Technology of thermo-mechanical hardening of rotary carbide tools

E V Vasil'ev, A A Rauba, A N Abakumov, N V Zakharova, V A Sergeev

Omsk State Technical University, 11 Mira ave., Omsk, 644050, Russia

Abstract. Improving physical and mechanical properties of tool materials is a complex scientific and technical problem. Application of thermo-mechanical hardening of monolithic carbide tools allows increasing the microhardness of at least 30%, which has a significant impact on the tool operating life. The use of the developed device allows for thermo-mechanical hardening of rotary carbide blanks for the manufacture of cutting tools, with high productivity and stability of the results.

1. Introduction

Industrial enterprises use a large number of monolithic rotary carbide tools (MRCT), with a significant part of the tool designed for roughing. Unlike multi-faceted carbide inserts (MCI), which use multi-layer wear-resistant coatings, MRCT coatings are applied to a small range of tools. The effectiveness of these coatings provides a several-fold increase in the period of tool-life. As a rule, this value is higher in finishing or semi-finishing operations, and is minimized in roughing or grinding operations, for example, cast blanks. Currently, there are many ways to improve the wear resistance of carbide exchangeable multi-faceted inserts (EMI) [1-8.]. These are ion-plasma application of multilayer coatings, electro-spark alloying, high-dose ion implantation, ion beam treatment and some others. All these methods have both advantages and disadvantages. Most of them have not been widely used in tool-making, either because of their high cost and high operating expense, or because of environmental restrictions. At present, high-dose ion implantation [8] and application of multilayer coatings are widely used, which have proven themselves in finishing and semi-finishing operations.

Performing roughing operations, deformation of the carbide tool blade occurs [9-11], and this minimizes the effectiveness of surface hardening methods. The hardness values in the deformed zone differ significantly from the initial ones [12]. At the same time, the depth of the change in properties can reach up to 1.5 mm. This does not happen with other methods of hardening, since they are either surface or volumetric ones, and these methods do not give a significant change in hardness.

G S Kramer [13] determines that the destruction of the tool blade begins on its front surface under the influence of tensile stresses that lead to the formation of cracks in the cobalt bond of the hard alloy. When using the shot blasting method, tensile stresses arising in the manufacture of a hard alloy are changed to compressive stresses, which prevents cracking. Studies on shot processing of carbide tools by G L Khayet [6] shows that the MCI hardening can be increased by 1.5–1.6 times.

2. Problem Statement

One of the methods based on high-temperature plastic deformation is known as thermo-mechanical processing (TMP) of hard alloy blades [14]. This method lies in heating the carbide insert to a temperature of 700-900°C, then plastic deformation is executed by a rotating roller with a load of 500-2500 N.

Thermo-mechanical processing of inserts RPUX 3010 MO and 2710 MO was performed at the laboratory unit [15] according to the diagram presented in Figure 1.

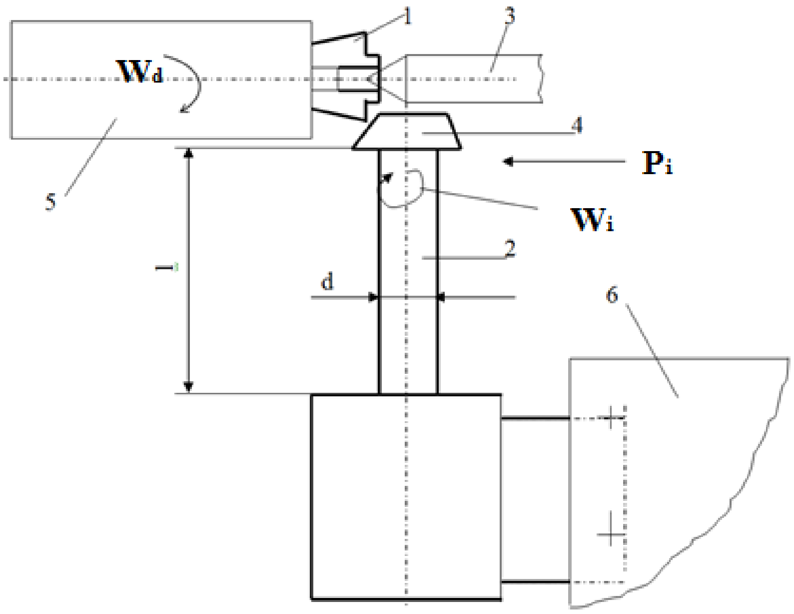

Figure 1. Diagram of the thermo-mechanical treatment of inserts RPUX 3010 MO and 2710 MO: 1 – rolling insert; 2 – knurl rod; 3 – exchangeable carbide center; 4 – carbide knurl; 5 – mandrel; 6 – lathe toolholder

Inserts of alloy T14K8 and alloys T1 and T5 which are close in composition to T14K8 were subjected to TMP. The inserts made of these alloys had no significant difference in deformation. Rolling operation was executed at different speeds of rotation of the processed insert: 20, 40, 60, 80, 125, 160, 315, 400, 500, 600, 1000 and 1600 rpm at a temperature of 700 – 900° C with cold and hot knurl.
Rolling operation in these modes gives a different shape to the deformed part on the rear surface of the inserts (Figure 2).

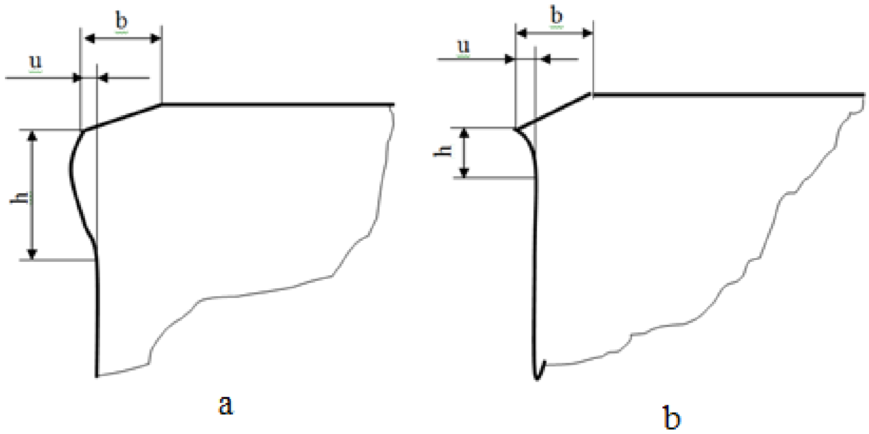

Figure 2. Contours of the inserts rolled at different speed with cold and hot knurl with the load of 500 – 2500 N: a – at 40–500 min $^{-1}$; b – at 600–1600 min $^{-1}$

After rolling, the final diamond sharpening of the inserts is performed according to existing technologies [16-21]. The allowance for sharpening on the front surface must be not less than the thickness of the defective layer, which reaches a range of 0.5-0.8 mm. As a result of production tests, the tool-life of the processed tool increased up to 2 times. Thus, this process flow diagram is effective for increasing the MCI operating life, but it has some drawbacks. Firstly, it is a heavy thickness of the defective layer, which requires the removal of an increased allowance when sharpening, and secondly, it is a load on the blank, acting only in one direction, which often leads to breakage of the MRCT when rolling. To provide the technology of thermo-mechanical hardening of MRCT, it is necessary to solve the following problems. The first is to determine the scheme of loading when rolling. The second is to develop the design of the device for rolling.

3. Theoretical Basis

The scheme of loading when rolling MRCT is shown in Figure 3. The knurled roller is mounted on a shaft of length *l*, and under the action of the force *F*, it is displaced by the value *y*.

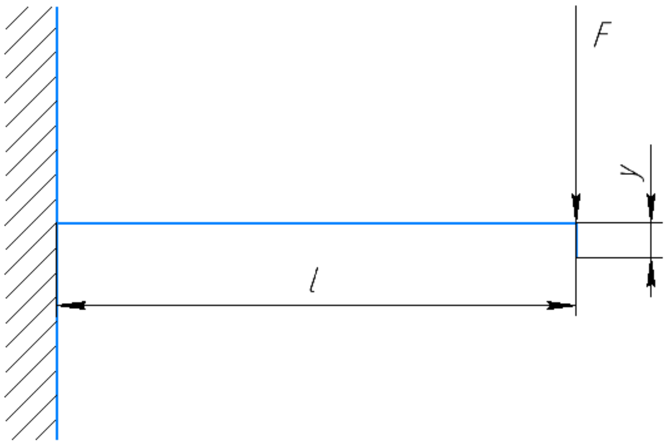

Figure 3. Scheme of loading MRCT

The maximum deflection value *y* is determined by the dependence 1[22]:

$$y = \frac{F * l^3}{3 * E * I_x}, \tag{1}$$

где *F* is force, N; *l* is the length of the beam, mm; *E* is the modulus of elasticity, Mpa; *I* is the inertia moment, m^4.

The moment of inertia is defined as:

$$I = \frac{\pi * d_э^4}{64}, \tag{2}$$

where *d* is the equivalent diameter, m.

The necessary clamping force of the knurled roller to the MRCT was experimentally determined during thermo-mechanical processing, which was in the range from 2000 to 9000N. The required clamping force *F* is determined by the value of the limit deflection *y*:

$$F = \frac{3 * y * E * I_x}{l^3} \quad . , \tag{3}$$

The design of the device was developed for the implementation of TMP MRCT. This kind of design allows for the rolling process on a screw-cutting lathe (Figure 4).

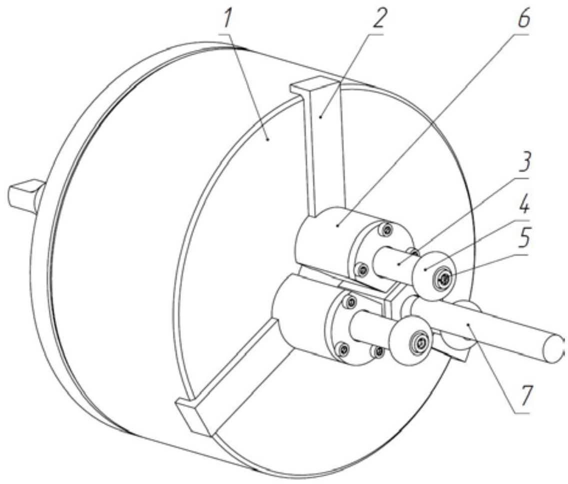

Figure 4. Design of the device for implementing TMP of the rotary cutting tool

The carbide blank (carbide column) 7 (Figure 4) is fixed to the mandrel installed in the chuck of the screw-cutting lathe. A rotating carbide column is heated with a gas-cutting torch to a temperature of 900 to 1000°C and in the heated state rolling plastic deformation is executed under the load of 2500 - 9000 N by the rotating rollers 4 fixed on the mandrel 3, mounted in the bearing support 6 and fixed, for example, by welding, to the cam 2 of the three-jaw chuck 1 installed in tail-stock of the screw-cutting lathe, with the tail-stock being moved by the longitudinal feed of the slide. The tool heating temperature and deformation force at the specified intervals, as well as the rolling operation time length are chosen to obtain the desired degree and depth of hardening and avoid the blade fracture.

To determine the load of the rollers on the blank, the mandrel design 3 is defined (Figure 5). The material of mandrel is steel 40, and the material of knurled rollers is T14K8.

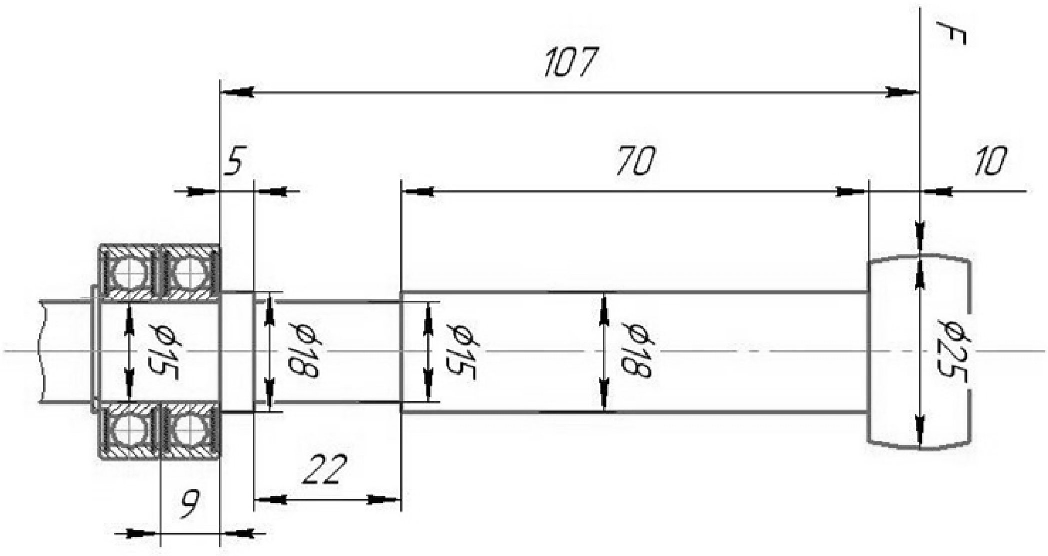

Figure 5. Design of the mandrel in the device for rolling MRCT

Journal of Physics: Conference Series **1441** (2020) 012126 doi:10.1088/1742-6596/1441/1/012126

Since the mandrel is stepped, we find the equivalent diameter d_e:

$$d_э = \sqrt[4]{\sum \frac{l_i}{l} * d_i^4} \, ., \tag{4}$$

In carrying out the experiment, the cam 2 of the three-jaw chuck 1 was moved by 2.8 and 3.5 mm. Substituting formulas 4 and 2 in 3, we obtain the calculated force F (table 1).

Table 1. Calculation results for the dependence of the force F on the deflection value y.

Y(mm)	F(H)
2.8	≈4800H
3.5	≈6200H

The results of the calculations were compared with the calculations performed in the SolidWorks software (Figure 6).

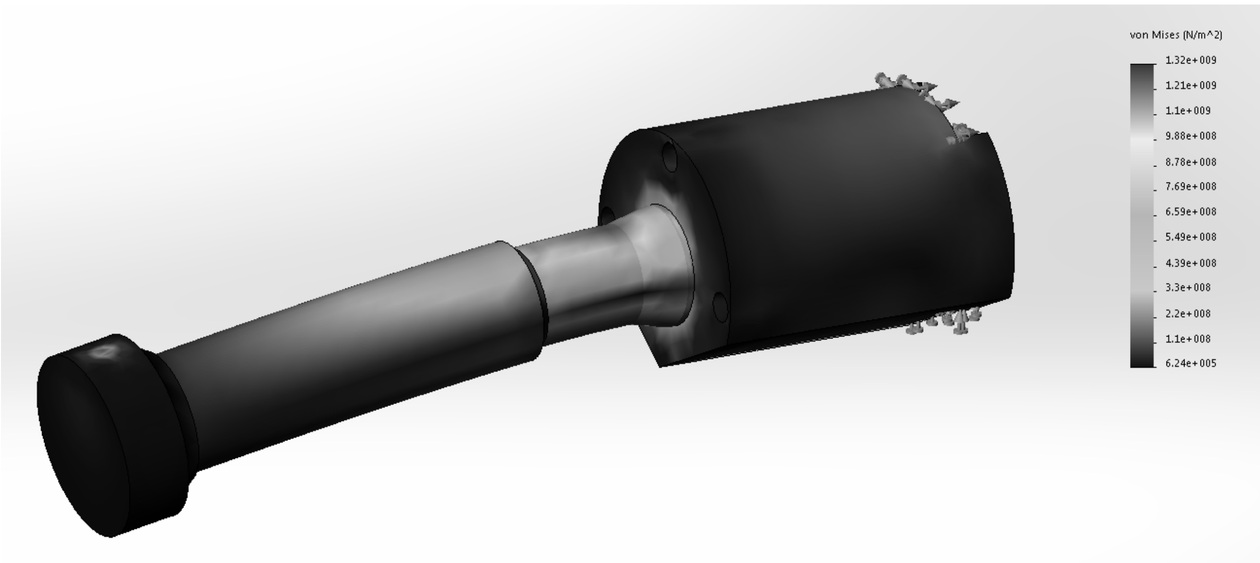

Figure 6. Calculation of beam deflection depending on the deformation force value

Since the deviation is less than 1%, we can conclude that the calculated clamping force of the knurled rollers to the blank is determined with sufficient accuracy.

4. Experimental Results

Figure 7 shows the TMP MRCT experiment. Since the bearings are not absolutely rigid, the displacement in them was compensated by pre-loading the mandrels with rollers relative to the blank.

Journal of Physics: Conference Series **1441** (2020) 012126 doi:10.1088/1742-6596/1441/1/012126

Figure 7. TMP of rotary cutting tool in the developed device

The rolling modes were as follows. The blank rotation speed was 74 rpm; longitudinal feed S = 0.07 mm / rev, blank heating temperature was 900–1000°C (Figure 8). The blank surface temperature was controlled by the optical thermal imaging device Fluke Ti400.

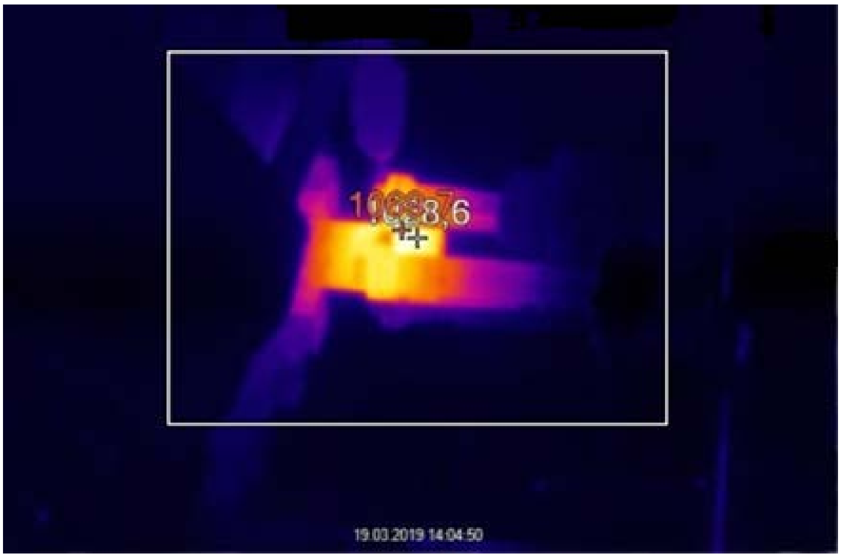

Figure 8. Blank surface temperature value during rolling

After the TMP the microhardness of the obtained samples was studied on the Zeiss hardness tester, which showed its increase from a depth of 2.5 to 6 mm from the outer rolling surface (Figure 9).

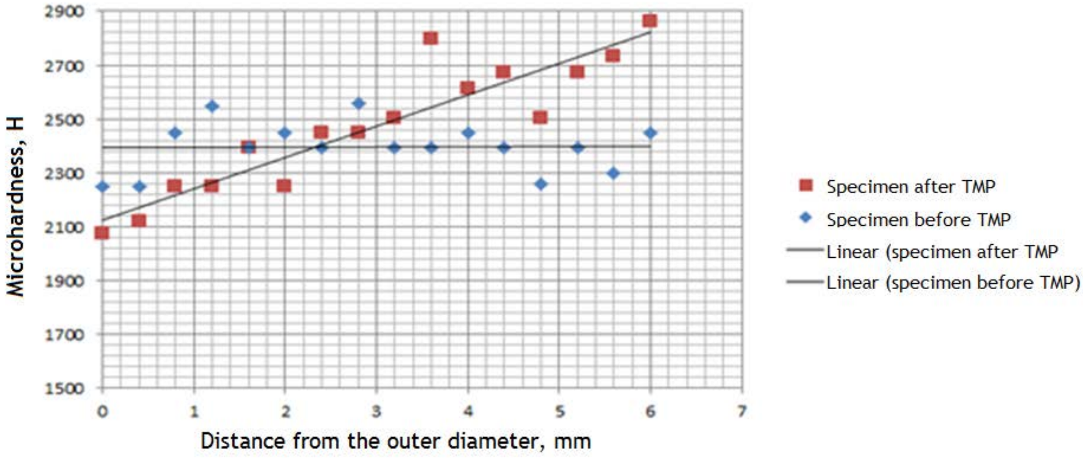

Figure 9. Distribution of microhardness values on the blank after TMP

Studying microhardness, the influence of grinding technology on its value was established. The following technology was used in the preparation of the polished sections. The samples were pre-polished with coarse-grained diamond rings, and finally they were polished with 7/5 µm grain size rings. Samples having been prepared under this technology, the values of microhardness over the entire surface did not differ significantly. Apparently, the fine-grained rings smear the cobalt bond over the entire surface, thereby equalizing the value of microhardness. To obtain reliable measurement results in the future, the premakeready technology of polished sections using suspensions and lapping discs was used.

5. Conclusion

The use of TMP can increase the microhardness of the base material to 30%, while there is a defective layer that must be grounded. Therefore, it is essential to consider methods and modes to eliminate or reduce the thickness of the defective layer. The proposed technology of blade surface hardening can be applied in the manufacture of carbide rotary tools such as end mills, spiral drills, countersinks, reamers, as well as in the manufacture of drilling tools.

References

1. Bespalov V V, Rauba A A, Popov A Yu, Gritsenko B P, Kashin O A and Sharkeev Y P 2000 *New technologies for railway transport: training of specialists, organization of rail traffic, operation of trafic facilities* **4** 167–9
2. Vereshchaka A S and Tretyakov I P 1986 *Mechanical engineering* 192
3. Lee K N, Fritze H, and Oqura *Y Coatings for Engineering Ceramics Euro Ceramics VII Part 1 session P(1-3,6)* Up Trans Tech. Publicans. Charter 27.
4. Kuklin L G, Sagalov V I, Serebrovsky V B and Shabashov S P 1968 *Mechanical engineering* 140
5. Polevoy S N and Evdokimov V D 1964 *Mechanical engineering* 496
6. Hayot G L 1975 *Engineering* 168
7. Bozhko I A, Rybalko, E V, Fedorischeva M V and Sergeev V P 2017 *Effect of magnetron deposition conditions on the structure, phase composition and properties of the coatings on the basis of the Al-Si-N system AIP Conference Proceedings,* 1909
8. Gritsenko B P, Ruzaev A V, Kosterina N G and Cherny S A. 1990 *A.S. No. 1777391 Method of ion-beam processing of products*
9. Loladze T N 1958 *Mashgiz* 355
10. Pinahin I A, Yagmurov M A and Vrublevskaya S S. 2019 *Investigation into strength T5K10 hard alloy after volumetric pulsed laser hardening (VPLH) Preprint* doi.org/10.1016/j.matpr.2019.07.538
11. Ostafyev V A 1979 *Mechanical engineering* 168

12. Bogdanov V M, Markov D P and Penkova G I *Bulletin Of VNIIZhT* **4** 3–9
13. Kreymer G C 1971 *Strength of hard alloys Metallurgy* 248.
14. Vasiliev N G, Popov A Yu and Rauba A A. 1999 *Method of hardening carbide tools Pat. 2137590 EN C1 N 6 B 24 B 39/00, C 21 D 7/00*
15. Vasil'ev N G, Popov A Yu and Rauba A A. 1997 *Installation for hardening carbide tools Certificate of utility model RU 7361 U1 6 B 23 P 6/00*
16. Vasily'ev E V, Popov A Y and Bugai I A 2014 *Dynamics of Systems, Mechanisms and Machines. – Dynamics* 7005643
17. Vasil'ev E V, Popov A Yu and Rechenko D S 2012 *Russian Engineering research* **11-12** 730–2
18. Paley M M, Dibner L G and Flid M D 1988 *Technology of grinding and sharpening of the cutting tool-Mashinostroenie* 288
19. Vasil'ev E V, Popov A Y, Lyashkov A A and Nazarov P. V. 2018 Russian Engineering research **8** 642-4
20. Vasil'ev E V and Popov A Y 2014 *Russian Engineering research* **7** 466–8.
21. Mogilnikov V A, Chmir M Ya, Timofeev Yu S and Poluyanov V S 2016 *18th CIRP Conference on Electro Physical and Chemical Machining (ISEM XVIII)* **42** 143– 8.
22. Alexandrov A V, Potapov V D and Derzhavin B P 2019 *Resistance of materials. In 2p. Part 1: textbook and workshop for academic undergraduate programme (Moscow: Publishing House URAIT)* 293