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Wear of diamond-coated cutting tool inserts upon machining of Al-12%Si and glass fiber/polyester resin composites

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Abstract

Results of the wear resistance of the diamond-coated cutting tool inserts upon machining Al-12%Si alloy and glass fiber/polyester resin composites are presented in this paper. The aim of this paper was to demonstrate the advantages of application of cutting tool inserts with the diamond coating over the conventional tungsten-carbide (WC) tools, and to obtain the cheaper serial production (shorter machining time) and satisfactory lifetime of the diamond cutting tool inserts. Surface roughness of the machined samples was measured for both as-received and diamond coated inserts. The diamond microstructure of undamaged part of inserts as well as the appearance of microstructure of diamond coated inserts after machining has been investigated. Results of the behavior of two regimes of preparation of diamond-coated inserts were compared and analyzed. Generally, the wear resistance of the diamond-coated cutting tool is superior over the conventional tool.

Keywords: *diamond-coated cutting tool insert, machining, wear resistance, microstructure*

I. Introduction

The cutting tool inserts with a diamond coating are relatively new material whose application is particularly important in the mass production of parts made of different materials such as Al-based alloys and glass fiber/polyester resin composites [1–3]. These tools found the broad application in auto and military industry. Two essential advantages of these inserts may be described as follows: greatly reduced wear and good quality of the machined surface, which considerably reduce the cost of machining in industrial production [4,5].

The object of the present study was to demonstrate the advantages of tungsten carbide (WC) tool inserts coated with diamond over the uncoated inserts in machining Al-12%Si alloy and the glass fiber/polyester resin composites. Comparisons of wear curves and surface roughness of these two inserts for two regimes of machining were presented.

II. Experimental procedure

The tungsten carbide inserts coated with the diamond were used in the present study. The coatings were obtained by two different pre-treatment procedures:

1. Treatment with an oxygen-acetylene flame, dissolving Co in strong acids (HCl and HNO_3), ultrasonic seeding of the surface with fine diamond powder, denoted as PT-A;
2. Treatment with the Murakami solution [6,7], passivation of Co using a H_2O_2 + H_2SO_4 mixture. The following deposition conditions were used: temperature T = 1073 K, time t = 20 min and the flow rate ratio of C_2H_2 and O_2 R = 1.5, denoted as PT-B.

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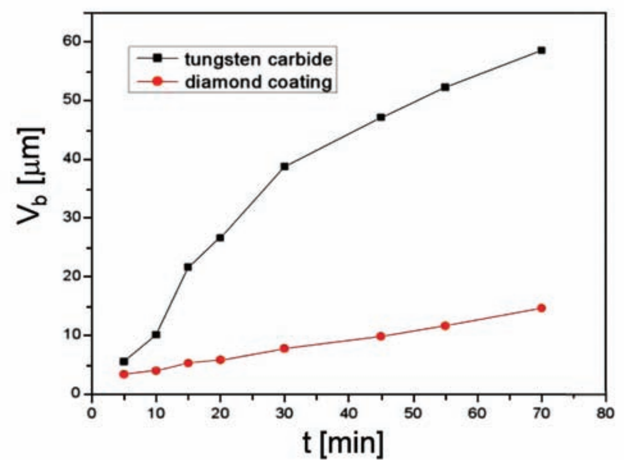


Figure 1 Comparison of wear with WC tool and diamond coated tool inserts processed with regime PT-A

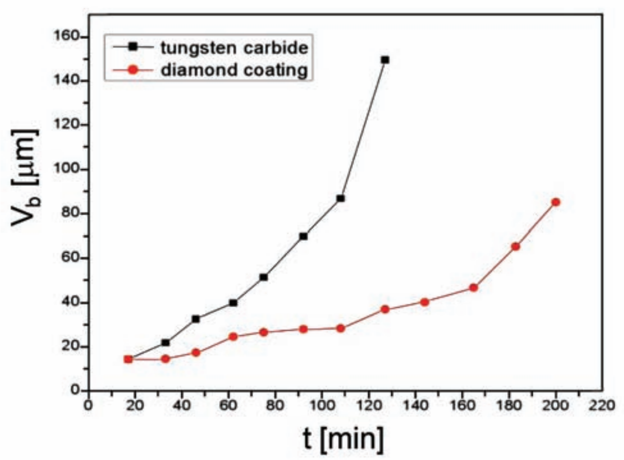


Figure 2. Comparison of wear with WC tool and diamond coated tool inserts processed with regime PT-B

Different machining regimes were applied for studying the wear behaviour [8–10]:

1. Machining of Al-12%Si alloy was done with: cutting speed n = 400 rev/min, feed rate s = 0.1 mm/rev; depth of cut d = 0.5 mm; diameter of sample Ds = 75 mm.
2. Machining of glass fiber/polyester resin composites was done with: cutting speed n = 400 rev/min; feed rate s = 0.196 mm/rev; depth of cut d = 0.25 mm (set of eight tubes with diameter Ds/Dv = 66/61 mm). In order to shorten the machining time for the set of fiber/polyester tubes the following regimes were applied: n = 740 rev/min; s = 0.196 mm/rev; d = 0.25 mm.

The same machining regimes were used for both pre-treatment conditions.

Surface roughness curves were obtained using a three-dimensional surface structure analyzer ZYGO New View 7100 optical profiler. Scanning white light interferometry was used to scan and measure test surfaces providing surface structure analysis without contact with the surface. Samples machined with tungsten carbide (WC) conventional tools and tools with diamond coating were analyzed applying magnification of 10× and 40× of ultra-high resolution camera. In case of the inserts with diamond coating wear curves were obtained after 15, 45, 125 and 160 min of Al-12%Si alloy machining, and after 15 and 45 min when WC conventional tool was applied. Scanning electron microscopy (SEM Type) was applied for characterization of tool surfaces.

III. Results and discussion

Wear diagrams obtained upon machining Al-12%Si alloy are shown in Figs. 1 and 2.

Wear curves obtained with the WC tool inserts and diamond coated inserts processed by pre-treatment regime PT-A are presented in Fig. 1. The crater height on the flank surface of the insert, Vb, was used as a measure of wear. The measurements were performed for both types of tools up to 65 min of machining. Compared with WC tool insert, the wear of the diamond coated insert after 5 and 65 min of machining was 2 and 4 times lower, respectively.

The wear diagram of inserts pre-treated according to the regime (b) is presented in Fig. 2. For 30 and 125 min of machining the diamond coated inserts show 2 and 5 times lower wear, respectively, than the WC tool inserts.

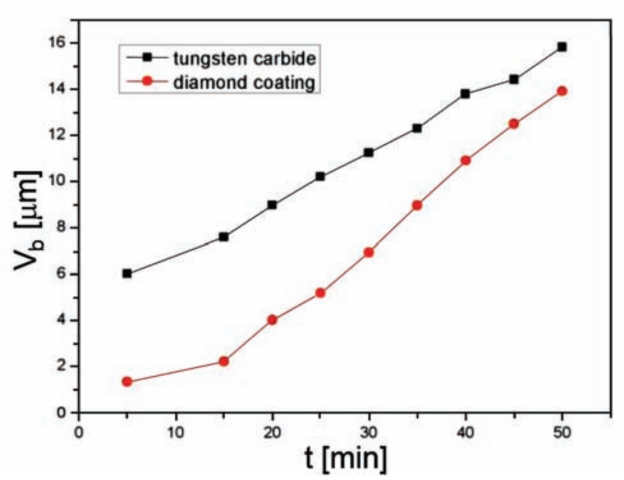


Figure 3. Wear diagram for cutting speed 400 rev/min

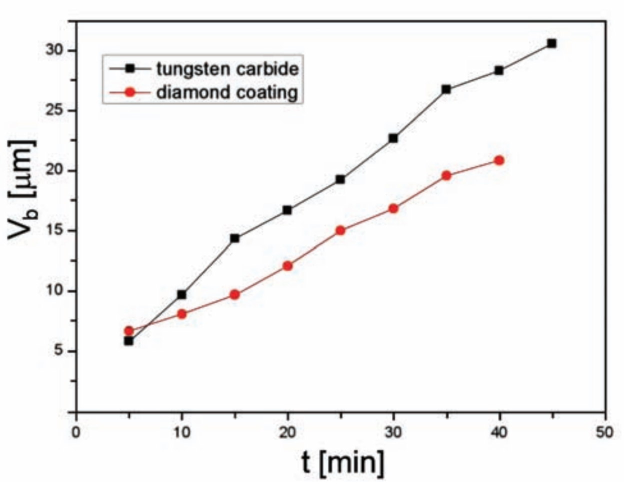


Figure 4 Wear diagram for cutting speed 740 rev/min

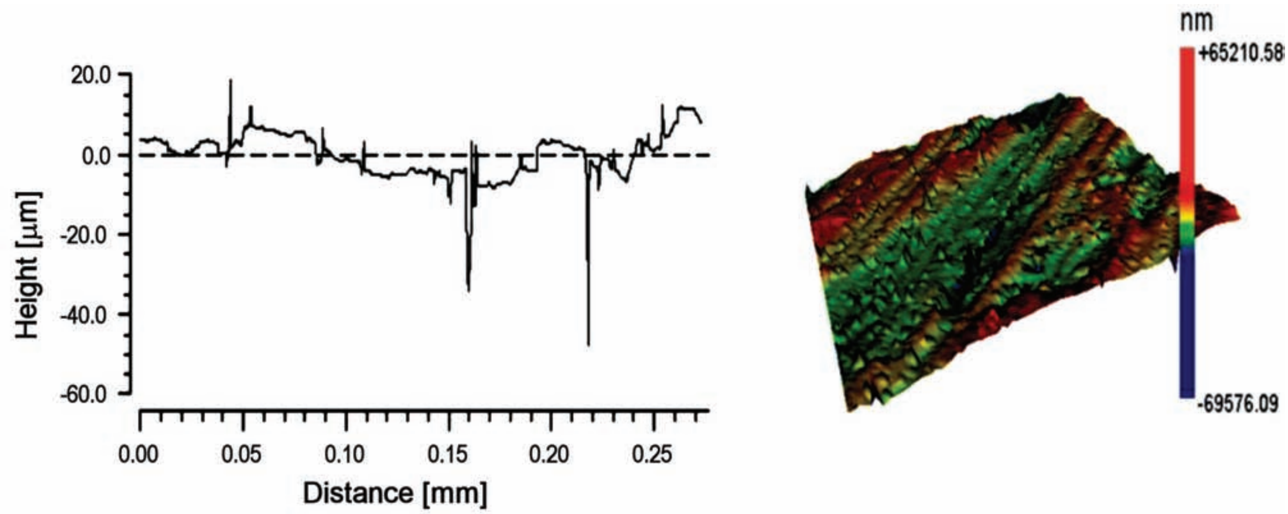


Figure 5. The 2D surface profile and 3D surface profile, after 45 min of machining (diamond coated insert)

Wear diagrams obtained upon machining glass fiber/polyester resin composites for different cutting speeds are shown in Figs. 3 and 4. From Fig. 3 (the cutting speed 400 rev/min) it may be seen the wear of diamond cutting inserts is significantly reduced (five times) over the WC tool insert at lower machining time. This advantage is decreased with machining time, but at 50 min of machining the wear of diamond coating is still 10% lower.

Wear diagram with increased cutting speed is presented in Fig. 4. It should be noted that the full time of machining of the set of 8 tubes was 45 min. It is obvious that with the increase of cutting speed the difference in wear between these two tool inserts was reduced, but upon the whole period of machining time the wear of diamond coated inserts is still lower for at least 30%. The results of this diagram show that higher cutting speed may be applied without any significant harmful effect on the wear of diamond coated inserts.

The surface roughness diagrams for both diamond coated and WC tool inserts after 45 min of machining are presented in Figs. 5 and 6, respectively.

The average surface roughness is obtained with the diamond coated tool inserts is about 2–3 times lower (Ra ~ 4.2 µm) (Fig. 5) than with WC tool inserts (Ra ~ 9.7 µm) (Fig. 6). These results were obtained with the pre-treatment procedure PT-B.

The appearance of the surface of the diamond coated inserts after machining Al-12%Si alloy for the longest machining time is presented in Fig. 7. The part of the coating that remained on the substrate does not show any visible damage (Fig. 7a).

The diamond crystals cannot be broken or damaged (except for some flattening of tips) during the machining. However, it is possible to rip off diamond crystals virtually undamaged from the substrate (see white spots in Fig. 7a). This indicates that adhesion of the coating is not strong enough in every point of the coating surface. Fig. 7b shows the surface coating at a point about 100 µm distant from the edge of insert. A part of the coating was peeled off during the machining process, which may be the cause of an intensive wear.

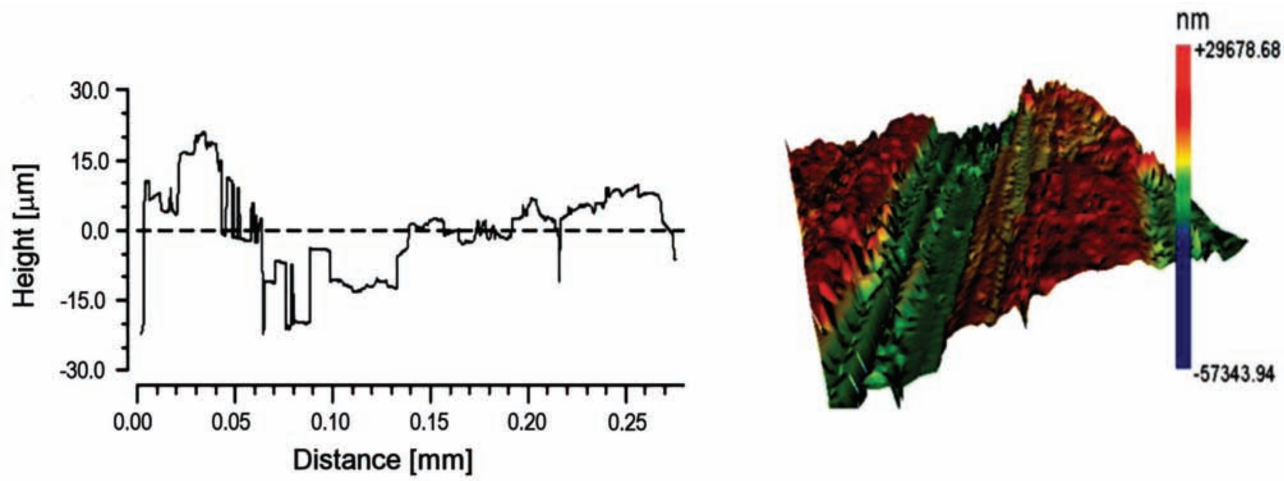
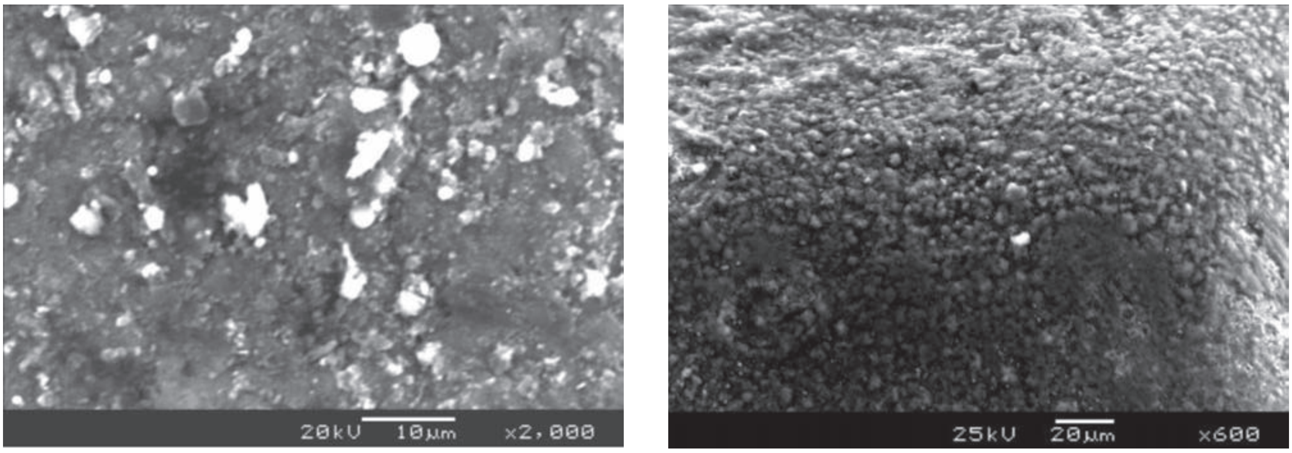


Figure 6. The 2D surface profile and 3D surface profile, after 45 min of machining (WC insert)



a) b)

Figure 7. SEM images of a) surface of undamaged diamond coated insert and b) surface of the diamond coated insert after use

IV. Conclusions

Comparing the wear results obtained by using diamond coated and tungsten carbide cutting tool inserts for machining the Al-12%Si alloy and the glass fiber/polyester resin composites under identical conditions, the following conclusions can be derived:

1. Wear of the diamond coated inserts is 2 to 5 times lower than that of the tungsten carbide insert for Al-12%Si alloy and 10% to 5 times lower for the glass fiber/polyester resin composites.
2. The average surface roughness of the machined surface is between 2 and 3 times lower when the diamond coated inserts are used for turning Al-12%Si alloy.
3. The diamond crystals in the coating surface are not broken or damaged during machining, but some of them may be removed virtually undamaged from the substrate.

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