COMPARISON OF OPTIMUM DRILLING CONDITIONS OF AIRCRAFT CFRP COMPOSITES USING CVD AND PCD TOOLS

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1 Introduction

Recently based on Boeing 7E7 (787) model carbon reinforced plastics (CFRP) with high specific strength can be used significantly more in the aircraft parts. The best disadvantage of composite structure is the difficulty to manufacture complicate structural parts. To compose the aircraft structure the unification of many parts using volts and nuts can be required. Thus the holes process is an important field in the composite manufacture. The development of materials processing and the optimum process conditions for holes drilling is essentially a keying issue.

Since more than 55,000 holes process is necessary to manufacture an Airbus aircraft, the tooling material development for drilling process is needed essentially. Purchasing fee of drilling processing materials due to many holes process can affect on total manufacturing cost of an aircraft. New drilling tool development rather than conventional PCD drill is needed in the economical aspects. In addition to financial point, some improvement is needed for peel-up crack in front of CFRP and micro-crack inside holes occurring during holes drilling process.

In this work, the processing comparison between CVD diamond drill and conventional PCD drill was investigated by changing the shape of drill to increase feed speed and materials development of processing were also studied as well [1,2].

2 Experimental

2.1 Materials

CFRP in 14 mm thickness was provided from Korea Aerospace Industries (KAI) Ltd. for holes drilling process. Hole processing capability was compared for PCD (Walter Co.,. 6.35 mm) and CVD diamond drill (AMAMCO Co., 6.38 mm) with different diamond coating methods and drill shape. Thermal image camera (Dail Co.) was used for analyzing thermal drilling process, and bore gage (Mitutoyo Co.) was also used for holes inspection.

2.2 Determination of Processing Condition using Machining Equation

$$V_c = \pi DF \tag{1}$$

$$F_t = \frac{F}{ZN} \tag{2}$$

In eq. (1), V_c is the cutting speed and F_t is feeding per tooth in eq. (2). D is diameter of drill, N is rpm, F is feeding value, and Z is blade number. As tooth number increases, feeding per teeth decreased. Feeding speed can enhance with increasing F since feeding per each teeth can be reduced. Thus 4 teeth drilling structure can be more productive than 2 blade type with increasing cutting speed. Using this point and eq. (2), process conditions were obtained for improving productivity based on the best feeding speeding.

2.3 Comparison of holes drilling process with different drill shape

Holes process of CFRP with laminate structure has some difficulty for finding an optimum process condition since they are composed of entirely different materials with fiber and epoxy matrix.

Therefore, the determination of the best process condition is important for suitable CFRP due to structural properties of CFRP. Two drill shapes were tested and compared to find out better shape pattern by showing different CFRP drilling process. CVD diamond drill with 4 blades and PCD drill with 2 blades were used to verify the difference in holes processing outcome.

2.4 The comparison of thermal damage of CVD diamond drill

Thermal damage transferring degree during holes drilling process was identified for CVD diamond drill by thermal image camera. Using TGA (TA Instrument Co., Q50), thermal damage history of epoxy matrix was evaluated before and after drilling process conditions. DSC (TA instrument Co., Q20) was also used to find out T_g and T_m of epoxy in CFRP. As temperature evaluating point during exothermal process, T_g was obtained.

2.5 The comparison of measured holes size and condition

Process capability analysis by comparing thermal damage occurring hole drilling process, the accuracy of measured hole diameter and micro-crack degree in the front and back of specimens [3]. Holes size accuracy was measured using Bore gauge and validity of drilling process condition based on cutting theoretical equation was compared. Drilled hole was finally examined visually to find out peel up crack and inside micro-cracks.

3. RESULTS AND DISCUSSION

3.1 Optimum condition of drilling process

Tab.1 Optimum drilling conditions for two drills

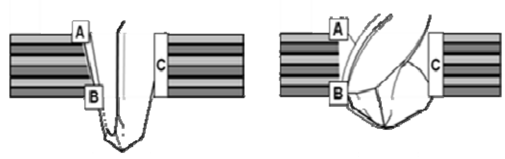
Drill Type	N	F	V_c	F_t	Performance
CVD diamond Drill	5600	400	112.19	0.018	X
Diameter: 6.38mm	4480	400	89.75	0.022	△
AMAMCO Co.	3360	400	67.31	0.030	◎
	2240	400	44.87	0.045	△
PCD Drill	5600	400	111.66	0.036	◎
Diameter: 6.35mm	4480	400	89.33	0.045	○
WALTER Co.	3360	400	67.00	0.060	△
	2240	400	44.66	0.089	X

◎: Excellent, ○: Good, △: Medium, X: Poor

The optimum drilling parameters for CVD and PCD drills were summarized in Table 1. Hole generated condition was checked based on feed per blade, F_t and cutting velocity, V_c for PCD and CVD diamond drills. PCD drill contains two blades with twisted types and rather difficult to process with high feeding condition.

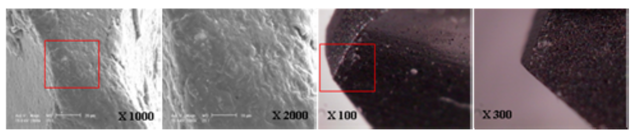
PCD drill was used for drilling fabrication as conditions shown in Table 1. PCD drill exhibited better processability at higher rpm, because of the more powerful drilling. On the contrary, CVD drill has a four teeth shape. Debonding of CFRP occurred at higher rpm due to high drilling power, whereas lower rpm also exhibited a poor processability with high frictional resistance. Optimum feeding per blade, F_t for CVD diamond drill was 0.03 mm/teeth, whereas it was 0.036 mm/teeth for PCD drill. It is to say that PCD drill needs to get faster speed than CVD diamond drill to obtain good hole processing quality.

3.2 Processibility evaluation on drilling



(a) (b)

Fig.1. Modeling of drilling process for: (a) CVD drill; (b) PCD drill



(a) (b) (c) (d)

Fig.2. Photos of drill surface: (a, b) PCD drill; (c, d) CVD diamond drill

Figure 1 showed the drilling modeling of CVD diamond coated drill and PCD drill, and figure 2 showed photos of different drill surfaces for processibility evaluation. PCD and CVD diamond drills showed the different surface modality. PCD drill exhibited a smooth diamond surface. Comparing to PCD drill, non-uniform diamond coating on CVD drill was observed by optical microscope. In PCD drill case, tip part had cutting effect in the drilling process. Delamination occurred easily before the ending of drilling process at high feed setting. Therefore, PCD drill was not fit into high feed condition. CVD drill had lower influence on feed condition than PCD drill. However, rpm was an important parameter for CVD diamond drill. There were some micro-cracks inside of holes at higher rpm condition, whereas CVD diamond drill obtained more damage itself at low rpm condition.

3.3 Comparison of thermal damage of CFRP with each drill

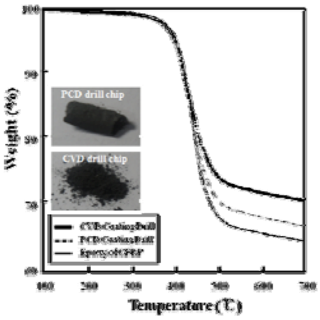


Fig.3. Thermal damages of different drilling process

Heat discharge of every drill was measured by thermal camera. In CVD drill case, the highest temperature inside drilling hole was around 200℃, whereas the highest temperature inside drilling hole for PCD drill was around 160℃. The glass transition temperature, T_g of epoxy in CFRP could be confirmed as 150℃ based on DSC test. High temperature in drilling process cased unstable hole sizes due to thermal damage of epoxy in CFRP. Figure 3 showed TGA results of drilling chips during drilling process for each drill, and thermal damage of CFRP was evaluated by this test. The epoxy content in drilling chips could be measured by heat discharge result. Epoxy content in original CFRP was 32%, whereas epoxy content decreased in drilling chips. From the comparison of epoxy content in chips of different drills, CVD drill exhibited higher heat discharge than PCD drill because of lower epoxy content in chips.

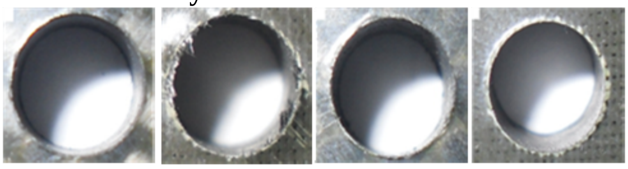
3.4 Evaluation of hole processibility with different chip type

(a) (b) (c)

Fig.4. Photos of different chips: (a) short carbon fiber + few epoxy powder; (b) long carbon fiber + few epoxy powder; (c) short carbon fiber + more epoxy powder

Figure 4 was the optical photograph of chips using different drill. Chips in figure 5(a) occurred in drilling process of CVD drill, because of the more powerful drilling of four teeth CVD drill. However, drilling chips in figure 5(c) occurred at a poor drilling condition. Conglomeration of chips during drilling process cased this phenomenon, since production rate was higher than emission rate. In addition, conglomeration of chips could case microcracks inside of drilling holes. On the contrary, chips of PCD drill were shown as figure 5(a) and 5(b). Chips emission was much easier for PCD drill due to higher helixes angle. Therefore, PCD drill exhibited better processability than the case of CVD diamond drill.

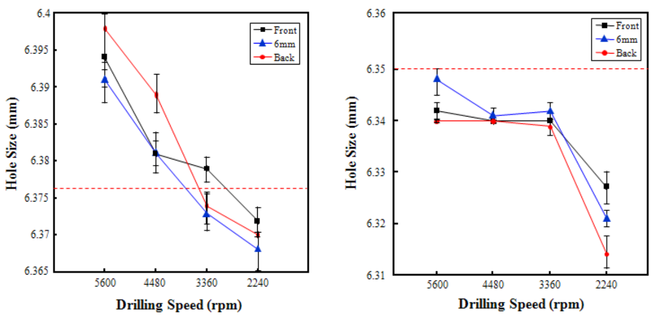
3.5 Processbility evaluation via hole condition



(a) (b) (c) (d)

Fig.5. Photos of hole conditions for: (a, b) PCD drill; (c, d) CVD diamond drill

Figure 5 exhibited photos of the front and back surfaces for two different drilling holes. Microcracks occurred on both sides of CFRP specimen when PCD drill was at high feed value. The reason was that large area tip did not drill the CFRP at the end of drilling process sufficiently under high feed condition. On the contrary, there was no microcrack on the back surface in CVD drill case. Because of the chips emission problem, microcracks were observed on the front surface of drilling holes.

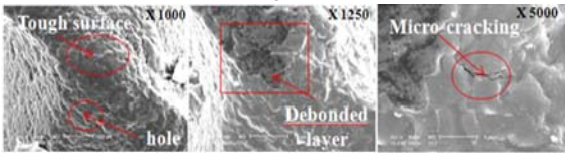


(a) (b)

Fig.6. Comparison of holes size for: (a) CVD diamond drill; (b) PCD drill

Figure 6 showed the comparison of holes size using CVD diamond and PCD drills. Hole size results using CVD drill exhibited a little larger size than standard and higher standard deviation (SD) at high rpm condition. However, SD of hole size was getting lower as rpm decreased due to smaller vibration of drilling process at lower rpm condition. In PCD drill case, higher rpm condition exhibited better hole size results. It is because there was more stable drilling for PCD drill shape at high rpm condition.

3.5 Evaluation of drilling life for different drills



(a) (b) (c)

Fig.7. FE-SEM photos of PCD drill wear condition

Life times of PCD and CVD diamond drill were evaluated by the wear of drill. Figure 7 showed the FE-SEM photos of PCD drill tip after drilling 500 holes. Comparing to CVD drill, PCD drill exhibited better processability due to more smooth diamond surface. There were just some debonding layers and microcrazing on tip surface of PCD drill even after drilling 500 holes. This result indicated that were state of PCD drill depended on diamond layer on drill tip part.

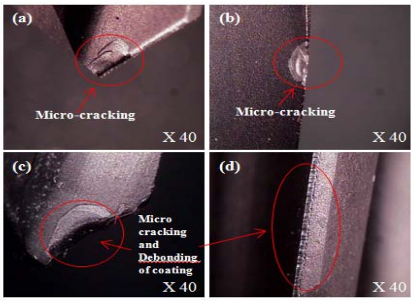


Fig.8. Optical photos of CVD drill wear condition

Figure 8 showed the optical photos of CVD diamond drill tip after drilling 500 holes, and the drill tip was totally different with original drill. CVD drill just had a thin and nonuniform diamond coating on drill surface. Furthermore, four teeth shape drill obtained more thermal and mechanical damages than two teeth shape drill during drilling process. Drilling with thicker CFRP specimen caused more serious wear of drill. 4 teeths of CVD drill played an important role in expanding hole size during drilling, thus tip parts of four teeth exhibited worst damage. CVD drill had a poor durability than PCD drill, since larger damages occurred in drilling process.

Conclusion

Drilling process was very important for construction using CFRP laminate materials. Moreover, drilling condition and design of drill were key parts for drilling industry. The processability of commercial PCD and diversified CVD diamond drill was evaluated in this research work. Four teeth shape design and higher feed value of PCD drill exhibited better processability. CVD diamond drill obtained more thermal and mechanical damages due to chips emission problem.

Acknowledgments

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