PROCESSING OF HIGH-SPEED STEELS BY PULSED LASER RADIATION

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Abstract

The paper considers the issues of improving the performance of cutting tools made of high-speed steels. The analysis of modern methods of changing the properties of the surface layers of tools according to the specified parameters is carried out. Currently, about a hundred types of hardening technologies of cutting tools are known to have been developed. Almost all performance criteria are determined by the properties of the surface layers. It is shown that the achievement of a given set of properties of surface layers is possible not only by conventional methods, but also by laser treatment. Various options for laser surface treatment of cutting tools made of high-speed steel are considered. It is determined that pulsed laser radiation has a number of advantages for such processing compared to conventional processing. Based on the results of the study, optimal modes of pulsed laser processing of high-speed steels were established, carried out without melting the surface.

Keywords: High-speed steels, Laser, Hardening technologies, Laser radiation.

I. Introduction

Increasing the life of the cutting tool is an urgent task of modern surface treatment methods. The surfaces of the friction pairs work in conditions of high temperatures, aggressive environments, and at the same time experience cyclic, alternating and shock loads.

In this case, the surface layers of the material are subjected to the processes of deformation, deformation, oxidation and destruction. The strength and geometric properties of the surface are the key factors determining its wear resistance. High-speed steels are widely used for metal-cutting tools [1], due to their higher viscosity and strength compared to other tool materials. Surface treatment is an integral part of the technological process of hardening machine parts, equipment and machining tools, which allows you to increase durability and wear resistance by 2 to 5 times [2]. To increase the life of cutting tools, well-known technologies are used aimed at improving the performance of already known tool materials by modifying its surface layer by processing high-energy beams and applying wear-resistant coatings. With the help of such processing, it is possible to significantly change the mechanical, electrical, thermal and chemical properties of the initial tool material, its real surface.

II. Research

One of the most promising ways to improve the performance of a cutting tool is to strengthen its working surfaces, while achieving a combination of high strength properties of the base material with hardness and heat resistance of the surface layer. Currently, about one hundred types of hardening technologies of cutting tools have been developed. Almost all performance criteria are determined by the properties of the surface layers.

To increase wear resistance, traditional methods of hardening are widely used: plasma-arc methods of applying composite coatings, mechanical methods of surface treatment, thermal and chemical-thermal treatment [2]. Since the durability of the tool material is an integral property that depends not only on viscosity and strength, but also on hardness, heat resistance and wear resistance, attempts have been made to harden the surface layer of high-speed steels using the following methods: chemical (CVD) and physical (PVD) deposition from the vapor or plasma phase, as well as chemical-thermal and laser surface treatments. The greatest interest at the moment is caused by laser treatment, which can be used not only for hardening, but also for local restoration of worn surfaces of tools [3]. The following methods of using a laser for surface treatment are known: thermal, which ensures a high rate of phase transformations in the solid state and the formation of highly supersaturated solid solutions; surface melting followed by accelerated crystallization of the melt and the formation of fine crystalline nonequilibrium phases; surface alloying, for example, laser cladding or laser remelting. Today, laser treatment is widely used to harden tool steels and alloys [4].

To improve the performance of cutting tools made of high-speed steels, the use of laser technologies is a very promising direction, among which laser hardening occupies an important place. The advantages of laser hardening are due to the possibility of supplying a high concentration of energy to the processing zone, ensuring locality of impact on the hardened surface of the tool, environmental cleanliness, as well as great automation and process control capabilities. Laser quenching is carried out outdoors without the use of vacuum or quenching media [5].

High-speed local laser heating followed by rapid cooling into the volume of the material makes it possible to obtain a finely dispersed nonequilibrium structure with a wide range of properties. At the same time, there is no mechanical impact and warping of the processed product, which, combined with easy automation and fast payback of equipment, makes laser surface hardening technology a worthy competitor to traditional processing methods.

Research in this area is aimed at improving the adhesion of the applied layer, increasing the hardness of the coating and the modified zone, and reducing residual stresses in the modified layer [6]. However, despite the development of a number of hard ceramic coatings resistant to various types of wear, having very high hardness and low coefficients of friction, intensive destruction during plastic deformation of the tool base cannot be avoided. In most cases, the destruction of the coating-substrate system begins with plastic deformation of the substrate near the interface, when this system is subjected to severe stress. Thus, the load resistance in the coating-substrate system also depends on the properties of the substrate. In order to improve the performance of products with wear-resistant coatings, it is necessary to balance the difference between internal stresses in the boundary layers of the substrate and in the coating without significantly reducing hardness and wear resistance. For this purpose, combined tool processing is increasingly used [7].

To improve the performance of cutting tools with high-speed steel coatings, methods of complex surface treatment are used, combining the processes of ion-plasma coating and surface hardening treatment. Pre-surface treatment helps to reduce the tendency of the cutting wedge of the cutting tool to elastic deflections and loss of shape stability, which helps to improve the performance of cutting tools. At the same time, such a preliminary surface treatment does not significantly affect the strength of the coating material and the adhesive bond strength of the coating with the tool base, which, as mentioned above, affect the process of coating destruction. An increase in these characteristics can be achieved by additional hardening treatment after coating [8].

The creation of structurally nonequilibrium states in the surface layer of the tool during their pulsed electron beam alloying seems to be a promising treatment of cutting tools as part of a wear-resistant complex before applying a wear-resistant coating.

In the last decade, the use of concentrated energy flows has become widespread, which make it possible to transfer high densities of absorbed energy (tens of J/cm2) to the material in relatively short (less than 100 microseconds) time intervals. In particular, research in the field of modification of the cermet surface by a pulsed electron beam has made serious progress. It has been established that with such processing, it is possible to obtain a multiple increase in operational characteristics due to a complex of modifying effects due to thermal, thermomechanical and diffusion phenomena [9]. The treatment is accompanied by a transformation of the phase composition and defective substructure of the surface layer, which consists in the formation of a submicron and nanoscale grain structure (100...200 nm). Due to the high temperature gradient and thermomechanical stresses, cascades of displaced atoms and a large concentration of structural defects occur, which, apparently, is the cause of the observed segregation phenomena and intense diffusion flows of atoms. At the same time, a variety of hardening mechanisms in a layer up to 10 microns was revealed.

The main factors of electron beam irradiation of materials that determine the temperature profiles of the surface layer heating zone, and, accordingly, the nature and kinetics of structural-phase transformations, are the energy density in the electron beam, the duration, number and frequency of irradiation pulses [10] [11]. An increase in the duration of the electron irradiation pulse leads to a decrease in the heating temperature of the irradiated surface with a noticeable increase in the depth of heating of the layers, which reduces the intensity of remelting of the composite structure. An increase in the energy density in the electron beam leads to an increase in the heating temperature of the irradiated surface and to a significant increase in the heating depth. An increase in the number of irradiation pulses also increases the depth of warming up of the instrument, but for each value of the energy density in the electron beam there is a limit value of the heating zone from the irradiated surface [12] [13].

The use of pulsed radiation for these purposes provides a greater effect than the use of continuous radiation, since the degree of hardening during pulsed laser hardening is greater than with continuous. This difference in the degree of hardening is explained by the fact that with pulsed laser hardening, the heating rate is 2 orders of magnitude higher than with continuous.

The influence of the power and duration of the laser radiation pulse on the microhardness of P6M5 steel coated with titanium nitride and uncoated has been studied. The surface laser treatment was applied to tool materials that had undergone heat treatment and final grinding. A Russian-made laser installation based on an IPG pulsed solid-state laser, widely used in industry, was used, made in the form of separate units: a machine with an optical-mechanical unit, a feed mechanism and a synchronizer; a modulator, which includes a current source, a storage device, a combined unit and a cooling device (Fig.1). The installation is used in surface treatment (hardening) of tool steels, as well as thermally non-hardening materials without disturbing the surface and geometry of the product. If it is necessary to protect the treatment area from oxidation, a protective gas blowing system is provided in the installation [2].

The principle of operation consists in pulsed laser generation of powerful light radiation. The optical system generates a laser beam of the required diameter and directs it to the workpiece [14] [15].

The processing process can be observed visually through the optical system of the installation.

The pulse duration (τ) was assumed to be 1.5; 2.5; 4 ms.

The pump voltage (Uh) varied from 380V to 800V.

Metallographic studies were carried out to study the structure of the surface layer treated with a laser beam and determine the depth of the zone of thermal influence along the section of the spot.

From the analysis of the results obtained, it was found that the change in microhardness significantly depends on the duration of the radiation pulse and the pump voltage (Fig. 2.). For example, with a pulse duration of τ = 1.5 ms, the microhardness of the sample at a depth of 0.05 mm increases by 10% compared to the initial one and reaches 9.2 GPa, and with a pulse duration of τ= 4ms, the microhardness increases by 18% and reaches (11 GPa).

When analyzing the dependences of the microhardness of P6M5 steel on the value of the pumping voltage, we see that the microhardness decreases and at a value of Up > 520V becomes lower than the initial one. This is explained by the melting of the surface layer, since the radiation energy density increases with increasing Uh.

Also, based on the results of the study, optimal modes of pulsed laser processing of high-speed steels were established, carried out without melting the surface.

Combined hardening treatment with the use of pulsed laser radiation as a hardening surface treatment was also studied. Two processing options were studied: - preliminary laser treatment of the contact pads of the RI with subsequent coating; - laser treatment of contact pads after coating.

Figure 1: *Example of the layout of a laser laboratory installation*

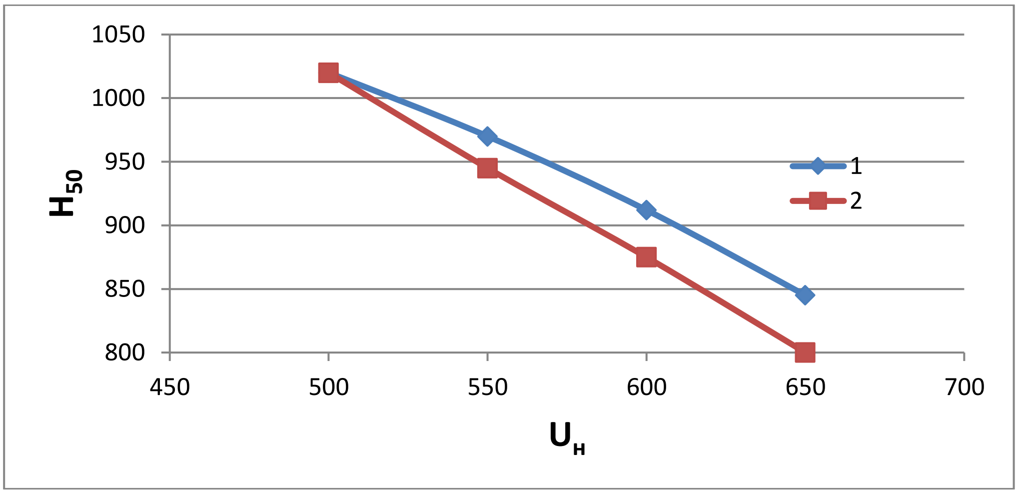

Figure 2: *Dependence of the microhardness of P6M5 steel*
on the pumping voltage (τ=4 ms, ΔF=18x4x, f=20 Hz, ν=3 mm/s)
1 – at a depth of 0.05 mm; 2 – at a depth of 0.1 mm

R6M5K5 steel was used as a tool material. Wear-resistant TiN coatings were applied with a thickness of 3-8 microns. Laser treatment of coatings and high-speed substrate was carried out on a pulsed laser installation at a power density of q = 2,7*104 – 5,2*104 W/cm, radiation pulse duration τ = 3.5 ms, laser spot diameter equal to 1 mm. The overlap coefficient of the laser spot was determined for each combination of treatment modes according to the criterion of the minimum volume of the non-hardened zone formed during laser treatment. The efficiency of the cutting tool was assessed by the intensity of wear during 30 minutes of operation and during resistance tests for the period of resistance to wear on the back surface hz = 0.75 mm.

A decrease in the amount of residual stresses occurring in coatings as a result of the use of complex leads to a change in the mechanical properties of coatings: increases the microhardness and adhesion strength of the coating to the tool base, as evidenced by a decrease in the peeling coefficient. In the entire range of laser radiation power density, high-speed tools that have undergone complex processing are characterized by higher microhardness values and lower values of the peeling coefficient. At the same time, the dependence of the separation coefficient on the power density of the laser radiation is extreme.

When implementing complex hardening options for high-speed steel tools, it is important to determine the depth of the hardening zone formed as a result of laser exposure. It is proved that the coating composition and thickness do not significantly affect the depth of the hardening zone. For all coating compositions, the decrease in the depth of the hardening zone compared to the high-speed uncoated base did not exceed 6 %, which allows us to conclude that approximately the same depths of the hardening zone for uncoated and coated cutting tools.

As a result, it was found that for high-speed tools, during complex processing, it is possible to increase the coating thickness by up to 20% compared with coatings obtained using traditional technology by increasing the resistance of the cutting wedge to elastic-plastic deformations arising under the action of thermal force loads during cutting, as a result of laser exposure.

III. Conclusion

Surface treatment of complex shaped tools made of high-speed steel is a necessary process to improve the efficiency of operation of such a tool. This processing is well implemented when using robotic complexes based on laser equipment. Laser hardening of the tool makes it possible to increase its durability by 2-6 times while creating optimal properties of the surface layer at a given depth in the absence of modification of the main material of the tool. The creation of structurally nonequilibrium states in the surface layer of the tool during their pulsed electron beam alloying seems to be a promising treatment of the surface layer of cutting tools before applying a wear-resistant coating.

Also, based on the results of the study, optimal modes of pulsed laser processing of high-speed steels were established, carried out without melting the surface.

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