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Methods of increasing the physical and mechanical strength of the working surface of rolling rolls

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Abstract. The article discusses the problem of rapid wear of the work rolls of a twenty-high rolling mill for plastic deformation of nitinol. The purpose of this study is a comparative analysis of hardening methods and the feasibility of their use to increase the hardness of a roller tool. As a result, a method of ion implantation of work rolls with boron and nitrogen was identified that is preferable for implementation and deeper experimental study.

1 Introduction

In the modern world for further economic growth, it is necessary to actively develop such industries as the space and aviation industries, medical instrument making, and microelectronics. Increasingly high demands are placed on products produced by enterprises, and, accordingly, on the materials used in their manufacture.

The thinnest nitinol strips, the manufacturing technology of which involves cold rolling on twenty-roll mills, are widely used in complex technical devices. Today, there is a problem of rapid wear of work rolls, which has a negative impact on the quality of the resulting strip.

2 Materials and methods

There are many methods for increasing the service life of parts aimed at increasing the wear resistance of the working surface by applying protective and hardening coatings. Among them are the diffusion saturation method, the detonation gas-thermal method, plasma spraying and the ion implantation method. Next, the above methods of hardening the working surface of a roller tool are discussed in more detail.

The diffusion saturation method is characterized by the production of coatings in a vacuum using an activator. Depending on the chosen coating material, the properties of the resulting surface are varied, which is an advantage of this method. For coating work rolls, borochrome plating of steels can be considered the best option. The negative aspects of this method include: a relatively low reaction rate, the need to maintain high temperatures (1000-1200 ° C). The thickness of the coating depends on the type of steel being processed and can

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reach 250 microns. The roughness of the diffusion coating usually does not exceed Ra 1.6 [1].

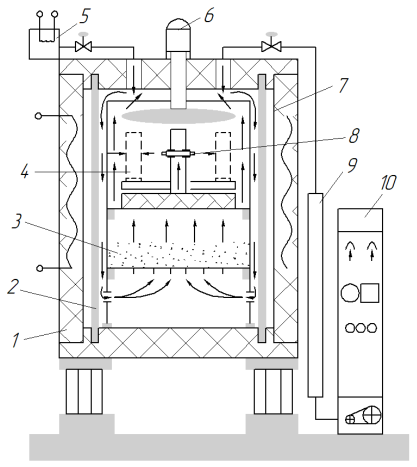


Fig. 1. Scheme of a circulation installation for diffusion saturation: 1 – heating furnace; 2 – sealed muffle; 3 – source of the diffusing element; 4 – object being processed; 5 – halide evaporator; 6 – fan; 7 – guide screen; 8 – part to be coated; 9 – condensation system of processed gases; 10 – suction and control panel.

Surface hardening by the detonation gas-thermal method is carried out using a special installation equipped with a gun in the form of a channel. This channel is filled with an explosive substance, which is ignited at the right time. The coating material powder is supplied between shots. The thickness of the coating varies from 10 microns to several mm. The roughness of the resulting surface is within the range of Rz 80-100 µm (Ra 20-25 µm) [2]. The positive aspects of this method are discussed below:

- temperature in the coverage area up to 250 °C [3];
- a wide range of materials used for coating;
- possibility of multi-layer coating.

The disadvantages include:

- as the hardness of the material being coated increases, the quality of the coating and its adhesive properties decrease. Maximum hardness 61 HRC;
- inability to cover a large area;
- high installation costs and increased danger of the work being carried out.

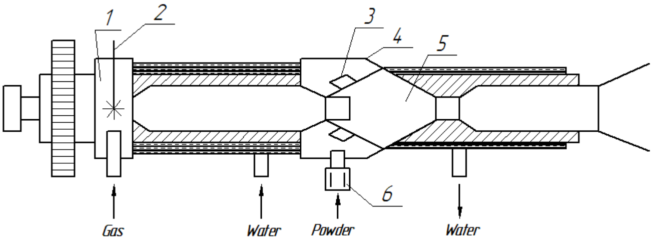


Fig. 2. Diagram of a detonation gas atomizer with radial powder input with a barrel of variable cross-section: 1 – pre-chamber; 2 – candle; 3 – radial holes; 4 – closed annular cavity with holes; 5 – camera; 6 – fitting.

Plasma spraying is a method of applying a coating to a surface using a high-temperature plasma jet into which the sprayed material is supplied. Under the influence of elevated temperature, the strengthening substance turns into a liquid state and is applied to the part. In this way, several layers of spraying are applied sequentially. But the resulting coating is characterized by low adhesion under loads of 10...50 MPa and porosity, as a result of which it requires subsequent abrasive treatment. May require subsequent abrasive treatment. The thickness of the coating does not exceed 1 mm. The temperature of the coated part is within 200 °C [4].

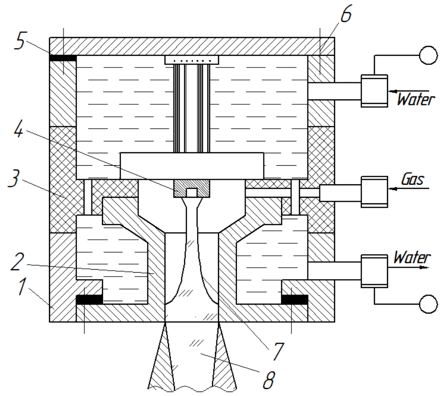


Fig. 3. Plasma sprayer diagram: 1 – spray body; 2 – nozzle; 3 – electrical insulating insert; 4 – electrode; 5 – gaskets; 6 – mounting screws; 7 – arc; 8 – plasma jet [4].

The ion implantation method is carried out by introducing ionized atoms and molecules of alloying substances into the surface of the part. In this case, there are various combinations of ions and targets. The ionizing substance enters the installation in the form of a gas (for example, nitrogen, helium, hydrogen) or in the form of gaseous compounds (boron fluoride III, phosphine). If solids are used, they are heated until they change from solid to vapor. If the vaporization temperature of the material is above 1000°C, then it is sprayed in a gas environment and ionized in a gas plasma [5]. A distinctive feature of this method is the absence of dependence of ion implantation on the limits of chemical solubility. Consequently, it is possible to obtain coatings with a combination and concentration of alloying substances on the surface that are not possible to obtain using standard methods.

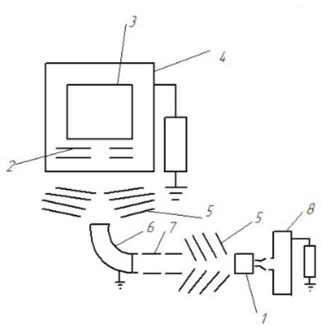


Fig. 4. Scheme of a high-energy ion implantation installation: 1 – adjustable diaphragm; 2 – system for pulling and primary beam formation; 3 – ion source; 4 – high-voltage module; 5 – acceleration system; 6 – magnetic mass separator; 7 – focusing lens; 8 – receiving chamber [2].

The main disadvantage is the possibility of occurrence of crystal lattice defects on the surface of the part as a result of knocking out an atom from a lattice site, as well as the formation of a Frenkel pair of point defects - a vacancy and an interstitial atom. Point defects are often combined into divacancies, trivacancies, and then develop into more complex types of damage. Currently, there are different ways to combat this disadvantage of ion implantation, they are associated with temperature changes. This is due to the opinion that the occurrence of crystal lattice defects in the target material directly depends on the sharp temperature drop that occurs during the process of "cold" ionization. In cases where it seems impossible to increase the temperature of the working medium, annealing is used to eliminate defects.

3 Results and discussion

The coating obtained as a result of traditional implantation is less than 1 micron. This layer often wears out even at the laboratory testing stage. The solution to the problem was the use of high-intensity ionization using elevated temperature and high current density (up to 10 mA/cm2). The use of these modes includes the diffusion effect and allows not only to increase the thickness of the outer coating, but also ensures the penetration of alloying ions into the target material up to 20 microns, which significantly strengthens the coating and increases service life [6]. The roughness of the resulting surface largely depends on the initial roughness of the part. So, in the case of parameters within Ra 0.02-0.04 μm, some deterioration in surface quality is noticeable, and in the case of the initial Ra 0.16-0.32, the intensity of negative changes decreases. For samples with Ra 0.63 μm, roughness indicators are unstable after ion implantation. In some cases there may be a slight deterioration, while in others the opposite effect is observed [6]. Considering that the technical requirements for the surface roughness of work rolls is Ra 0.1, it can be assumed that the effect of ion implantation will be insignificant and, in theory, it can be neglected.

Boron, nitrogen and boron nitride are considered as alloying substances for rolling rolls.

Boron is a solid with a high temperature of gas formation, therefore it is used in the form of a compound with other elements. One option is boron fluoride III - a binary inorganic compound of boron with fluorine, where boron is the alloying substance, fluorine is the necessary "gassing agent". As a result of using boron as an ionizer, a coating is obtained with increased resistance to wear, corrosion and cavitation, which can reduce the harmful effects of aggressive environments. It is worth noting a decrease in the coefficient of sliding friction - even when the lubricant film ruptures, there is no severe damage to the interacting surfaces. A significant disadvantage of such a coating is its small thickness - not exceeding 0.6 μm even in the case of using high temperatures and high-density currents [7].

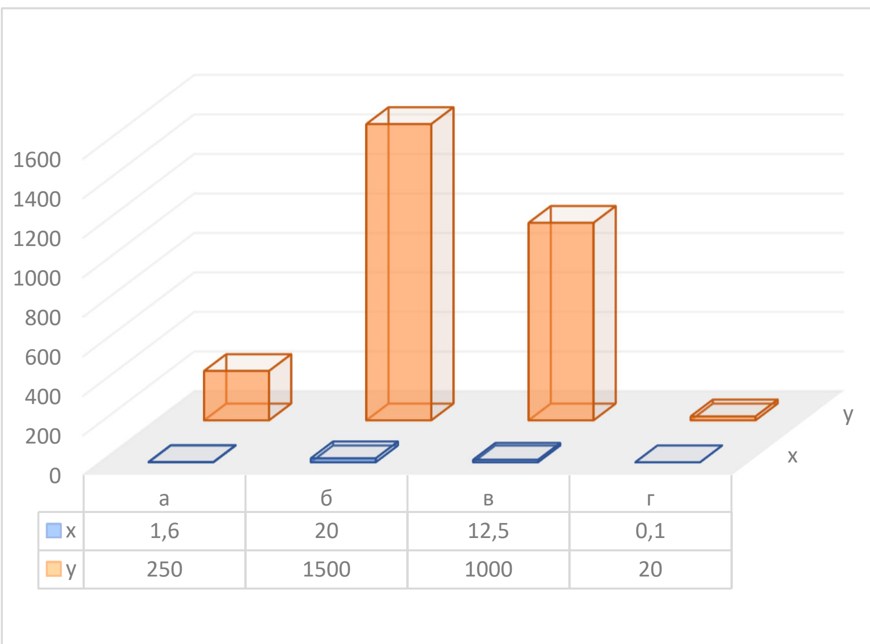
Nitrogen is widely used to strengthen and increase the corrosion resistance of steels, including during ion implantation. Unlike boron, implantation with nitrogen has a greater coating thickness of up to 20 μm, considering penetration into the depth of the surface of the target material [8]. However, it has significantly fewer quality properties that positively affect the surface of the work rolls. Separately, it is worth noting that rolling rolls are often made of alloy steels with a high carbon content, the chemical compatibility of which with nitrogen has a number of disadvantages. One of which is a sharp decrease in the effectiveness of the positive properties of the coating. However, ion implantation offers the possibility of combining materials that are otherwise incompatible. Consequently, the question of the qualitative properties of nitrogen ionization of steels with a carbon content of more than 0.5% remains open today.

Boron nitride ion implantation is a combination of ionization with both boron and nitrogen. On the one hand, this combination assumes all the previously discussed positive aspects of both types of coatings, as well as the elimination of some disadvantages, in particular the small thickness of the boron coating, while maintaining all its properties that are lacking in nitrogen. On the other hand, the issue of insufficient knowledge of the compatibility of nitrogen and carbon remains open, since it is nitrogen ions that are characterized by deeper penetration into the surface of the part.

Each of the considered methods of applying hardening coatings combines both positive and negative aspects. When choosing a particular method of coating a roller tool, it is important to comprehensively consider all the nuances. The following is a comparative analysis of the properties of the resulting coatings.

Table 1. Comparative analysis of the properties of the resulting coatings.

Coating method	Maximum coating thickness, microns	Surface roughness, Ra
Diffusion saturation	250	1.6
Detonation gas-thermal	1500	20 … 25
Plasma spraying	1000	12.5
Ion implantation	20	Depends on the initial roughness of the sample



a – diffusion saturation method, b – detonation gastremic method, c – plasma spraying method, d – ion implantation method (x – surface roughness, Ra; y – coating thickness, μm)

Fig. 5. Comparison of roughness and coating thickness using different application methods.

Having carried out a comparative analysis of the above-described methods of surface hardening, it is worth noting the insignificant effect of ion implantation on the roughness and geometric parameters of the product in comparison with other methods. Therefore, it will not require subsequent technological processing. The ratio of the resulting characteristics of the surface obtained by the ion implantation method is more consistent with the requirements for work rolls.

4 Conclusion

Using the method of ion implantation of work rolls, a protective layer is formed on the surface, the characteristics of which contribute to the maximum strengthening of the surface layer of the roll tool. Which will lead to an increase in its durability. At the same time, no deterioration in the geometry and roughness of the roll surface was noticed. Consequently, ion implantation of rolling mill work rolls is a fairly innovative method that can have a significant impact on the quality of the working surface, and, accordingly, the resulting nitinol strip. To draw specific conclusions about the effectiveness of ion implantation for hardening rolls, it is necessary to conduct a series of practical experiments.

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