Improvement of high-speed steel cutting tool production technology using the method of nanostructure generation by laser ablation

Elmar Yagyaev¹* and Seran Akimov¹

¹Crimean Engineering and Pedagogical University, per. Uchebnij, 8, Simferopol, 295015, Russian Federation

*elmar1875@gmail.com

Abstract. The article reveals a problem of improving the production technology of cutting tools made of high-speed steels by the method of generating nanostructures on their surface with the help of laser ablation. The spiked microstructures obtained on the surface of the instrument are coated with nanostructures. Experimental studies to modify the surfaces of cutting tools with laser ablation method are performed in air and in liquids. As a result of the analysis of the experimental samples surface morphology we can conclude that the modification of the surface of cutting tools made of P6M5 high-speed steel with laser pulses of nanosecond duration can be used in air and in liquids as a method of increasing the resistance characteristics of a cutting tool.

1. Introduction

The operating capacity of the machining technological system mainly depends on the operating capacity of cutting tool. The product processing is accompanied by the inevitable wearing of the cutting tool. Fragmentary wearing or complete destruction of the cutting edges occurs. At the same time, cutting tool operability depends on the various surface hardening treatments used to increase the wear resistance of the contact pads [1-6]. Table 1 presents methods of increasing the cutting ability of a tool by changing the physical mechanical properties of the material [4].

Table 1. Methods of increasing the tool cutting ability

| Production technologies by groups | wear-resistant coating | anti-friction coating | galvanic methods | chemical methods | chemical thermal methods | physical methods | mechanical methods | thermomechanical methods | finish grinding and sharpening | method of electric spark hardening and tool extension |
|----------------------------------|------------------------|----------------------|-----------------|-----------------|-------------------------|----------------|-------------------|---------------------------|---------------------------------|---------------------------------------------------|

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The solution to the problem of wearing is timely replacement or regrinding and comprehensive restoration of the cutting tool.

Replacing a cutting tool with a new one in cases of using replaceable blades is economically justified and expedient, however, when dealing with a monolithic tool, buying a new tool each time will lead to a significant increase in the cost of products.

Objective: To increase the cutting properties of a tool made of high-speed steels by nanostructuring the surface when irradiated with laser pulses of nanosecond duration.

2. Materials and Methods

Improving the wear resistance of the contact areas of the cutting tool is ensured by the application of various methods of surface hardening treatment of chemical-thermal, deformation, coating, modification of the surface layer properties of the tool and other methods [1].

An effective method of increasing the operating capacity and improving the characteristics of a cutting tool is to apply wear-resistant coatings to the working surfaces. Wear-resistant coatings reduce friction at the tool pads, increase the hardness and wear resistance of the surface layer of the tool, reduce the heat input deep into the tool, and increase heat resistance [2]. The life of the tool is increased by 4 times when processing heat-resistant steels and 5-10 times when processing structural steels.

The tool regrinding along the front and back surfaces is accompanied by the complete removal of the wear-resistant coating from the pads. After regrinding the tool, the cutting conditions are reduced by 20 - 30% compared with a tool with a wear-resistant coating. The durability period of reconditioned tools decrease by 5-10 times.

Currently, there are services for the comprehensive restoration of cutting tools with regrinding and restoration of wear-resistant coating. Resistance of reconditioned cutters and drills with restoration of coating is not inferior to the resistance of a new tool.

However, a comprehensive restoration of tools with coatings is not always feasible at an enterprise. The cost of plants for applying wear-resistant coatings is very high and not always justify its expenses for an enterprise, and besides sending to comprehensive restoration services requires a large number of cutting tools in circulation.

One of the promising methods for increasing the resistance of a cutting tool after regrinding is the generation of nanostructured coating on the surface of contact pads with laser ablation in a liquid [7-10].

Laser ablation is a method of removal (evaporation) of a substance from a surface by a laser pulse. At a low laser power, the substance evaporates or sublimes in the form of free molecules, atoms and ions [11-18]. The depth of the laser pulse action and the amount of the removed substance depend on the material, its optical properties, and also the laser power. Modern laser processing technologies make it possible to control the power and duration of a laser beam in the range from nano to femtoseconds [19-20]. Laser ablation is a well-controlled and promising process for many technological applications, which is very important for the formation of nanostructures during laser spraying.

Figure 1 shows the effect of nanosecond and femtosecond laser pulses on a metal [9, 11].

3. Result and Discussion

Experimental studies of the application of wear-resistant coatings by ablation in liquids were carried out on a MiniMarker 2-20A4 experimental setup with a ytterbium fiber laser, IPG Photonics [Figure. 2]. Maximum pulse energy – 1 mJ, working radiation wavelength – 1.064 μm, maximum power – 20 W, the pulse duration is 4-200 ns, the pulse frequency in the experiments is 100 kHz.
Figure 1. The effect on the metal of nanosecond and femtosecond laser pulses.

Figure 2. MiniMarker 2-20A4 experimental laser ablation unit with ytterbium fiber laser, IPG Photonics.

Table 2. Modes of laser ablation of turning tools plates

| Plate material | Pulse power P, W | Processing speed V, mm / s | Number of passes per mm. | Pulses duration, ns. | Ablation step lin / mm | Pulse frequency kHz |
|----------------|------------------|-----------------------------|--------------------------|----------------------|------------------------|---------------------|
| Insert 1       | HSS              | 10                          | 800                      | 50                   | 10                     | 50                  | 200                |
| Insert 2       | HSS              | 15                          | 800                      | 50                   | 10                     | 50                  | 200                |
| Insert 3       | HSS              | 5                           | 800                      | 50                   | 10                     | 50                  | 200                |
| Insert 4       | HSS              | 10                          | 800                      | 20                   | 10                     | 20                  | 200                |
| Insert 5       | HSS              | 15                          | 800                      | 20                   | 10                     | 20                  | 200                |
| Insert 6       | HSS              | 5                           | 800                      | 20                   | 10                     | 20                  | 200                |

The results of the obtained surfaces were investigated using a 4XB metallographic microscope, with an increase in the objects under study by 250, 650 and 1250 times, and are presented in Table 3 (material of experimental plates HSS (1.3343 / S6-5-2 DIN). Table 4 presents the results of surface modification in a liquid (water).
**Table 3.** Surface morphology of HSS (1.3343 / S6-5-2 DIN) plates after laser ablation

| Surface morphology after laser ablation, x250 magnification | Surface morphology after laser ablation, x650 magnification | Surface morphology after laser ablation, x1250 magnification |
|-------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|
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Table 4. Surface morphology of HSS (1.3343 / S6-5-2 DIN) plates after laser ablation

| Surface morphology after laser ablation, x250 magnification | Surface morphology after laser ablation, x650 magnification | Surface morphology after laser ablation, x1250 magnification |
|-------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|
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4. Conclusion

(1) As a result of the analysis of the experimental samples surface morphology, it can be concluded that modifying the surface of a cutting tool made of high-speed steel HSS (1.3343 / S6-5-2 DIN) with laser pulses of nanosecond duration in air and in liquid can be used as a method of increasing the resistance characteristics of a cutting tool.

(2) In further work, to determine the operational properties of the cutting tool plates coatings obtained by laser ablation, experimental studies of the tool life period and the treated surface quality indicators should be performed.

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