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Wear Characteristic on BAM Coated Carbide Tool in Drilling of Composite/Titanium Stack

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This paper studied characteristics on a BAM coated carbide, which comes from a ceramic alloy of boron, aluminum, magnesium, etc., in drilling of CFRP and titanium (Ti) stacks. A series of drilling test was performed starting from drilling of CFRP (top) to Ti (bottom) in the stacks using uncoated tungsten carbide (WC) and BAM coated WC. The BAM coating, which is known for one of the hardest and slipperiest materials. In this regard, BAM coating can be used for cutting tool by reducing the adhesion of work material and interfacial friction. Tool surfaces were periodically measured during the drilling tests using scanning electron microscope (SEM), energy dispersive X-ray spectroscopy (EDS) and confocal laser scanning microscope (CLSM) in order to analyze the tool wear evolution and metallurgical changes on the tool surface. From the experiment, it was observed that no major wear occurred on rake surface and center of the tool while flank wear was significant. The wear mechanisms on flank surface were abrasion and titanium adhesion. The abrasion wear took place by the hard carbon fibers in CFRP and the hard inclusions in titanium. On the other hand, the adhesive wear occurred by pulling out the carbide grains when the adhered titanium layers detached from the tool surface. BAM coated carbide tool showed substantially reduced Ti adhesion especially at high cutting speed. In addition, the lower flank wear was observed for BAM coated tool compared with for uncoated carbide tool.

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1. Introduction

Carbon fiber reinforced plastics (CFRP) and metal (titanium) stacks has been increasingly used in aircraft and transportation industries for increase in fuel efficiency and lifecycle due to its unique properties including high strength to weight ratio, corrosion resistance, etc.[1-4] However, the stacks bring increased challenges for tooling to produce high hole quality and longer tool life. This is because mechanical and thermal properties for these two materials in the stacks are so different. Drilling the stack at one go with same cutting conditions can cause reduced tool life and hole quality, which means that ideal conditions for titanium cutting could not be same for CFRP cutting and vice versa. Therefore, the rapid tool wear and poor hole quality is main concern for stack drilling.

Many works have been performed for analysis of tool wear mechanisms in drilling tools for CFRP and titanium.[8-10] From the literature, it was found that tool wear mechanism in drilling CFRP is completely different that in titanium drilling. In CFRP drilling, the hard carbon fibers can cause the severe abrasive wear on the cutting edge. On the other hand, the titanium can lead built-up-edge (BUE) due to low thermal conductivity and high adhesion tendency to carbide tool, which can cause larger drilling hole size.[4,11] In addition, adhesive wear also takes place by grain pull out when the adhered titanium detached from the cutting surface. Conclusively, these two materials cause the different wear behaviors such that CFRP contributes on edge wear while titanium causes the flank wear. In this regard, the study on the tool coating material, which could reduce the tool wear, has been made. And it was found that the coated tool was outperformed the uncoated tool in terms of the tool wear and surface finish.

In this paper, drilling test for the stacks was performed starting from CFRP (top) to Ti (bottom) in the stacks using uncoated tungsten carbide and BAM (boron aluminum magnesium). Tool surfaces were periodically measured during the drilling tests using scanning electron microscope (SEM) and confocal laser scanning microscope (CLSM) in order to observe the tool wear evolution and to analyze the tool behavior.

2. Experimental setup

2.1 Work and tool material

The CFRP laminates, which is multidirectional graphite epoxy composites consisting of graphite fibers and an epoxy matrix with a quasi-isotropic ply orientation, and Ti-6Al-4V were used in this study. And the stacks were supplied by The Boeing Company. In the stack, the CFRP had a thickness of 7.54 mm while the titanium plate had a thickness of 6.73 mm.

The BAM, which is a ceramic material that combines metal alloy of aluminum, magnesium and boron, was coated on carbide tools by PVD. And the BAM coating has a high hardness and low friction coefficient as low as 0.02.

The uncoated and BAM coated carbide tools (WC: 9% Co ultra fine grain grade) were test to characterize the machining performance of BAM coating in drilling stacks. In this study, BAM coating were provided by Fraunhofer CCL in USA.

2.2 Drilling test

The drilling tests were performed on the CNC HAAS MiniMill. The drilling sequence was starting from CFRP (top) to titanium alloy (bottom) as shown in Fig. 1. The stacked materials were clamped to Al fixture for drilling test. As summarized in Table 1, the cutting speed for CFRP drilling was 2000 RPM while that for titanium drilling was reduced to 400 RPM to avoid catastrophic tool failure. However, the feed rate was kept constant. A water soluble oil mist was also applied during the test.

The tool wear was measured by means of CLSM and SEM after drilling of 20 holes. And then the 3D surface profiles were extracted to analyze tool wear progress and amount of titanium adhesion. The detail information of tool wear characterization method can be found in.[9,10]

3. Results and discussion

Fig. 2 shows the SEM images of the uncoated and BAM coated drills after drilling of 20 holes. Both cases show titanium adhesion on the entire cutting surfaces. This is mainly due to high affinity of the titanium to the carbide. As seen in Fig. 2, the more adhesion was observed on the uncoated carbide than on the BAM coated one, especially at high cutting speed. From the observation, it was found that BAM coating slightly hindered the titanium adhesion on the drill surface, as low friction coefficient of the coating.

To characterize the tool behavior during the drilling, the CLSM images were also taken at every 20 holes. Fig. 3 represents the flank surface of the drill at 60 holes before and after etching of the titanium by CLSM, which can be converted to 3D surface topography as seen in Fig. 4. This surface topography in turn was used for tool wear evolution and quantity of the titanium adhesion.

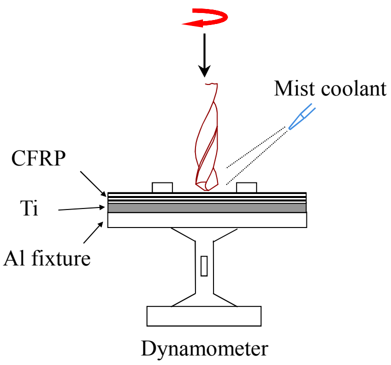


Fig. 1 Drilling test setup

Table 1 Drilling conditions

Cutting speed	Low: 2000 RPM in CFRP, 400 RPM in Ti High: 6000 RPM in CFRP, 800 RPM in Ti
Feed	0.051mm/rev

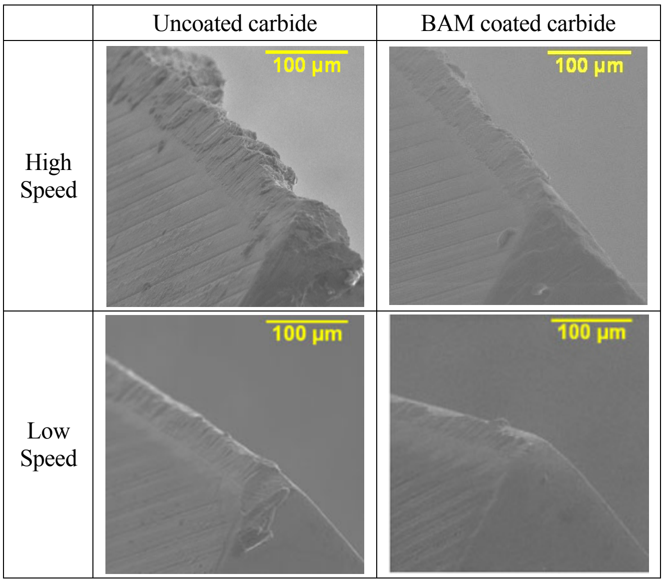
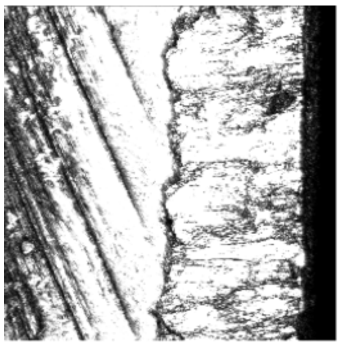
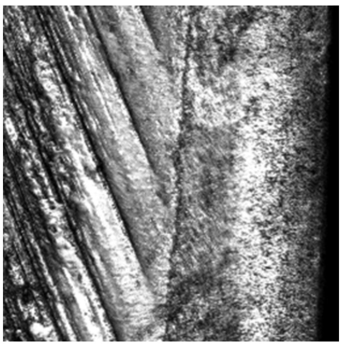


Fig. 2 SEM images of the drill surfaces



(a) Before etching



(b) After etching

Fig. 3 Flank surface images by CLSM

Fig. 5 shows the 2D cross-sectional profiles of the flank surfaces at various holes drilled using CLSM images for the uncoated and BAM coated carbide drills at high cutting speed. It was clearly observed that the BAM coated drill substantially reduced the titanium adhesion as well as the flank wear. From the previous work, it was found that the edge wear occurred by hard carbon fiber in CFRP while the flank wear increased mainly by hard inclusion such as TiC in titanium alloy.[9,10] And Fig. 5 shows that dominant wear mechanism is the edge wear for BAM coated carbide, especially at 40 holes. Therefore, it can be concluded that the BAM coating worn down during the drilling mainly by the carbon fibers. In addition, energy-dispersive X-ray spectroscopy (EDX) shows that the BAM coating was started to be abraded after 20 holes drilling so that the carbide substrate was exposed as shown in Fig. 6 (#4 & #5). However, the BAM coating exhibited the resistance against the titanium adhesion and flank wear, which is beneficial effect of BAM coating. This is because low friction coefficient of the BAM coating can reduce the adhesion tendency of the materials and the flank wear.

However, the adhesion quantity of the titanium was slightly increased after drilling 40 holes as shown in Fig. 5(b). One possible reason can be that the cutting temperature was increased due to the tool wear. On top of that, the BAM coating was delaminated at 40 holes drilling as seen in Fig. 7. This is because that the BAM coating was taken off when the adhered titanium was detached. Therefore, this coating delamination caused to increase the adhesion tendency, which accelerates titanium adhesion and flank

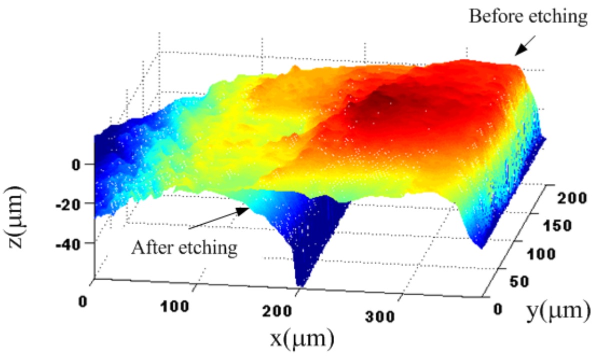
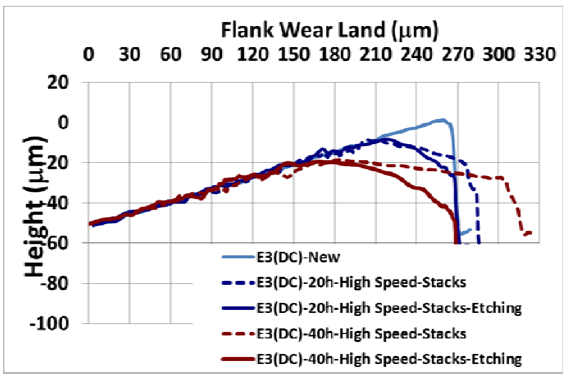
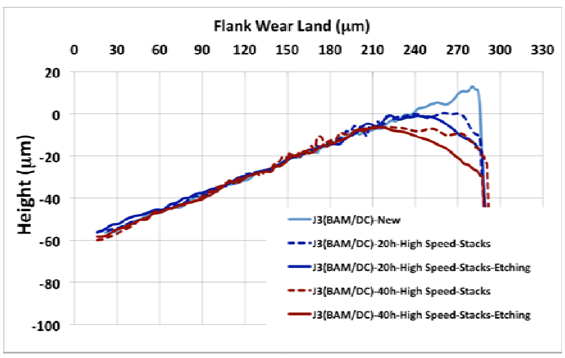


Fig. 4 3D surface topography by image processing technique



(a) Uncoated carbide drill



(b) BAM coated carbide drill

Fig. 5 Tool wear evolution at high cutting speed

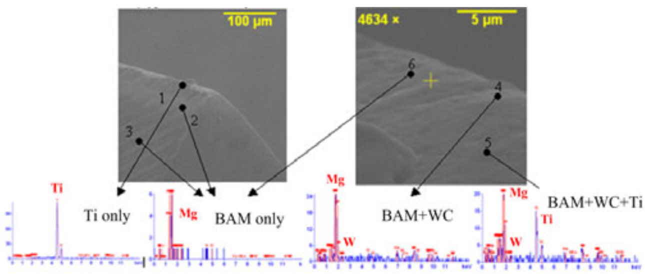


Fig. 6 EDX results of BAM coated carbide drill

Fig. 7 Coating delamination on flank surface

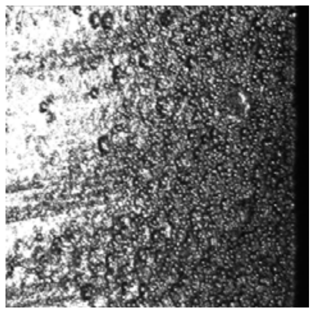


Fig. 8 The surface image of BAM coating

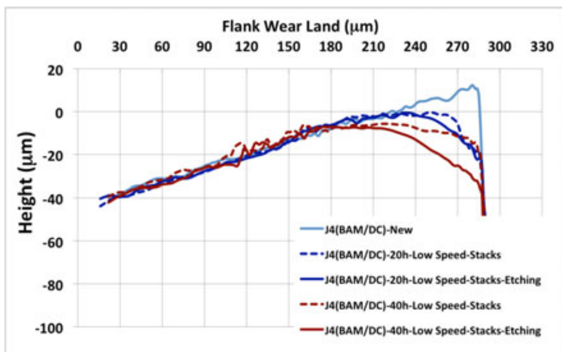


Fig. 9 Tool wear evolution for BAM coating at low cutting speed

wear again.

One of the reasons that the BAM coating was delaminated can be because of rough surface of the BAM coating as shown in Fig. 8. The rough surface of the coating can be easily flaked off from the carbide substrate with shear force generated during the drilling.

Fig. 9 shows the tool wear evolution of BAM coated tool at low cutting speed. Similar to the case of the high cutting speed, the quantity of the adhesion became increase as drills with same mechanism. It was observed that the flank and edge wear at high cutting speed were not higher than those at low cutting speed. In fact, the flank wear was higher at low cutting speed after 40 holes drilling. This phenomenon could be explained by that at low cutting speed the cutting temperature was not that high so the carbon fibers can more abrasive than that at high cutting temperature. Therefore, it can be said that the BAM coating was more beneficial at high cutting speed.

4. Conclusions

The following conclusion can be drawn from this work.

1. BAM coating was effective on the titanium adhesion and tool wear especially at high cutting speed compared to uncoated carbide case. Therefore, the BAM coating can be more beneficial in severe machining condition.
2. The BAM coating was worn down at drilling of 20 holes and the adhesion and wear was increased after 40 holes drilling mainly due to the coating delamination.
3. The coating delamination occurred possibly due to the rough surface of BAM coating on the carbide. So, if the case, the surface quality of BAM coating has to be improved to be more effective in drilling process.
4. The dominant tool wear mechanism in drilling was edge wear by hard carbon fibers in CFRP.
5. Therefore, the BAM coating can be beneficial CFRP/titanium stack drilling at high cutting speed unless the coating is delaminated from the cutting surface.

ACKNOWLEDGEMENT

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