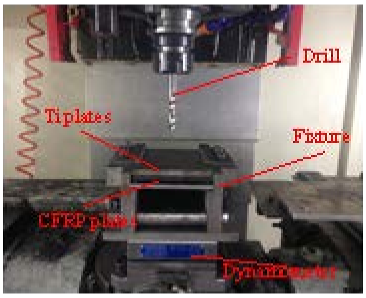


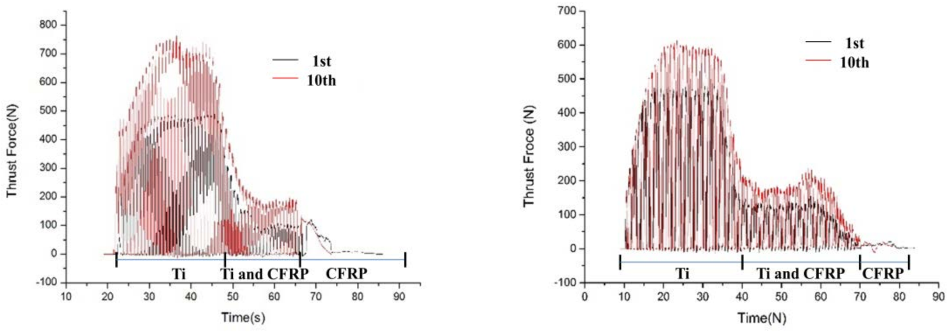
Figure 4. Experimental equipment

4 RESULTS AND DISCUSSION

4.1 Thrust force

The data obtained from drilling is filtered in the software with a low pass filter set to 10Hz, because the axial motion is a continuous low frequency process. The obtained typical thrust force curves are shown in Figure 5. It can be seen that thrust force curves of two different peck drill parameter. The main cutting edges enter the workpiece gradually in drilling the Ti layer, which leads to the thrust force increasing rapidly; furthermore, a stable value is maintained during the machining of titanium alloy by itself in both kinds of peck drill. In

Parameter B, the machining time of Ti and CFRP is longer than another, which is because the peck drilling process is longer. And there is a sensible rise in machining the CFRP only in Parameter A. But due to the long process of picking, the thrust force is relatively smooth and the value is very small. This is because there is only a small part of the uncut material at this time. In both processes, with the increase of the number of holes, the thrust force will rise significantly, and the second processes are particularly obvious, this indicates that tool wear is more severe in Parameter A.



(a) (b)

Figure 5. Typical thrust force curves (a)Parameter A (b)Parameter B

4.2 Exit damage

According to observation, the main damage types of the CFRP are delamination, burrs and cracks when drilling the Ti/CFRP stacks. Among them, delamination effect bearing capability of parts greatly, so the paper adopts it as the basis of evaluating quality and in this experiment we choose the widely applicable and convenient delamination factor as evaluation basis. The delamination factor was defined as the ratio of the maximum delamination diameter, Dmax to the hole normal diameter, Dnorm, as shown in the Fig 6, described as the equation(1).

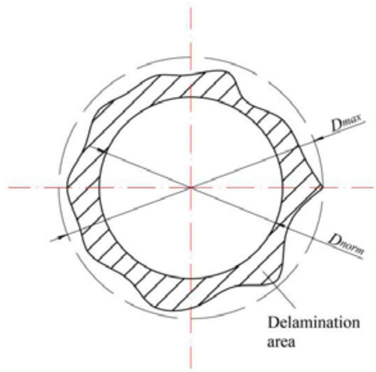


Figure 6. Schematic diagram of delamination factor

The delamination factor curves of end holes with different parameters (Figure 7) are all found to: first increase, then drop rapidly at the second hole, and then delamination factor expands rapidly. But at fourth and fifth holes, however, the curves declined again. In Parameter A, the delamination factor rose again, and then began to decline gently, the overall trend of this curve is steady at the beginning and at the end, but in the middle part, the fluctuation is more intense. In Parameter B, after the sixth hole, the curve becomes up and down. In contrast, the delamination of end holes in the Parameter A is more severe than the Parameter B. This due to that, the CFRP is subject to greater impact in the case of lower speed and feed, and easily occur delamination, as shown in Fig 8. In conclusion, the drilling quality of Parameter B is better than that of Parameter A.

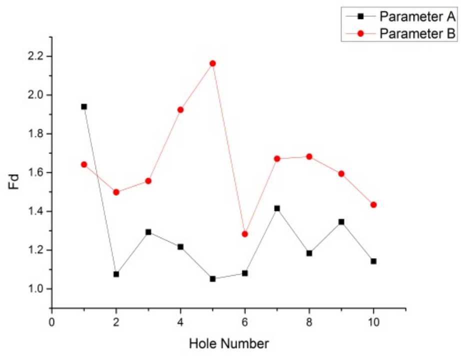
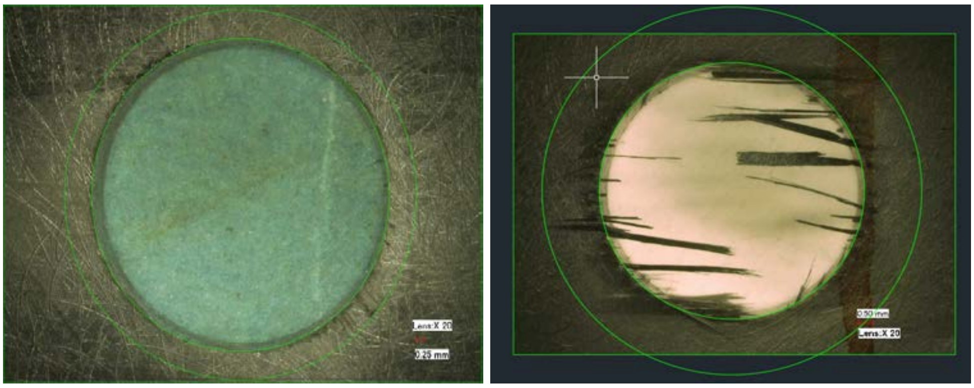


Figure 7. Typical delamination factor curves of different parameters

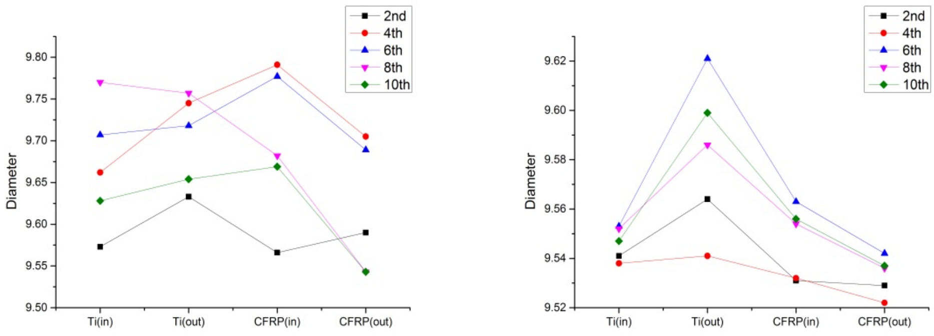


(a) (b)

Figure 8. The final exit quality of different parameters (a)Parameter A (b)Parameter B

4.3 Hole size

The hole diameter at in and exit of both Ti and CFRP side are shown in the Fig. 8. In the parameter A, the hole diameter curve seem generally smooth expect the 8th and 10th hole. In Parameter B, holes diameter at exit hole measured in the Ti side are much larger than for CFRP. This is because the reaming part drill in the interface of the stack, and since the property of the CFRP itself, the drill bit is unstable and the tool eccentricity. The maximum hole size of titanium alloy is 9.62mm, which is approximately 10% greater than the nominal diameter (Ø9.53 mm). These hole sizes are not acceptable. Due to the wide variation in results seen, nostatistical analysis could be performed due the large error value returned.



(a) (b)

Figure 8. The final exit quality of different parameters (a)Parameter A (b)Parameter B

5 CONCLUSIONS

Compare with the thrust force, delamination factor and holes quality, it can be found that, this special step drill performs better in the Parameter A. Further work is needed to improve hole size and delamination which will be based on the Parameter A. Additionally more tests are needed to evaluate other key factors which have an influence on the tool performance while CFRP/Ti drilling. The length of the First stage of the drill has an important influence on the quality of the processing and the choice of the process. If the first stage is too long, it will lead to more serious delamination damage. When the length of the first stage of the drill is suitable, the better processing quality can be obtained in the parameter B. Although CFRP/Ti forms a hybrid material, with widely different mechanical and thermal properties, it is clear that tool performance and hole quality are largely controlled by titanium.

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