Development of combined method of hardening parts used in manufacture of cutting tools for band-cutting machine tools

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Abstract. The article presents the results of the development of a combined method of hardening the parts used in the manufacture of cutting tools for band-saw machines, working in the conditions of wear and alternating loads.

1. Introduction
One of the most common methods of metal cutting is cutting operations, which is an important procurement technological operation, with which the whole process of turning a workpiece into a future part begins. The most effective and productive type of equipment that performs this type of processing is belt cutting machines that use closed band saws as a cutting tool. As in modern production, materials with high physical-mechanical characteristics (hardness, strength, etc.) are increasingly used, which significantly complicates the cutting process and places high demands on the cutting tool. To expand the range of materials to be processed, for which productive use of band-cutting machines is possible, it has become necessary to create a band saw with higher cutting characteristics. The specificity of the working conditions of the band saw shows that the blade must have such characteristics as increased vibration resistance, resistance to alternating and dynamic loads, and the cutting part of the saw must have increased resistance to impact, dynamic, alternating loads, have high hardness, and also increased wear resistance [1,2].

Taking into account the working conditions of this cutting tool, bimetallic saws were developed. These saws are a welded structure consisting of a hard-alloy top of the teeth with high microhardness values, wear resistance and a spring steel backing sheet with high resistance to vibration and alternating loads. However, such tool is sensitive to impact and dynamic loads that may occur during the cutting process when the tooth is embedded in the material being processed (when the structure of the material is heterogeneous due to the presence of solid inclusions, in the case of pores in the material being processed, when the saw blade is jammed, etc.) and leads to breakage of the teeth, at the base and at the place of welding or places, weakened after the operation of welding the blade with the cutting edge. Thus, the most common technology today for the production of band saws does not fully meet the requirements of the current level of engineering development [3].

However, the idea of creating a laminated composite is one of the right directions to solve this problem. Thus, the layered composite material proved to be efficient under complex conditions of loading on other engineering products and firmly strengthened its position in production, as with proper analysis of the working conditions of the product, be it a part or a cutting tool, in particular, a
band saw. This or that zone or layer can work for a specific type of loading. Therefore, it can be made of a material with characteristics that satisfy these load conditions. Thus, based on the analysis of the loading conditions during operation of the band saw blade, the idea of a bimetallic saw was proposed, which is the right way to solve the problem, but the main drawback is the presence of a welded joint sensitive to vibration, dynamic and shock loads, as well as the difficulty of obtaining defect-free welded seam. An alternative may be surface plasma alloying of the teeth of the band saw blade, which allows one to significantly change the physical and mechanical characteristics of the material of the cutting edge of the teeth (which will be the material of the entire band saw blade - spring-spring steel). At the same time, the output is a layered composite with high adhesion, comparable in value to metallurgical, since the material of the band saw blade is alloyed, which is also the base material, and with correctly selected modes it is possible to reduce the possible residual deformation to zero as a result of heat treatment [4].

2. Materials and Equipment
The following equipment was used to carry out the research (Figure 1): JET band saw machine (testing of the received saws under conditions close to the factory ones), Falcon 500 microhardness meter (microhardness test for preliminary analysis of wear resistance), Instron 8801 (fatigue test), plasma doping unit (directly carrying out doping), HFC.

![Equipment used in research](image)

Figure 1. Equipment used in research: a – JET band saw machine; b – Falcon 500 microhardness meter 500; c – Instron 8801.

With preliminary surface local doping from the coating with the use of heat, the alloying components of chromium, manganese, and titanium were used as the coating materials in the following ratio, wt. %: Cr - 48-49, Mn - 48-49, Ti - 2-4.

3. Analysis of Simulation Results and Experimental Data
In the development of this technology, a method of low-temperature nitriding of steel parts was adopted as the basis, including preliminary surface local doping with nitride-forming elements during laser heating of parts coated on their surface with coating and subsequent low-temperature nitriding, including heating to a predetermined temperature, exposure and cooling, while before nitriding, it is necessary to carry out the process of thermal diffusion saturation with alloying nitride-forming elements when heated to a temperature of $T = 690-710 \, ^\circ C$ with a holding time of 3-4 hours. And the subsequent nitriding process is carried out at a temperature of $T = 570-590 \, ^\circ C$ with holding for 6-8 hours in an ammonia medium. The disadvantage of this method is the low impact resistance and increased fragility of the resulting product.

The use of a plasma arc for heating in the process of preliminary local doping makes it possible to increase the wear resistance of the workpiece surface due to the possibility of using metals with high melting points in the coating that form solid carbide phases (CrC, MnC, TiC), and the use of argon protective atmosphere allows using active elements (such as Ti) in the coating composition for doping, avoiding their possible oxidation with the formation of oxide phases [5].
Increasing the temperature of diffusion saturation up to 760-850 °C with a dwell time of 2-2.5 hours ensures a uniform distribution of alloying elements throughout the entire volume of the doped part to a depth of up to 0.5 mm due to the message of the required amount of energy for diffusion movement of atoms-components in the part material.

Let us use alloying components of chromium, manganese and titanium in the following ratio, wt. %: Cr - 48-49, Mn - 48-49, Ti - 2-4, allows for increasing resistance to alternating and shock loads, and wear resistance. In particular, using chromium and manganese as the alloying components accelerates the process of diffusion saturation, ensuring their uniform distribution over the entire cross section at a given depth, having good solubility due to a slight difference in the atomic radii of chromium and manganese together with iron. It also increases the efficiency and the speed of the cementation process by reducing the temperature of the phase transformation of α to γ iron (when heated), while the face-centered crystal lattice, corresponding to The γ-iron, makes it possible to increase the efficiency and speed of the cementation process due to the better solubility of carbon in comparison with α-iron. In turn, during the carburization of HFC, steel becomes saturated with carbon, which, together with manganese and chromium, forms solid carbide phases. The alloying of steel with chromium and manganese, followed by cementation allows one to obtain CrC (chromium carbide) and MnC (manganese carbide), which increase the hardness and wear resistance of the working surface of the part, and manganese itself can increase the resistance to shock loads and ensure cold workability of working surface of the part during operation. It was established experimentally that the use of Ti in the composition of the coating in the amount of 2-4 wt.% positively affects the increase in impact strength of the alloyed material, as well as resistance to impact and alternating loads as a result of grinding the grains of the structure of the alloyed layer. Also in the process of cementation of an HFC part at a temperature of 1200-1250 °C for 20-30 minutes, Ti forms a carbide TiC phase which has high hardness and significantly increases wear resistance. At the same time, the introduction of Ti coating in an amount of less than 2 wt.% does not significantly affect the change in the physical and mechanical properties of the alloyed layer of the hardened steel part, and more than 4 wt.% leads to an increased content of hardly soluble titanium carbides when heated. Grain boundaries contribute to brittle fracture [6,7].

Using HFC to heat the surface of the part to a temperature of 1200-1250 °C with a holding time of 20-30 minutes during cementation allows carbon atoms to penetrate into the cemented part to a depth of 0.5 mm with the formation of carbide phases as well as with alloying components and with the material details. At the same time, the use of high-frequency current together with carbon coating during cementation allows it to be carried out locally due to the directional heating of the treated area, without affecting the temperature on the entire volume of the part.

In addition, the combination of the proposed features allows you to avoid an increase in the grain of the material of the hardened part, which leads to its embrittlement, a decrease in the strength of toughness, as well as a decrease in wear resistance and resistance to alternating loads [8].

The method of surface hardening parts made of steel is as follows.

On the hardened surface of the steel part, one puts a layer of coating containing alloying components Cr, Mn, Ti in the following ratio, wt. %: Cr - 48-49, Mn - 48-49, Ti - 2-4. Then it is necessary to heat the plasma arc of the surface with the applied coating to form doping foci. After heating by the plasma arc, thermal diffusion saturation is carried out at a temperature of 760-850 °C with an exposure of 2-2.5 hours, followed by cooling in the oven. After cooling, one must carry out the cementation in HFC at 1200-1250 °C for 20-30 minutes.

The method of surface hardening of steel parts is illustrated by specific examples.

Example 1

On the cutting part of the saw, the blade of which is made of spring-steel, let us put a layer of coating containing alloying components Cr, Mn, Ti in the following ratio, wt. %: Cr - 48, Mn - 48, Ti – 4. Then let us heat the plasma arc of the surface with the applied coating to form doping foci. After heating by the plasma arc, thermal diffusion saturation is carried out at a temperature of 760 °C with
an exposure for 2.5 hours, followed by cooling in the oven. After cooling, one must carry out cementation in HFC at 1250 °C for 20 minutes.

Example 2

On the cutting part of the saw, the blade of which is made of spring-steel, let us put a layer of coating containing alloying components Cr, Mn, Ti in the following ratio, wt. %: Cr - 48.5, Mn - 48.5, Ti – 3. Then one must heat the plasma arc surface with the applied coating to form doping foci. After heating by the plasma arc, thermal diffusion saturation is carried out at a temperature of 800 °C with an exposure for 2.3 hours, followed by cooling in the oven. After cooling, let us carry out cementation in HFC at 1225 °C for 25 minutes.

Example 3

On the cutting part of the saw, the blade of which is made of spring-steel, let us put a layer of coating containing alloying components Cr, Mn, Ti in the following ratio, wt. %: Cr - 49, Mn - 49, Ti – 2. Then the plasma arc of the surface is heated with the applied coating to form doping foci. After heating by the plasma arc, thermal diffusion saturation is carried out at a temperature of 850 °C with an exposure for 2 hours, followed by cooling in the oven. After cooling, it is necessary to carry out cementation in HFC at 1200 °C for 30 minutes.

The results shown in Table 1 and in Figure 2 confirm that the steel part obtained by the inventive method has increased wear resistance due to the increase in microhardness due to the presence of carbide phases (MnC, CrC and TiC) and resistance to shock and alternating loads owing to increase in the toughness due to the steel alloying with manganese and the part obtained by a known method [9].

| Name of the indicator   | Prototype | Example 1 | Example 2 | Example 3 |
|-------------------------|-----------|-----------|-----------|-----------|
| Micro hardness, GPa     | 8-16      | 22        | 21        | 20.5      |
| Impact strength, kJ / m²| 140       | 170       | 180       | 185       |

Figure 2. Studies of the microhardness of the samples after plasma doping followed by cementation: a - according to example 1; b - according to example 2; c - according to example 3.

Thus, the inventive method of hardening parts made of steel allows one to obtain products with enhanced performance characteristics, namely, high wear resistance and resistance to shock and alternating loads [10].

4. Conclusion

As a result of the research, a combined method of hardening the part was developed, which can be used in the manufacture of cutting tools for band-cutting metal-cutting machines operating under conditions of wear and alternating loads.

The method of surface hardening of a steel part includes preliminary surface local doping from the coating with the use of heat, thermal diffusion saturation of the surface of the part with alloying elements from the coating applied on its surface by heating, aging and cooling, while local doping
from the coating is carried out by heating the plasma arc in a protective atmosphere argon. Thermal diffusion saturation is carried out at a temperature of 760-850 °C with an exposure for 2-2.5 hours after cooling, additionally carried out cementation of the part with high frequency currents (HFC) at a temperature of 1200-1250 °C for 20-30 minutes. And the coating contains alloying components of chromium, manganese, titanium in the following ratio, wt. %: Cr - 48-49, Mn - 48-49, Ti - 2-4. The result is an increase in wear resistance, resistance to shock and alternating loads.

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