EFFICIENCY IMPROVEMENT OF SMALL-DRILLING ON TITANIUM ALLOYS BY DIAMOND-LIKE CARBON COATINGS

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ABSTRACT

Hydrogen and silicon-nitrogen incorporated into diamond-like carbon films were prepared on tungsten carbide drills by the PBII technique. The small drill with 1 mm diameter drilled on Ti-6Al-4V titanium alloy plate with 1 mm thickness. The dry drilling experiments were conducted until each drill produced 200 holes. The efficiency of uncoated- and coated-drills were investigated in term of hole diameter and hole surface roughness, as well as wear on the tool surface. It was observed that by increasing the number of drilling, the hole diameter drilling by uncoated- and coated-drill tends to decrease. This is due to wear occurred on drill tool. H-DLC- and Si-N-coated-carbide drill showed efficiency improvement of 1.4 times longer tool life than uncoated-drill tool. This is due to high film hardness of H-DLC film, and low friction coefficient and low internal stress of Si-N-DLC films. H-DLC-coated-drill showed lowest hole diameter transfiguration percentage at 0.6. H-DLC-coated-drill showed best surface finish with R_a value of 7.587 µm.

1. INTRODUCTION

Titanium and its alloys are attractive materials in many engineering fields such as aerospace, vehicles, engines and gas turbines, biomedical, etc. This is mainly due to their mechanical and physical properties such as, high strength to weight ratio, high yield stress, very high creep and corrosion resistivity, high wear resistance and good biocompatibility (Choragudi, et al., 2010), (Ulutan, et al., 2011), (Ohkubo, et al., 2006). In addition, titanium alloys are low density materials which maintain their hardness and strength to weight ratio between all common metals up to 550°C. However, its application is limited to 400°C as it can ignite and cause serious problems during operation (Jeffery, et al., 2008). These properties conjunction with high chemical reactivity, low thermal conductivity, high specific heat and high strain hardening, (work hardening) have made machining of titanium alloys extremely difficult, which is often associated with low productivity and very short tool life (Jeffery, et al., 2008), (Zhang, et al., 2009). As titanium alloys maintain their strength even at very high temperatures, increases in the cutting temperature is not beneficiary for machining these materials where the cutting tools suffer from heat softening.

Diamond-Like Carbon (DLC) film are amorphous film that exhibit properties of high hardness and elastic modulus, low friction coefficients, good wear resistance and excellent corrosion resistance. Therefore, the films are commonly applied in magnetic storage, automobile, tooling, biomedical, and other applications. Many researchers have reported that the introduction of additional elements such as silicon, oxygen, nitrogen, and various metals, can improves the properties of DLC films (Kwak, et al., 2005), (Cruz, et al., 2006). Methods for preparing DLC films include ion beam-assisted deposition, magnetron sputtering deposition, plasma assisted chemical vapor deposition and plasma-based ion implantation. Currently, there is no report aimed to study the efficiency improvement of small-drilling on titanium alloys by DLC coatings.

In this paper, Plasma based ion implantation (PBII) technique was utilized to prepare hydrogen, and silicon-nitrogen incorporation into DLC films. The aim was to study the efficiency improvement of small-drilling on titanium alloys by DLC coatings.

2. EXPERIMENT

2.1 Workpiece materials

The workpiece material used in machining test is Titanium alloy Ti-6Al-4V. An annealed titanium workpiece was a rectangular plate of 50x65 mm with 1 mm thickness.

2.2 Coated and uncoated drills

Un-coated, H-DLC and Si-N-DLC coated drills made of WC were used in this investigation as shown in Fig. 1. The carbide drills with diameter of 1 mm had the flute length of 5 mm. The shank diameter and overall length were 3 mm and 38 mm, respectively. The drills had the point angle of 130°.

Fig. 1 Tungsten carbide drills used in this experiment.

(Union Tool Co., Ltd.).

2.3 Drilling experiments

Drilling experiments with dry condition were carried out on the CNC machining center (RXP300, Roder TEC). The spindle speed and feed rate were kept constant at 19200 RPM and 120 mm/min. The drilling experiments were conducted until each drill produced 200 holes or failed.

2.4 DLC films preparation

A schematic of the PBII apparatus used for the deposition of hydrogen and silicon-nitrogen into DLC films was previously shown (Moolsradoo, et al., 2010).

The substrate of small drills were sputter cleaned with Ar^+ for 20 min to remove surface contaminants and surface oxides using a negative bias voltage of -10 kV. The first layer was deposited with CH_4 for 60 min to improve the adhesion between the film and the substrate using a negative bias voltage of -20 kV. The H-DLC and Si-N-DLC films were deposited from gaseous mixture showed in Table 1. The bias voltage was set to -5 kV, at an RF power of 300 W. The pulse frequency was set to 1 kHz at a pulse width of 5 µs and a pulse delay of 25 µs. The deposition pressure was set to 2 Pa. The total deposited thickness of all films was approximately 500 nm. For comparison, pure DLC film was also deposited on drills substrate using C_2H_2 gas by the same deposition process at 2 Pa deposition pressure. The relative concentration and the mechanical properties of all films were shown in Table 2 and 3.

Table 1 Deposition conditions for all films.

Film types	Gaseous Mixture	Flow rate ratio
H-DLC	C_2H_2:H_2	2:1
Si-N-DLC	C_2H_2:TMS:N_2	14:1:2

* TMS = Tetramethylsilane ($C_4H_{12}Si$)

Table 2 Relative concentrations (Jongwannasiri, 2013).

Film types	Flow rate	Relative atomic content (at.%)		
		C	Si	N
H-DLC	2:1	-	-	-
Si-N-DLC	14:1:2	69	23	8

Table 3 Properties of all films (Moolsradoo, et al., 2010).

Film types	Mechanical properties		
	Hardness	Friction	Stress
H-DLC	12.2 GPa	0.07	1.32 GPa
Si-N-DLC	11.1 GPa	0.05	1.02 GPa

2.5 Tool wear evaluation

The hole diameter on titanium plated was measured by optical microscope. The hole surface roughness (R_a) was measured by surface roughness tester (Surfcorder; SE1200). Tool wear was measured by scanning electron microscope (SEM).

3. ANALYSIS

3.1 Hole diameter after drilled at 200th hole

The hole diameter at 200th hole are shown in Fig. 2. The results showed that the hole diameter of uncoated- and coated-drill tends to decreased with hole quantity. Moreover, it was found that uncoated-drill brittle failed at the 145th hole, while the longest tool life up to the 200th hole was recorded for both H-DLC and Si-O-DLC coated-drill. This is due to high film hardness of H-DLC film, and low friction coefficient and low internal stress of Si-N-DLC films. The resulted showed an outstanding performance of the coated-drill when prepared to uncoated-drill tool. Therefore, the results indicated that the H-DLC- and Si-O-DLC-coated-drill presenting the 1.4 times longer tool life than uncoated-drill tool. Moreover, the hole diameter transfiguration percentage of H-DLC-coated showed lower than Si-O-DLC-coated drill. The values obtained for H-DLC-coated drill was 0.6%, while for Si-N-DLC-coated drills was 1.3%.

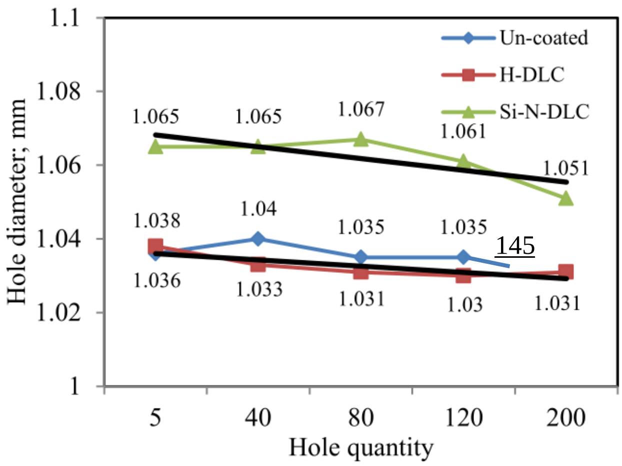

Fig. 2 Hole diameter of all films after drilled.

From Fig.3 and 4, the wear occurred along the drill's cutting edge and the flank faces. Moreover, it was found that the titanium workpiece material adhered to the chisel and the cutting edges. The adhered titanium was the main factor to the tool failure. Titanium is highly chemical reactive with the tendency of welding on the cutting tool during machining. In the beginning, the adhered titanium may protect the cutting edges from wear, with prolonged drilling the adhered titanium becomes unstable and breaks away from the tool carrying along small amount of tool particles. This leads to severe chipping on the cutting edge.

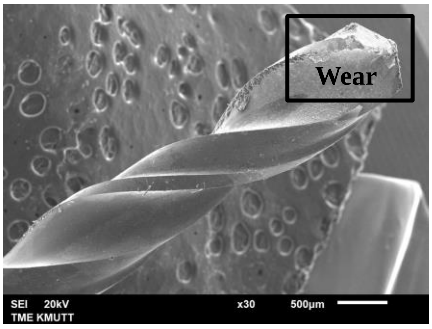

Fig. 3 Wear of Drill coated by Si-N-DLC film after drilled at 200 holes.

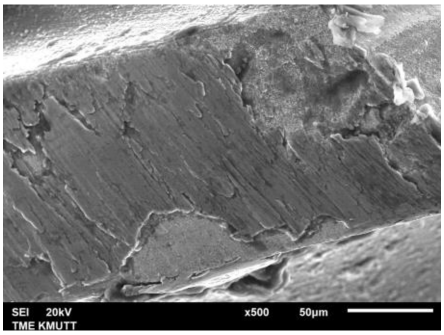

Fig. 4 Wear of Drill coated by Si-N-DLC film after drilled at 200 holes.

3.2 The hole surface roughness

Fig. 5 showed the hole surface roughness value (R_a) of the final hole when the tool criteria were met for each test. It is evident that H-DLC-coated drill produced better surface finish when compared to Si-N-DLC-coated and uncoated-drills. The R_a values obtained for H-DLC-coated drill was 7.587 μm, while for Si-N-DLC-coated- and uncoated-drills were 9.765 μm and 11.297 μm, respectively. The wear pattern of the coated-drill may have an influence on the surface roughness since the damage on the cutting edge was less when compared to uncoated-drills.

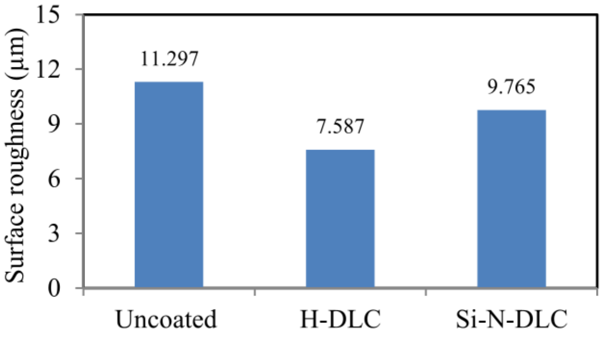

Fig. 5 Hole surface roughness of all drills.

CONCLUSION

Hydrogen and silicon-nitrogen incorporated into diamond-like carbon films were prepared on tungsten carbide drills by the PBII technique. The small drill with 1 mm diameter drilled on Ti-6Al-4V titanium alloy plate with 1 mm thickness. The dry drilling experiments were conducted until each drill produced 200 holes. The efficiency of uncoated- and coated-drills were investigated in term of hole diameter and hole surface roughness, as well as wear on the tool surface. It was observed that by increasing the number of drilling, the hole diameter drilling by uncoated- and coated-drill tends to decrease. This is due to wear occurred on drill tool. H-DLC- and Si-N-coated-carbide drill showed efficiency improvement of 1.4 times longer tool life than uncoated-drill tool. This is due to high film hardness of H-DLC film, and low friction coefficient and low internal stress of Si-N-DLC films. H-DLC-coated-drill showed lowest hole diameter transfiguration percentage at 0.6. H-DLC-coated-drill showed best surface finish with R_a value of 7.587 μm.

REFERENCES

Union Tool Co., Ltd., http://www.uniontool.com/cgi-bin/pdfs/metalworking/utdsx.pdf

Choragudi, A., Kuttolamadom, M.A., Jones, J.J., Mears, M.L., Kurfess, T., Investigation of the machining of titanium components in lightweight vehicles, *SAE International Congress*, 2010.

Ulutan, D., Ozel, T., Machining induced surface intergrity in titanium and nickel alloys: a review, *Int. J. Mach. Tool Manu.*, vol. 51, pp. 250-280, 2011.

Ohkubo, C., Hosoi, T., Ford, J.P., Watanabe, I., Effect of surface reaction layer on grindability of cast titanium alloys, *Dental Mater.*, vol. 22, pp. 268-274, 2006.

Jaffery, S.I., Mativenga, P.T., Assessment of the machinability of Ti-6Al-4V alloy using the wear map approach, *Int. J. Adv. Manu. Tech.*, vol. 40, pp. 687-696, 2008.

Zhang, S., Li, J.F., Sun, J., Jiang, F., Tool wear and cutting forces variation in high-speed end-milling Ti-6Al-4V alloy, *Int. J. Adv. Manu. Tech.*, vol. 46, pp. 69-78, 2009.

Kwak, S.C.H., Wang, J., Chu, P.K., Surface energy, wettability, and blood compatibility phosphorus doped diamond-like carbon films, *Diamond Relat. Mater.,* vol. 14, pp. 78-85, 2005.

Cruz, R., Rao, J., Rose, T., Lawson, K., Nicholls, J.R., DLC-ceramic multilayers for automotive applications, *Diamond Relat. Mater.,* vol. 15, pp. 2055-2060, 2006.

Moolsradoo, N., Watanabe, S., Modification of tribological performance of DLC films by means of some elements addition, *Diamond Relat. Mater.,* vol. 19, pp. 525-529, 2010.

Jongwannasiri, C., Watanabe, S., Improvement of thermal stability and tribological performance of diamond-like carbon composite thin films, *Mater. Sci. Appl.*, vol. 4, pp. 630-636, 2013.

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