Thermomechanical method of increasing the mechanical properties of cermets

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Abstract. Thermomechanical method of increasing the mechanical properties of cermets leads to a buildup in the durability of cutting tools up to 2 times. However, after thermomechanical processing, a defective layer of 0.8 mm in-depth forms on the outer surface of the processed workpiece, which is caused by of the oxidation of WC tungsten carbide. In order to prevent oxidation on the workpiece surface, it is proposed to use a nickel coating, which reduces the oxidation of WC by more than 30 times when it is heated to a temperature of 1000 ºC.

1. Introduction

The wear of cutting tools has been the subject of many researches [1-6]. In these articles, the features of the interworking of the cutting material with the workpiece material are considered. The basic kinds of wear on cutting edges are: 1 – adhesive; 2 – fatigue; 3 – abrasive; 4 – thermal; 5 – oxidation; 6 – diffusion processes; 7 – high-temperature creep. There are various methods of increasing the durability of the cutting edges: ion-plasma deposition of multilayer coatings, electro-spark alloying, high-dose ion implantation doping, treatment with powerful ion beams, grinding of the cutting edges, etc. [1, 7–10]. Using these methods in most cases leads to increasing the durability of the cutting edges: an adhesive, fatigue, abrasive wear and oxidation is reduced; but in rough machining, when high-temperature creep and thermal wear are prevail, the effectiveness of these methods is minimized. The method, which allows increasing the mechanical properties of the cemented carbides to a greater depth than the above methods, is known [11]. This method is based on high-temperature deformation of the cutting edges of cemented carbides. But this method leads to the forming of a defective layer on the machined surface up to 0.8 mm. There is also no data on the influence of processing modes on microhardness.

2. Formulation of the problem

The mechanical properties of cemented carbides are the subject of many researches [12-14]. In [11], the technology of thermomechanical processing (TMP) of a cutting edges of cemented carbides is considered, the essence of which is that a cutting tool heated to a temperature of 700-900 ° C is plastically deformed by a carbide roller with a force of 500-2500 N. Thermomechanical processing of WC-Co is based on the following properties of cobalt: cobalt has two allotropic forms — high-temperature β with face-centered cubic lattice with a period of a=0.354 nm and low-temperature α with a hexagonal close-packed lattice with periods of a=0.25053, s=0.409 nm. The temperature of the polymorphous (α ←→ β) transformation cannot be accurately indicated, since during heating the transformation go by intensively at 477 °C, but does not end at 600 °C, while the reverse transformation (when cooling) begins only at 403 ° C, i.e., it is overdue. When there an iron addition in Co, it is bent to strainer-hardening (the hardness of cobalt annealed at 1200 °C is 1320 MPa, after cold rolling with 30% reduction – 2800 MPa).

The results of microhardness measured diagonally at an angle of 45 ° from the cutting edge deep into the body (Fig. 1): 0,15 mm – 1100 $H_{\mu 200}$; 0.3 – 0.7 mm – 1260–1790 $H_{\mu 200}$; 0.7–2.5 mm – 1525–1790 $H_{\mu 200}$ – maximum microhardness; 2.5–5.0 mm – reducing microhardness to a 1363 $H_{\mu 200}$.
As a result of TMP, the depth of plastic deformation can reach 4.5 mm.

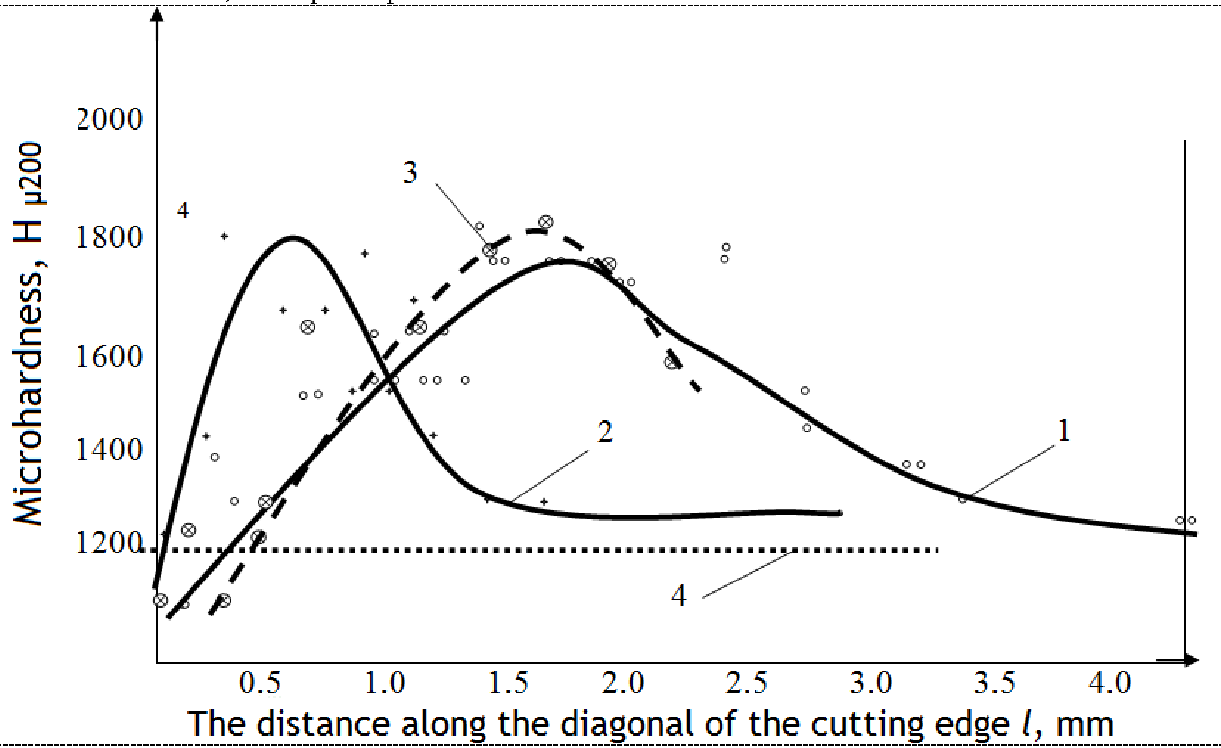

Figure 1. Data of changes in microhardness over the cross section of the deformed metal: line 1 – 2nd, 3rd specimens; 2 – 2nd specimen after annealing at 800 °C for one hour; 3 – 4th specimen; 4 – 2nd specimen after annealing at 1000 °C for 1.5 hours.

At a distance of up to 0.8 mm, a decrease in microhardness is observed, which is explained by the high intensity of flame and the low thermal conductivity of the cermet. It is necessary to develop a TMP method that allows reducing the depth of defective layer.

3. Theory

The capability of a carbide tool is evaluated by the following properties: hardness, elasticity modulus, melting point, conduction. In the works carried out by Russian researchers [15, 16], the influence of temperature on the oxidation of a cermets was considered. Oxidation studies were carried out in air when heated workpiece with a rate of heating of 20 °C per minute from 20 to 1000 °C, with subsequent cooling. The measurement of mass growth to the total area of the workpiece before oxidation is calculated by the equation [16]:

$$q = \frac{\Delta m}{S_0}, \tag{1}$$

where Δ_m is workpiece mass change after oxidation, r; S_0 – workpiece area before oxidation, m^2.
At a temperature of 1000 °C, the mass growth in tungsten carbide is about 420 g/m^2, and cobalt is about 25 g/m^2. The value of the equilibrium constant for the oxidation of WC is calculated as:

$$WC + \frac{5}{2} * O_2 \rightarrow CO_2 + WO_3, \tag{2}$$

Then the oxidation rate for tungsten carbide is calculated by:

$$K_{WC} = [O_2]^{\frac{5}{2}} / [CO_2]. \tag{3}$$

Figure 2 shows the macrostructure of tungsten carbide before and after oxidation. On it can be seen that as a result of heating, the WC specimen increases up to 2 times.

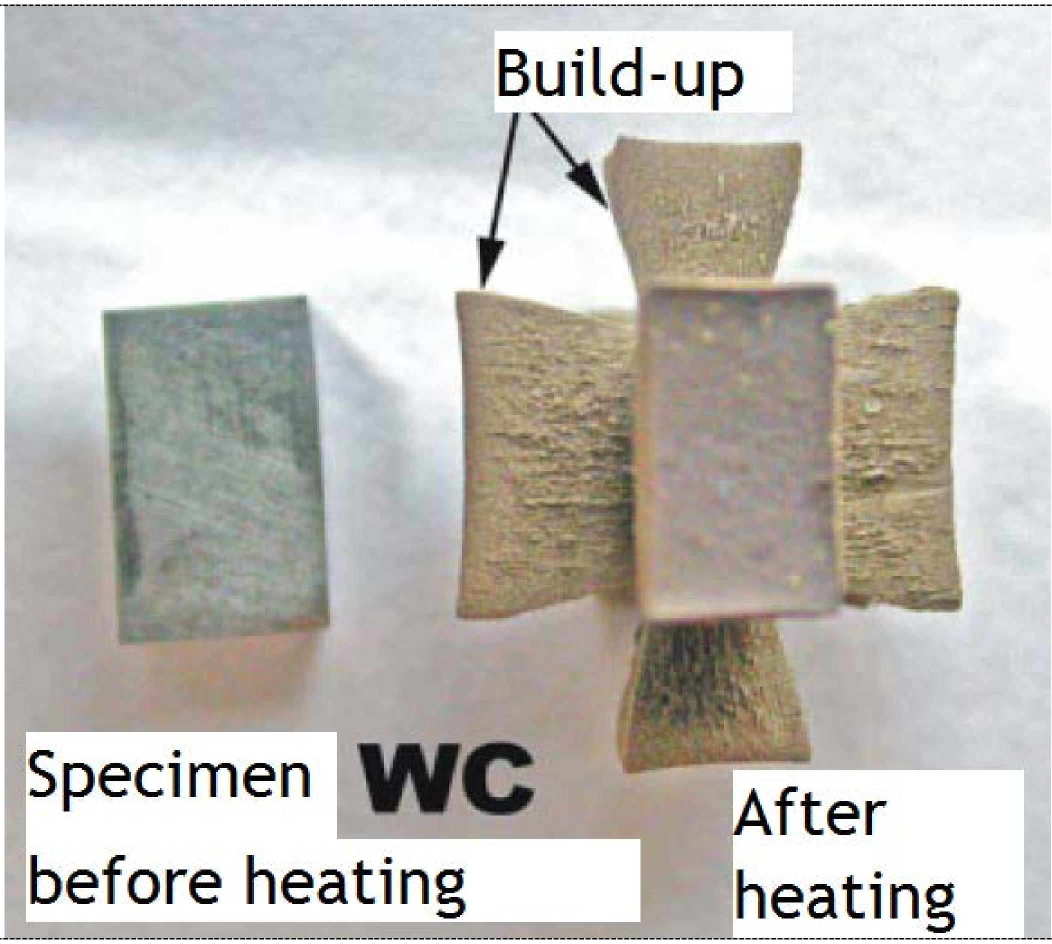

Figure 2. The structure of tungsten carbide before and after oxidation; ×14.

In [16], it was found that after oxidation of the WC volatile WO_3 oxides are formed, which crystallize at the base and $CoWO_4$. The constants of the formation of various constituent during heating of tungsten carbides are discernible using the law of mass action. When WC is oxidized in a matrix from Co, the following takes place:

$$Co_3O_4 \rightarrow 3CoO + \frac{1}{2}O_2, \tag{4}$$

$$CoO + WO_3 \rightarrow CoWO_4. \tag{5}$$

Subsequently, based on the law of mass action:

$$[CoWO_4] = \frac{[Co_3O_4]^{\frac{1}{3}} * [WC] * [P_1O_2 + P_{11}O_2]^{\frac{5}{2}}}{[P_{11}O_2]^{\frac{1}{6}} * [CO_2]}, \tag{6}$$

The partial pressure of oxygen affects the formation of $CoWO_4$ spinel. In the case of suppression of cobalt on the surface of the WC, only WO_3 will be present. To prevent the WC from oxidation during TMP, a protective coating that will reduce the partial pressure of oxygen can be used.

4. Experimental results

In the TMP experiment, two workpieces of 90%WC and 10%Co highly fine grained alloy were used: uncoating and with nickel coating 20 μm thick. The modes of TMP were: workpiece rotational speed 74 rpm; traverse motion S = 0.07 mm/rev, workpiece temperature 900-1000 ° C, pressure of the roller 6000 N. Figure 3 shows the machined workpieces after TMP.

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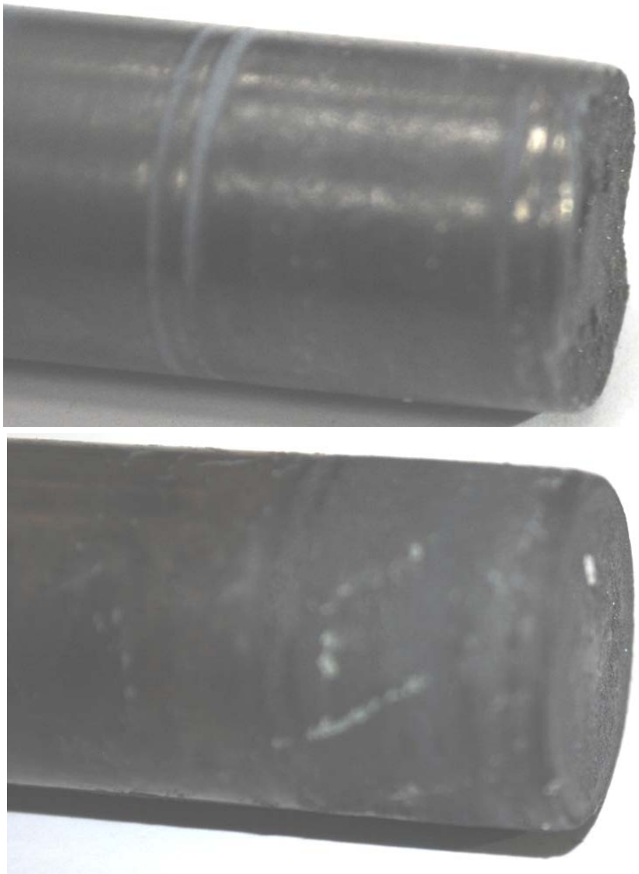

a)

b)

Figure 3. Workpieces after TMP: a – uncoated workpiece; b – workpiece with nickel coating.

The defective layer was defined at the end of the workpieces. On workpieces without coating (Fig. 3, a), a large pitting and flaking was observed at the intersection of end and outer diameter, and an oxidized layer formed on the surface of the machined workpiece. On workpieces with nickel coating (Fig. 3, b), a slight oxidation and pitting near the end without flaking were observed. At the same time, the oxidation value on coated workpieces decreased by more than 30 times in comparison with uncoated.

Also, when conducting experiments, the influence of the roller radius and additional vibrations on the value of deformation of the superficial layer was determined (Figures 4-6).

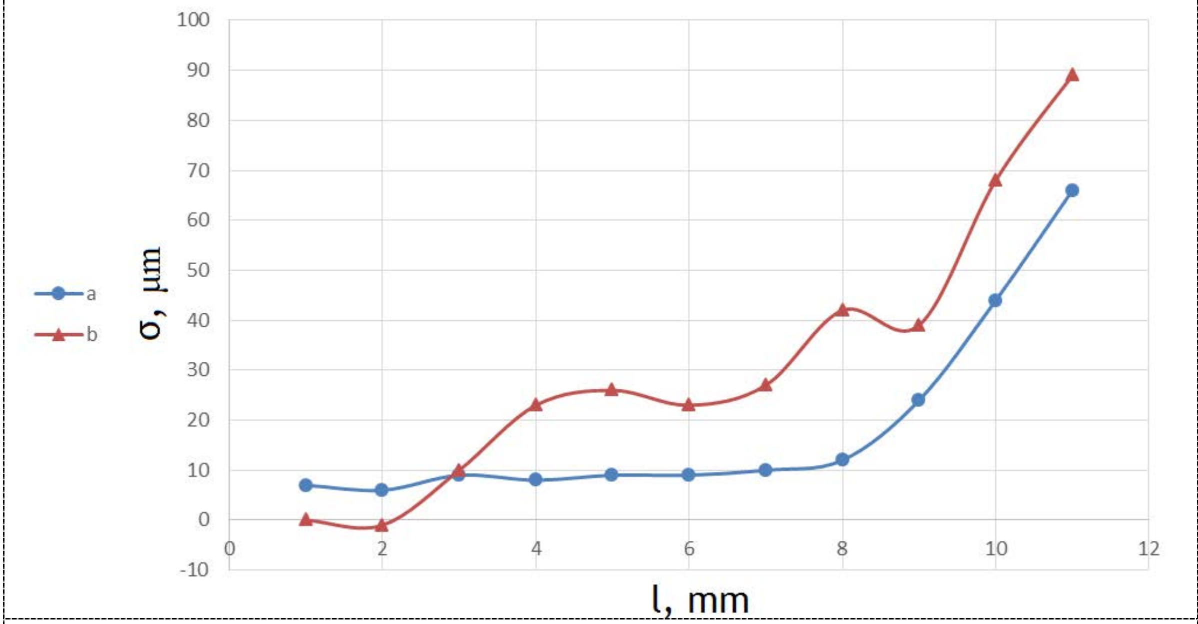

Figure 4. The influence of the roller width on the outer diameter deformation value: a – roller with a radius of 100 mm; b – roller with a radius of 4 mm.

As a result of the experiment, it was found that the width of the roller affects the deformation value when the pressure force is more than 5000N. With less pressure force, the deformation value does not change.

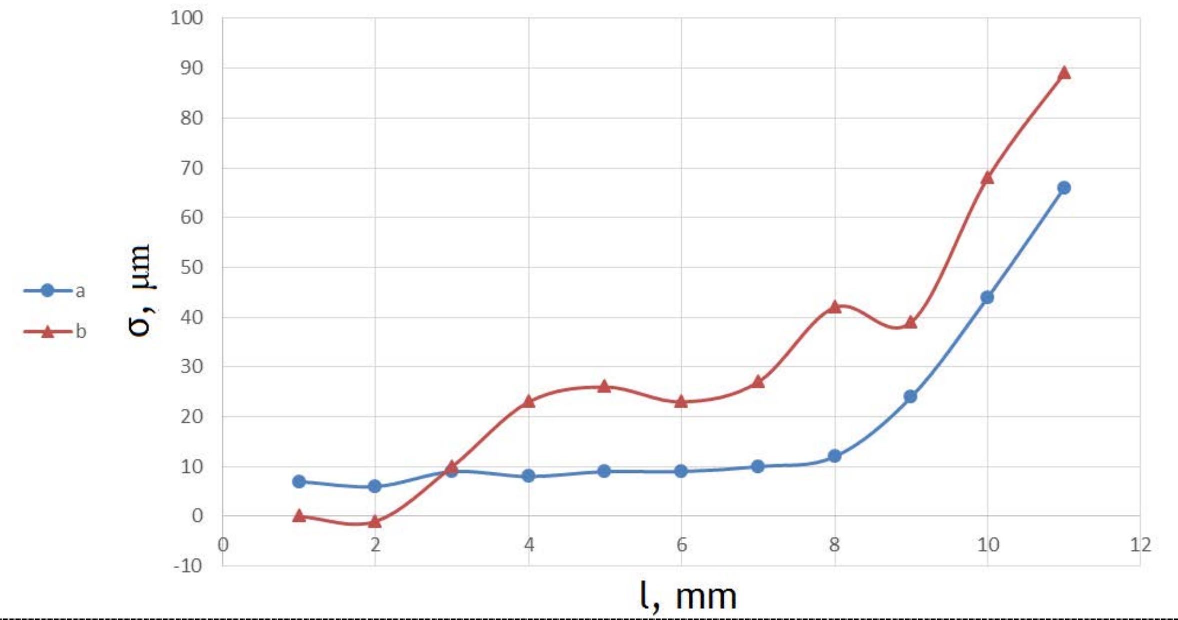

Figure 5. The influence of coating on the outer diameter deformation value: a – with nickel coating; b – without coating.

The nickel coating of the workpiece significantly reduced the outer diameter deformation value. This is in a greater degree due to a decrease in the oxidation of WC.

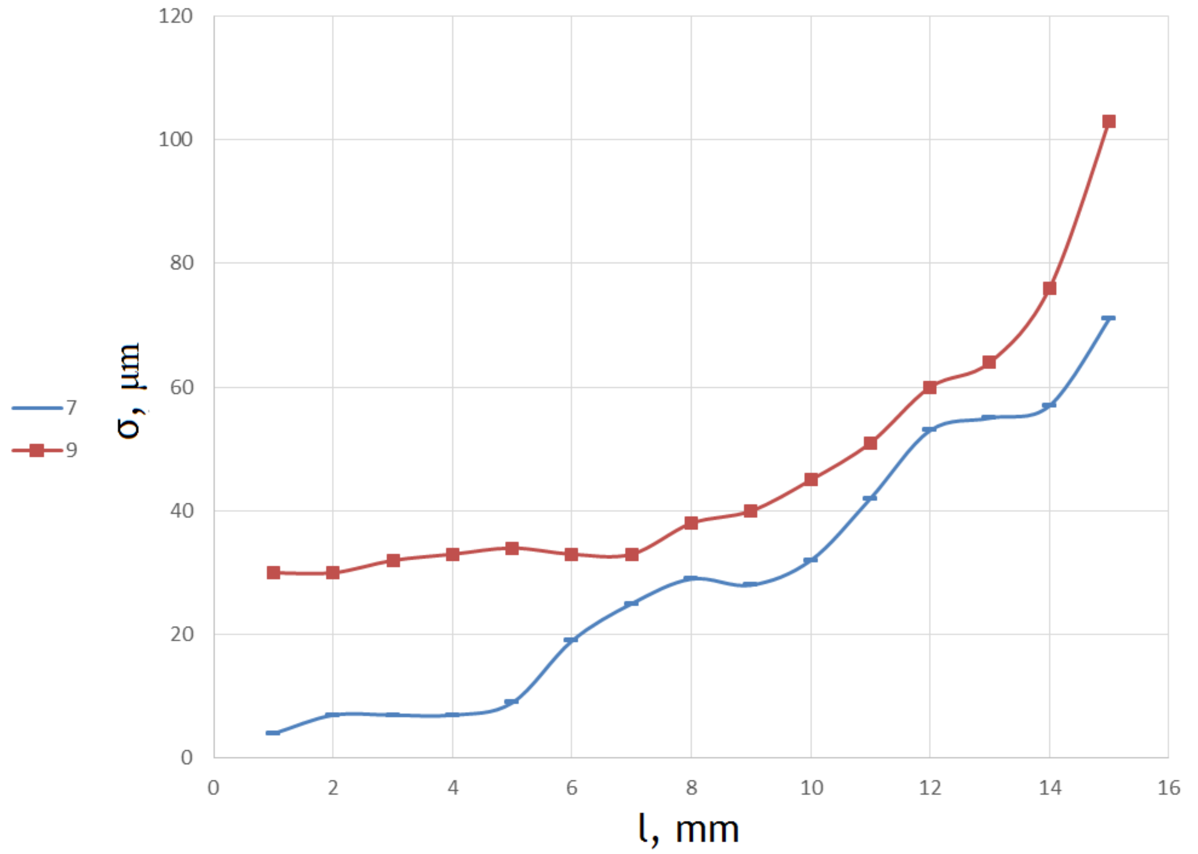

Figure 6. The influence of additional vibration on the roller on the outer diameter deformation value: 7 – without vibration; 9 – with vibration.

The use of a device that addition a vibration allowed to increase the outer diameter deformation value from the base to 50%.

5. Conclusion

The occurrence of a coating on the workpiece allows reducing the oxidation of WC by more than 30 times and it's also prevents forming of a defective layer. The provision of the coating may facilitate a stable temperature over the workpiece, which has a significant effect on crack formation during TMP.

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