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WEAR RESISTANCE OF DIAMOND-COATED WC TOOLS WHEN MACHINING Al-12% Si

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Abstract

The study began with experimentally obtained wear curves for diamond-coated and uncoated tungsten carbide turning inserts after 100 min of continuous machining of Al-12%Si alloy. With the help of a mathematical model, more precisely, numerical interpolation methods, these curves have been "expanded" to quite reliable wear curves up to 1700 min. of continuous cutting and during this time, wear resistance curves were determined as the best parameter for expressing various tribological characteristics, and above all, the durability of tungsten carbide turning inserts with diamond coating during machining of Al-12%Si. Wear resistance also indicates the machinability properties of Al-12%Si. The experiment is only related to recording wear curves; everything else has a theoretical approach.

Keywords: numerical interpolation, wear resistance, theoretical approach

1 INTRODUCTION

All tool materials have the property of resisting wear, i.e. have a certain wear resistance.

By resistance to wear we essentially mean the ratio of the work spent (W_τ) from the frictional force to convert the worn body into wear products, and the mass of the wear products (m_τ),

$$R = \frac{W_\tau}{m_\tau} \quad (1)$$

Wear resistance depends on a number of factors such as: contact kinetics, contact surface, friction coefficient, pressure and temperature on the contact surfaces, etc. The parameters affecting wear resistance may vary during contact depending on the physical and mechanical properties of the contacting bodies. Consequently, wear resistance should be regarded as a variable

property rather than a fixed material characteristic. Therefore, the wear resistance of cutting tools is defined as the quantitatively expressed ability of the material to resist wear under specific cutting conditions. The quantitative assessment of tool wear resistance is expressed by the first derivative of the cutting time function (τ) by the amount of tool wear (h).

$$R = \frac{d\tau}{dh} \quad (2)$$

where R (min/mm).

In this paper, we started from the wear functions obtained experimentally during the machining of Al-12%Si on a lathe after 100 minutes of continuous cutting. These curves were then "expanded" with the help of the Numerical Interpolation Method (which will be presented later in the paper)

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to wear curves after 1800 minutes of continuous cutting, from which the durability of the used diamond-coated tool can be determined with sufficient reliability. Then, the wear resistance was obtained on the basis of the wear curves thus obtained, and from the wear resistance curves the durability of the tool was determined.

It should be noted here that wear resistance is the best parameter for expressing various tribological characteristics, such as tool durability, which will be shown later. Given that wear resistance is a function of tool wear, on the basis of relation (2) in practice, tool durability is often determined using the radioactive method.

2 EXPERIMENTAL CONDITIONS

Diamond-coated tungsten carbide inserts were used in this study. The coatings were obtained by means of two different pre-treatment procedures: (a) oxygen-acetylene flame treatment, dissolution of Co in strong acids (HCl and HNO₃), ultrasonic seeding of the surface with fine diamond powder; (b) processing with Murakami's solution [1,2], passivation of Co using a mixture of

H₂O₂ + H₂SO₄. The following application conditions were used: temperature T=1073 K; time t=20 min; R - ratio of C₂H₂ and O₂ flow rate=1.5

To study the wear behavior, the machining mode was applied [3-5]. Processing of Al-12%Si alloy: cutting speed n=400 revolutions/min, displacement speed s=0.1 mm/revolution; depth of cut d=0.5 mm; sample diameter Ds=75 mm.

An optical microscope was used to determine individual points for the wear curves. After the specified time of machining, the size of the crater on the back surface of the worn turning plate was measured - V (μm). In the following text, the diagrams will show the size V(μm) instead of h.

3 DETERMINATION OF CURVE WEAR OF TOOLS

Based on the experimental results, wear curves were obtained without a diamond coating (Figure 1) and with a diamond coating (Figure 2), as well as with a diamond coating obtained by applying the Murakami solution (Figure 3).

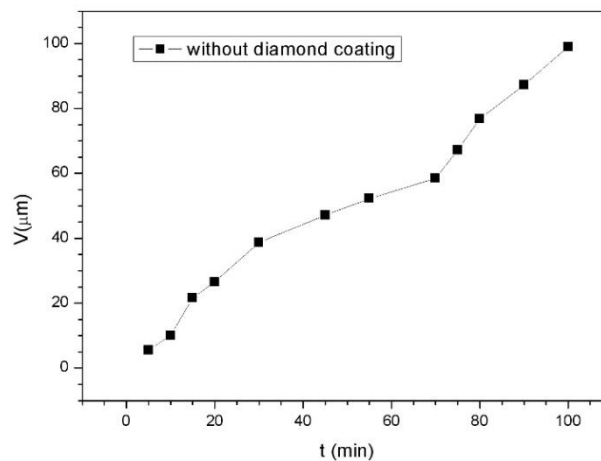


Figure 1 Experimental wear curve of tools without diamond coating

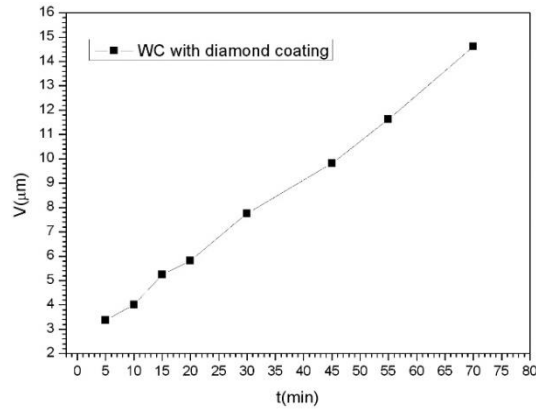


Figure 2 Experimental wear curve of diamond-coated tools

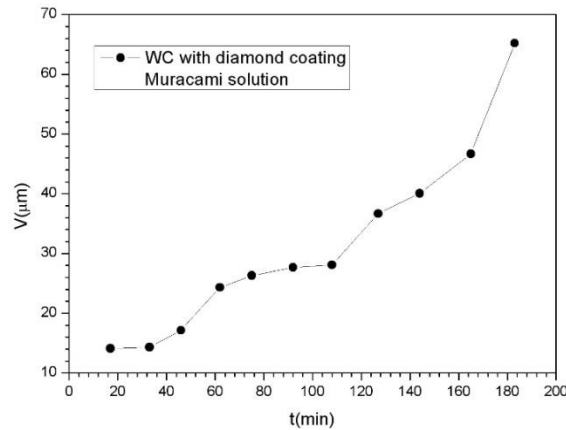


Figure 3 Experimental wear curve of diamond-coated tools obtained using Murakami solution

The tool wear function describes the tribological state and behavior of the machining process. In this case, the wear process on the back surface of the tool is primary, and on the chest surface is secondary. The width of the wear belt on the back surface of the tool, as a linear parameter, in theory and practice in the science of cutting tools, is most often represented by functions of the form:

$$h = B_1 \cdot \tau^{\Psi_1} \quad (3)$$

$$h = h_0 + B \cdot \tau^{\Psi} \quad (4)$$

Based on the experimental curves shown above and the mathematical model, "extended" tool wear curves will be shown, which can be applied in practice with high accuracy.

In order for the regression function of wear (4) to satisfy two arbitrary points 1 and 2 on the curve, in the second stage of wear there will be:

$$h_1 = h_0 + B \cdot \tau_1^{\Psi}, h_2 = h_0 + B \cdot \tau_2^{\Psi}$$

Dividing these equations gives:

$$\frac{h_2 - h_0}{h_1 - h_0} = \left(\frac{\tau_2}{\tau_1} \right)^{\Psi}$$

The exponent in the regression function will be from here:

$$\Psi = \frac{\ln\left(\frac{h_2 - h_0}{h_1 - h_0}\right)}{\ln\left(\frac{\tau_2}{\tau_1}\right)} \quad (5)$$

For a more accurate determination of ψ according to (5), several points on the wear curve obtained experimentally can be taken and the method of mean values can be applied.

If the experimental points are chosen so that they form a geometric progression, solving the problem becomes much easier:

$$\frac{\tau_3}{\tau_1} = \frac{\tau_2}{\tau_3}, \quad \tau_3 = \sqrt{\tau_1 \cdot \tau_2} \quad (6)$$

If the exponent ψ is expressed according to (5), through points 1 and 3, i.e. 2 and 3, it will be:

$$\Psi = \frac{\ln\left(\frac{h_3 - h_0}{h_1 - h_0}\right)}{\ln\left(\frac{\tau_3}{\tau_1}\right)}$$

$$\Psi = \frac{\ln\left(\frac{h_2 - h_0}{h_3 - h_0}\right)}{\ln\left(\frac{\tau_2}{\tau_3}\right)}$$

Hence, given (6), it follows that:

$$\ln\left(\frac{h_3 - h_0}{h_1 - h_0}\right) = \ln\left(\frac{h_2 - h_0}{h_3 - h_0}\right)$$

By solving this equation, the size of the section of the regression function on the ordinate is obtained:

$$h_0 = \frac{h_1 h_2 - h_3^2}{h_1 + h_2 - 2h_3} \quad (7)$$

The accuracy of relation (7) will be higher if the distance between points 1 and 2 is larger, which must be taken into account.

Based on this mathematical model and our experimental results, an "extended" tool wear curve without diamond coating is obtained:

$$h = 23,78 + 0,543645 \cdot \tau^{0,9877} \quad (8)$$

and the "extended" diamond-coated tool wear curve:

$$h = 0,704606 + 0,29124 \cdot \tau^{0,9044} \quad (9)$$

The curves are then shown in Figures 4 and 5.

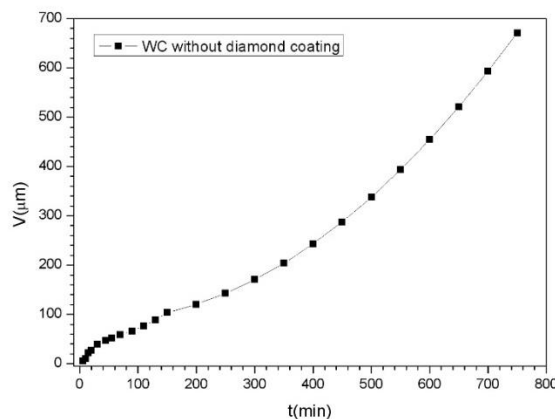


Figure 4 "Extended" tool wear curve without diamond coating

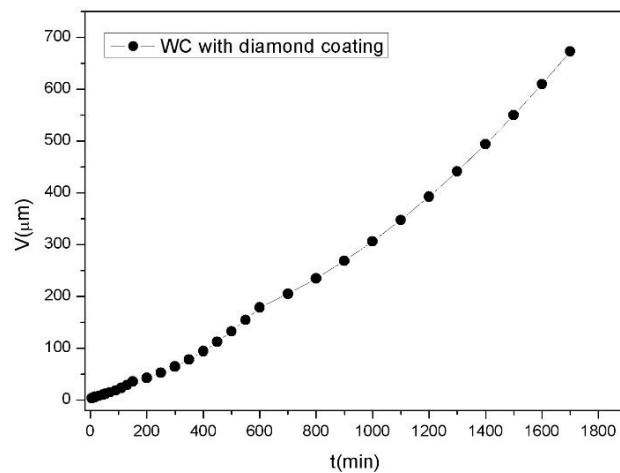


Figure 5 "Extended" wear curve for diamond coated tools

4 DETERMINATION OF WEAR RESISTANCE OF TOOLS

Based on the diagram from Figures 4 which is shown in Figures 6 and 7. and 5, the function $\tau=\tau(h)$ was created,

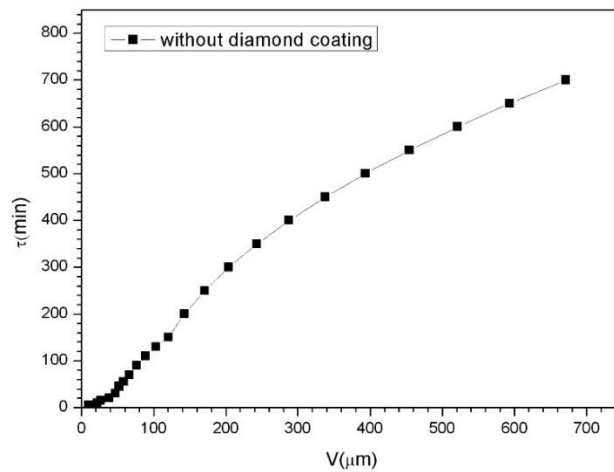


Figure 6 Wear curve in the coordinate system $\tau=\tau(h)$ for the tool without diamond coatings

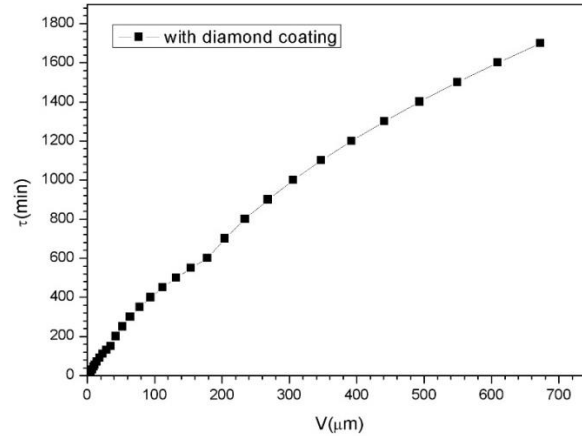


Figure 7 Wear curve in the coordinate system $\tau=\tau(h)$ for the tool with diamond coating

The experimental function $\tau=\tau(h)$, Figures 6 and 7, for area I of intense wear ($h \leq .25$ mm), can be mathematically described with sufficient accuracy by a regression function:

$$\tau = 318,30 \cdot h^{1.4967} \quad (10)$$

In the same way for class II stabilization wear ($0.25 \text{ mm} \leq h \leq 0.7 \text{ mm}$), we get that:

$$\tau = 109.54 \cdot (h - 0.25)^{0.7884} \quad (11)$$

By differentiating expressions (10) and (11), according to definition (2), we obtain

analytical wear resistance functions for areas I and II:

$$R_I = 476,40 \cdot h^{0.4967} \quad (12)$$

$$R_{II} = \frac{86.361}{(h-0.25)^{0.2116}} \quad (13)$$

Figures 8 and 9 show a graphical representation of the obtained functions (12) and (13) for tools without and with diamond coating, where different monotony is observed depending on the wear phase.

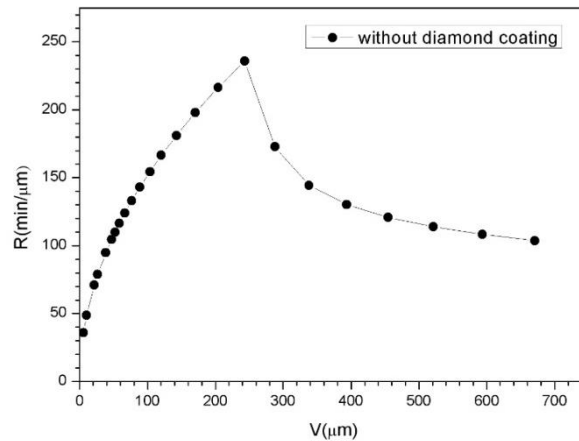


Figure 8 Wear resistance function of tools without diamond coating

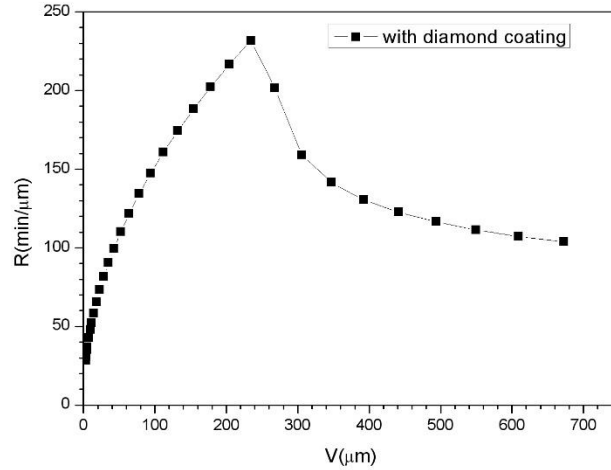


Figure 9 Wear resistance function of diamond coated tools

If we compare the wear resistance functions obtained according to the analytical expressions (12) and (13) with the same functions in Figures 8 and 9 obtained by the graphical method, it is noted that the deviations are relatively not high. It is interesting that according to the diagrams in Figures 8 and 9, the maximum wear resistance value is $R_{\max} = 239$ (min/μm).

Starting from relation (2), the elementary cutting time can be expressed as:

$$\tau = R \cdot dh \quad (14)$$

Integrating this relation within the appropriate limits will yield:

$$\int_{T_0}^T d\tau = \int_{h_0}^{h_k} R dh \quad (15)$$

In relation (15), T and h_k represent durability, i.e. tool wear criterion. By solving the integral (15), we get that the stability of the tool can be expressed in the form:

$$T = \int_0^{h_1} R_I(h) dh + \int_{h_1}^{h_k} R_{II}(h) dh \quad (16)$$

that is,

$$T = \tau_I + \tau_{II} \quad (17)$$

If we replace the sub-integral functions R_I and R_{II} from (12) and (13) in (16), and perform integration, tool stability is obtained as an analytical solution.

In this case, tool durability without diamond coating when machining Al-12%Si is $T_{bp} = 95.349$ min, and tool durability with diamond coating is $T_{sp} = 102.29$ min.

5 CONCLUSIONS

Taking into account the presentation in this paper, the following conclusions can be drawn:

1. Using the experimental results obtained during the machining of Al-12%Si tools without and with diamond coating, it is possible to obtain, with sufficient reliability, an "extended" tool wear curve with all three wear phases.
2. Based on the used mathematical model, the tool wear resistance functions without and with diamond coating are obtained, where the maximum value of the tool wear resistance is $R_{\max} = 239$ (min/μm).

3. Based on the presented mathematical model, as an analytical solution, tool durability without diamond coating is $T_{bp} = 95.349$ min, tool durability with diamond coating is $T_{sp} = 102.29$ min.
4. It is the first time that you can through the wear resistance of tool material by analytical solution using adequate mathematical model find work life of tool with sufficient accuracy.

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