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STUDY ON DRILLING CHARACTERISTICS AND MECHANICAL PROPERTIES OF CFRP COMPOSITES

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ABSTRACT Stacking plates of CFRP composite materials are increasingly used because of their unique characteristics. However, unlike other materials used in metallurgy they have a disadvantage of uneven quality and anisotropy when combined with other composites. Hence, specimens of CFRP stacking plates are manufactured by changing orientation angles throughout three quasi-isotropic plies $(0°/45°/90°/-45°)_{6s}$, $(0_3°/45_3°/90_3°/-45_3°)_{2s}$, and $(0_6°/45_6°/90_6°/-45_6°)_s$ and throughout three cross plies $(0°/90°/0°/90°)_{6s}$, $(0_3°/90_3°/0_3°/90_3°)_{2s}$, and $(0_6°/90_6°/0_6°/90_6°)_s$. In this study 3-point bending tests and transverse bending tests have been carried out in order to find out mechanical characteristics according to orientation angles by stacking in 6 different types along with the change of stacking composition method of a CFRP composite.

KEY WORDS composite materials, stacking plates

I. INTRODUCTION

Fiber reinforced plastics (FRP) are so called advanced composite materials (ACM) made of heat-hardened resin with an epoxy resin matrix having excellent chemical characteristics.

These new materials are very lightweight, heat resistant and have excellent mechanical characteristics and control characteristics. Therefore, they are increasingly used as structural materials in such fields as space and aviation industry, mechanical engineering, shipbuilding, and manufacturing of sporting goods, medical instruments and mechanical parts[1–6].

This increased demand necessitates researches on the improvement of processing technology and processing characteristics according to different orientation angles of the stacking or the interface number of the composite material[7,8].

Radhakrishnan investigated evaluating the processing quality of holes generated by dynamic signals in the case of processing the drilling of FRP[9]. Koeng carried out the exfoliation phenomenon of the outer side with the variation of trust as processing the drilling of FRP[7,10]. Caprino investigated the effect of parameters on surface roughness and the mechanical characteristics of GFRP[11].

In this research, drilling characteristics of a CFRP composite have been examined based on lamination thickness and drilling diameter in order to come up with optimum drilling conditions and techniques that are of great practical interest. Then, by carrying out 3-point bending tests and transverse bending

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⋆ Corresponding author. Email: kjcho@chosun.ac.kr tests according to the orientation angle for 6 different stacking composition methods, processing data have been obtained, which can be referenced in the examination of mechanical characteristics of CFRP composite materials.

II. TESTING EQUIPMENTS AND METHODS

Specimens used in these tests are cross plies and quasi-isotropic plies CFRP stacking plates manufactured by stacking one-directional carbon fiber prepreg sheet combined with carbon fiber/epoxy resin (CF/EPOXY) produced by HAN KUK Fiber Co., Ltd. Carbon fiber is a long fiber with a diameter of 8 μm and the thickness of 1 ply of CF/EPOXY prepreg sheet is 0.125 mm. Plies were laminated using the method shown in Fig.1. The specimen of 48 plies was laminated by $[0^\circ/45^\circ/90^\circ/-45^\circ]_{6s}$; that of 32 plies by $[0^\circ/45^\circ/90^\circ/-45^\circ]_{4s}$, and that of 16 plies by $[0^\circ/45^\circ/90^\circ/-45^\circ]_{2s}$. Specimens have been formed in the autoclave. In order to be fixed in test jigs, specimens were cut into 30 mm × 30 mm using a diamond wheel cutter.

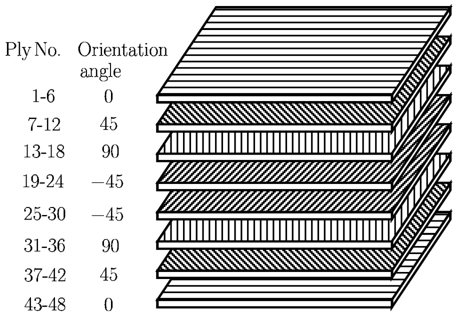


Fig. 1. Stacking sequences of multi-direction hand lay-up.

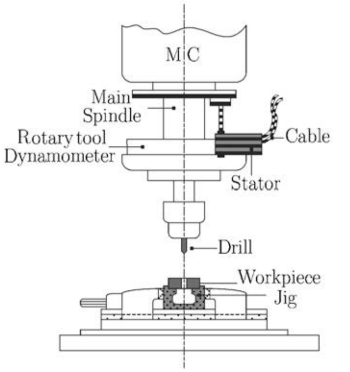


Fig. 2. Schematic of experimental set up.

Figure 2 shows the schematic of the experimental setup. The device used for the experiment is a vertical machining center (Hwachon, HIPLUS-V4). On its vise, a jig manufactured for the experiment was installed to fix the object to be cut. The cutting force was measured using a real-time monitoring system, a rotary tool dynamometer (Kistler, Type 9123c), in wireless data transmission mode. Throughout the entire cutting process, the force applied to the tool and its cutting edge was amplified by the charge amplifier and recorded on the data logger. The recorded signal was once again amplified, and went through A/D conversion at Dynoware (Kistler, Type 2825A). The converted data were analyzed for torque and thrust.

III. EXPERIMENTAL RESULTS AND CONSIDERATIONS

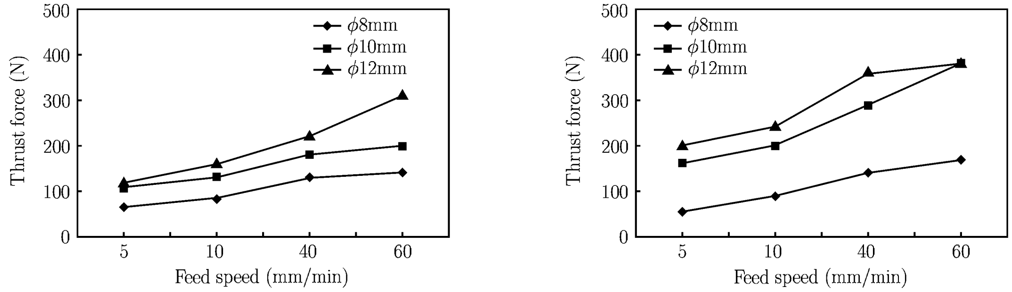
3.1. Relationship between Cutting Force and Feed Speed with Respect to Specimen Thickness and Drill Diameter

Figures 3(a), (b) and (c) show the relationship between the cutting force and the feed speed with respect to specimen thickness and drill diameter at fixed cutting speed of 25.12 m/min.

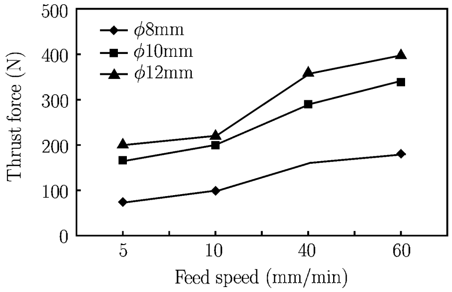
As shown in Fig.3(a), for the lamination of 16 plies, the cutting force does not change significantly with the drill diameter. In other words, thrust changed by about 40 N because of the feed speed difference.

Figures 3(b) and (c) show specimens of 32 plies and 48 plies, respectively. Unlike the case of 16-ply specimen, thrust rapidly increases when the feed speed becomes higher than 10 mm/min, resulting in a considerable difference of thrust of about 170 N.

When the feed speed increases, thrust increases as well. The cutting force for the drill diameter of ϕ8 mm was greatly different from thrusts for drill diameters of ϕ10 and ϕ12 mm. It seems that as the drill diameter gets smaller, the drilling space becomes smaller as well and thus the smaller cutting force is generated.



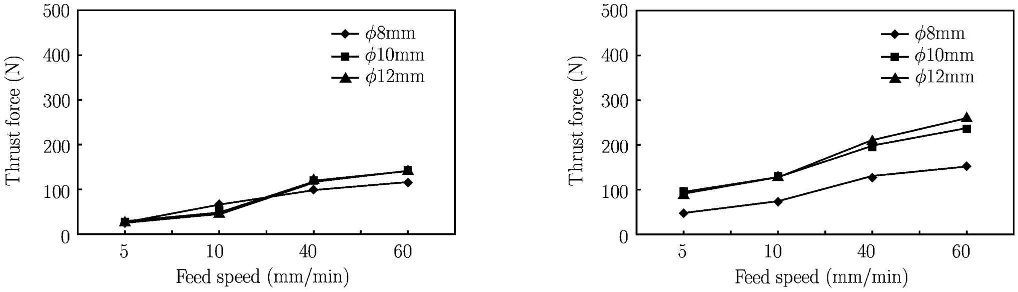
(a) Stacking sequences of specimens ($[0°/45°/90°/-45°]_{2s}$) (b) Stacking sequences of specimens ($[0°/45°/90°/-45°]_{4s}$)



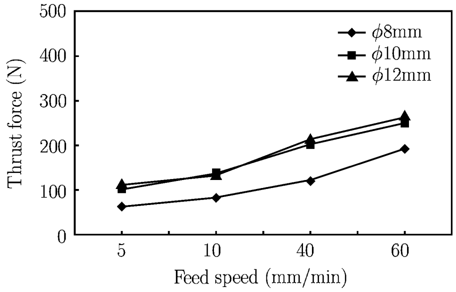
(c) Stacking sequences of specimens ($[0°/45°/90°/-45°]_{6s}$)

Fig. 3. Relationship between cutting resistance and feed speed with respect to thickness of specimens (v: 25.12 m/min).

Figure 4 shows the relationship between the cutting force and the feed speed with respect to specimen thickness and drill diameter at fixed cutting speed of 47.1 m/min. As shown in Fig.4(a), when the feed speed is 5 mm/min, a thrust of about 40 N is generated, but there is almost no thrust difference with regard to the drill diameter.



(a) Stacking sequences of specimens ($[0°/45°/90°/-45°]_{2s}$) (b) Stacking sequences of specimens ($[0°/45°/90°/-45°]_{4s}$)



((c) Stacking sequences of specimens ($[0°/45°/90°/-45°]_{6s}$)

Fig. 4. Relationship between cutting resistance and feed speed with respect to thickness of specimens (v: 47.1 m/min).

In Figs.4(b) and (c), at drill diameters of ϕ10 mm and ϕ12 mm, thrusts are almost the same, but about 40 N larger than those for the drill diameter of ϕ8 mm, which were much smaller than those generated when the specimens were drilled at the cutting speed of 25.12 m/min.

With regard to the drill diameter, less cutting force is generated as the feed speed increases, when the cutting speed was 47.1 m/min rather than when it was 25.12 m/min. When the specimen was drilled with ϕ8 mm drill, the cutting force was hardly affected by the specimen thickness. However, with ϕ10 mm and ϕ12 mm drills, the cutting force was significantly influenced by the specimen thickness. With 16-ply laminated composite, the difference of cutting force was big. For 32- and 48-ply laminate composites, there was almost no difference in the cutting force. This tendency existed in the relationship between specimen thickness and drill diameter, regardless of the cutting speed.

3.2. 3-point Bending Tests and Transverse Bending Tests

Mechanical characteristics of CFRP composite materials are changed by many factors such as the method of stacking prepreg sheet (cross plies, quasi-isotropic plies, etc.), interface number or fiber strength, and also affect the cutting force or processing status during the cutting processing. Therefore, in this study, mechanical characteristics have been examined according to stacking compositions using 3-point bending tests and transverse bending tests for 6 types of CFRP stacking plates including three stacking compositions of quasi-isotropic plies and three compositions of cross plies.

3-point bending tests of CFRP stacking plates have been carried out by placing specimens manufactured according to ASTM standards on top of 3-point bending jig of a universal materials testing device and the load-displacement diagram was obtained as shown in Figs.5 and 6. Figure 5 shows the load-displacement diagram for quasi-isotropic plies specimen and Fig.5 for cross plies specimen.

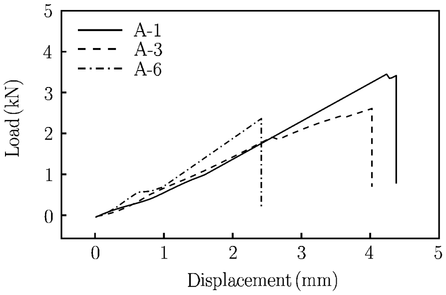


Fig. 5. Relation between displacement and load of quasi-isotropic plies after 3-point bending test.

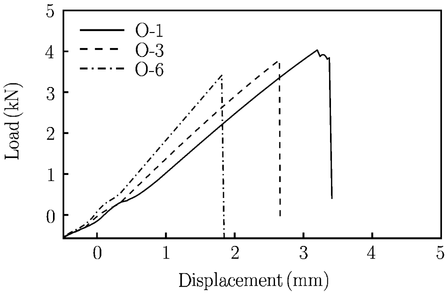


Fig. 6. Relation between displacement and load of cross plies after 3-point bending test.

According to Fig.5, stacking even with the same plies (48-plies) shows an increasing trend of maximum load and displacement as the interface number increases and it was evaluated by considering the area of load-displacement diagram obtained as the result of the bending energy of specimens observed during 3-point bending testing. In addition, the results of 3-point bending tests for cross plies specimen in Fig.6 show the similar trend.

A test was carried out by placing the specimen of a jig with the square orientation frame of 200×200×200 mm^3 and by fixing the clamp plate on its top again to install the transverse static jig of a universal materials testing device in the centre of the specimen. Figures 7 and 8 show load-displacement diagrams for each quasi-isotropic plies and cross plies specimen. Figure 7 shows the load-displacement diagram for quasi-isotropic plies specimen and Fig.8 shows that for cross plies specimen. As shown in the figures, quasi-isotropic plies demonstrate larger maximum load and displacement than the cross plies. The reason might be that specimen stacked with quasi-isotropic plies have bigger elasticity than that of cross plies when the static load is applied. By the same reason, specimen with quasi-isotropic plies stacking demonstrates less exfoliation than that with cross plies stacking.

As one can see from Fig.7, it showed the trend that the maximum load and maximum displacement were increased as interface number increased even when it was stacked in the same plies (48-plies) in the 3-point bending testing, and also it showed the trend that the bending energy was also increased. In addition, the results of 3-point bending testing of cross plies specimen in Fig.8 showed the similar trend.

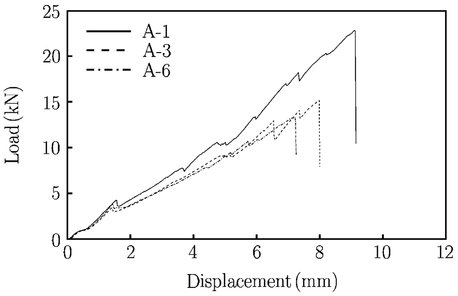


Fig. 7. Relation between displacement and load of quasi-isotropic plies after transverse bending test under static loading.

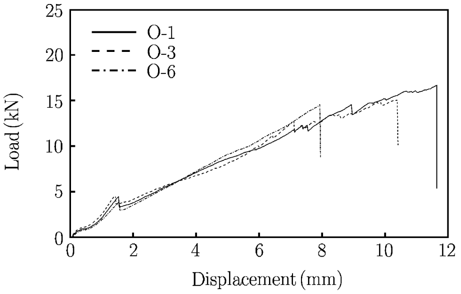


Fig. 8. Relation between displacement and load of cross plies after transverse bending test under static loading.

IV. CONCLUSION

1. With the drill with a diameter of $\phi 8$ mm, thrust almost does not change according to the feed speed, however, as the drill diameter increases, it also increases remarkably.

2. As the interface number increases in the transverse bending test, the initial peak load is increasing as the initial peak load of specimens stacked in quasi-isotropic plies is operated more than cross plies. This conforms well to quasi-isotropic plies stacking composition, in which processing status is excellent during drilling and less cutting force is generated. Therefore, it is believed that specimen shall be stacked with quasi-isotropic plies.

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