Increase in wear resistance of nickel plasma coatings under traditional and combined treatment conditions

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Increase in wear resistance of nickel plasma coatings under traditional and combined treatment conditions

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Abstract. The paper reports the prospective approaches to the increase in wear resistance of nickel plasma coatings. We considered the features of the two methods: combined high-energy heating by high frequency currents and spraying of composite cermet coatings of powder mixtures. The research provides the results of comparative wear resistance tests of the investigated nickel coatings under the conditions of sliding friction. The obtained fused and cermet coatings have a higher wear resistance compared to the original ones. The samples with composite coatings showed a significant decrease in the volumetric wear, averaging 56% along the entire length of the friction path due to the introduction of ceramic particles with high hardness (12150...15840 MPa) into the powder mixture. We present the results of the chemical composition research of nickel-ceramic powder mixture components and the sprayed cermet coating. The composite coating is established to have an increase in oxygen content owing to the intensive oxidation in the process of plasma spraying. There is a decrease in the percentage of the basic elements of the powder mixture, namely of aluminum and nickel. There is also an insignificant change in the share of the remaining chemical elements.

1. Introduction

Various methods of machine parts surface hardening are used in the technology of mechanical engineering to increase the resource of process equipment, with plasma spraying of coatings being among them [1, 2]. A widely known and used industrial group of materials for acquiring wear resistant coatings are nickel based self-fluxing powders. Continuous development of mechanical engineering connected with toughening loading regimes requires a constant increase in coatings wear resistance. This aim can be achieved by application of various combined technologies and by formation of composite cermet coatings for the improvement of their qualitative indices.

The essence of the combined treatment consists in additional high energy heating of coatings with the purpose of porosity reduction, elimination of unmelted structural particles and discontinuity flaws at the transitional boundary. The comparative possibilities analysis of the various treatment methods by concentrated energy sources demonstrated the evident advantage of the high energy heating by the high frequency currents [3-5]. The peculiarity of this process is the energy release in the surface layer.

A characteristic feature of wear-resistant cermet coatings formation is the possibility of receiving mixtures, in which one component provides a high level of hardness and the other serves as a bond, which ensures efficient correlation of properties. The use of powder mixtures materials is preferable among the variety of technologies for the production of composite coatings [6], since plasma spraying
of powders in the form of mixtures is technologically more productive and less labor intensive, as well as allows for the modification of the coatings structure and properties by changing the mixture or the ratio of the components.

The purpose of this work is to study plasma nickel coatings obtained under the conditions of traditional and combined treatment schemes.

2. Materials and methods

Plasma coatings deposition was performed by 40 kW electric arc plasma torch PUN-3. The samples were thin bushings of steel 20 with external diameter of 25 mm and width of 12 mm (Figure 1). The surface of the workpieces was previously subjected to the sand blasting processing.

The mode parameters of plasma spraying were: the value of the plasma torch arc current, the voltage, the flow of plasma gas (air), the distance of spraying, the feed of plasma torch and rotation speed of the samples were chosen on the basis of previous research [7]. The coating thickness was within 500...540 µm. The material for coatings deposition was nickel self-fluxing powder PG-12N-01 with particle size of 50...100 µm.

The surface fusing of the samples was performed on the experimental installation equipped with the generator VChG 6-60/0.44 with the operating frequency of 440 kHz and the controlled drive of rotary motion. The heating process was provided for by the loop type inductor equipped with the $N_{87}$ magnetic conductor (Figure 1), the depth of energy output was about 0.6...0.8 mm. The specific power ranged from $3.1 \times 10^8$ W/m$^2$ to $3.2 \times 10^8$ W/m$^2$, and the velocity $\nu$ of the sample surface movement relative to the inductor ranged from 70 mm/s to 75 mm/s [8].

Figure 1. Schemes of plasma coatings deposition and high-energy heating by high frequency currents

For the deposition of cermet coating we used a powder mixture obtained from nickel powder and 15A oxide ceramics with grain size of 20...28 µm, with a volumetric ratio of components equal to 1/4.

Coatings wear resistance tests in sliding friction conditions were performed on experimental installation which implement the scheme presented in Figure 2a. The friction pair consisted of a motionless fixed coated sample and a rotating VK8 hard alloy indenter with the diameter of 30 mm and the width of 22 mm. The rotation speed of the indenter in the experiments was 1500 min$^{-1}$, with the load on the friction pair being 20 N.

As a generalized characteristic of the wear value we used the volume loss of the samples material calculated by the formula:
\[
\Delta V = \left( \frac{\pi \cdot r_1^2 \cdot \arcsin \frac{a}{2 \cdot r_1} + \pi \cdot r_2^2 \cdot \arcsin \frac{a}{2 \cdot r_2} - \frac{a}{2} \left( \sqrt{r_2^2 - \frac{a^2}{4}} + \sqrt{r_2^2 - \frac{a^2}{4}} \right)}{180} \right) \cdot b,
\]

where \(r_1\) is the sample radius, mm; \(r_2\) is the radius of indenter, mm; \(b\) is the width of the sample, mm; \(a\) is the width of the wear hole, mm.

The research of the chemical composition of the nickel-ceramic powder mixture and the sprayed cermet coatings was performed with the help of scanning electron microscope Carl Zeiss EVO50 XVP, equipped with a microanalyzer of chemical elements EDS X-Act (Oxford Instruments). Prior to performing the chemical analysis of the coatings, the samples were subjected to grinding since the surface of the samples is intensively oxidized during spraying.

3. Results and discussion

After the high energy heating, the significant changes occurred in the structure of the plasma coatings. The surface of nickel coatings acquired a more uniform relief; the coating porosity and the areas of discontinuity flaws at the transitional boundary decreased; the unmelted powder particles were eliminated as evidenced by the results of metallographic studies [9].

Plasma spraying of cermet coatings of powder mixtures has its specific formation features. The structure is characterized by the presence of the expressed boundaries between the particles of nickel powder and oxide ceramics and mutual wrapping of these components. Metallographic analysis showed a noticeable decrease in the content of ceramics in the coatings compared to the original mixture, caused by the effect of the components segregation in plasma spraying [10].

Figure 2b presents the comparative wear kinetics of the examined coatings after the fusion by high frequency currents at the combined processing and the obtained cermet coatings on the basis of the powder mixture compared with the original plasma coatings made of nickel powder.

The results of the studies show that both fused and cermet coatings have a higher wear resistance in the conditions of sliding friction compared to the original coatings. The volumetric wear of the samples after high-energy heating by the high frequency currents decreased on the average by 22% along the entire length of the friction path. The samples with cermet coatings obtained from the powder mixtures demonstrate a significant increase in wear resistance, on the average by 56% along the entire length of the friction path. Such increase of wear resistance is explained by introduction of ceramics particles possessing high hardness into the structure of the powder mixture because the
microhardness of oxide ceramics is within 12150...15840 MPa and that of nickel powder is within 7750...9600 MPa.

At plasma spraying heterogeneous particles of a powder mixture have different values of temperature, speed and duration of flying state. During the application of cermet coating within the accepted modes the average values of temperature and speed of a plasma jet were about 6000...7500 K and 630...750 m/s, respectively [11]. At such high level of energy influence of a plasma jet on powder materials there is a necessity to estimate the change of a chemical composition.

Figure 3a demonstrates the image of the original nickel-ceramic powder mixture obtained with the help of a scanning microscope. The image shows that the particles of nickel powder have a form close to spherical and a large fractional size. The particles of oxide ceramics are close to the sharp-grained form. In general, there is a uniform distribution of the powder particles. Spectral analysis, which allows one to determine the composition and ratio of chemical elements, was performed separately for each component of the powder mixture. Zones 1, 2 correspond to nickel particles and zones 3, 4 correspond to oxide ceramics.

![Figure 3a](image1.png)

Figure 3b presents the image of the cermet coating surface after plasma spraying. For the analysis of the obtained image, it is noteworthy that the light particles are the constituents of nickel powder and the gray particles are those of oxide ceramics in the structure of cermet coating. In general, there is a significant change in the shape of particles and their uniform distribution after spraying.

The results of chemical composition studies for the powder mixture components are presented in Table 1. There is a slight fluctuation in the percentage of chemical elements in the local zones of the powder mixture, within the normal range.

| № of spectrum | O   | Al | Si   | Ti  | Cr  | Fe   | Ni   |
|---------------|-----|----|------|-----|-----|------|------|
| 1             | 1.54| -  | 2.90 | -   | 11.52| 3.43 | 80.60|
| 2             | 3.34| -  | 2.88 | -   | 10.66| 3.29 | 79.84|
| 3             | 53.87| 43.38| 0.28 | 1.41 | 1.06 | -    | -    |
| 4             | 52.86| 43.26| 0.56 | 2.10 | 1.23 | -    | -    |

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A local chemical composition study of the mixture surface layer was conducted to assess the impact of high-temperature plasma jet on the quality of the deposited coating. Similar to the study of the initial powder mixture the zones 1, 2 correspond to nickel particles, and zones 3, 4 correspond to oxide ceramics. The results of the chemical composition analysis of the sprayed cermet coating are given in Table 2.
Table 2. The results of chemical composition analysis of the sprayed cermet coating

| № of spectrum | O          | Al | Si  | Ti | Cr | Fe | Ni  |
|---------------|------------|----|-----|----|----|----|-----|
| 1             | 6.16       | -  | 2.87| -  | 11.33 | 3.41 | 76.23 |
| 2             | 7.43       | -  | 2.40| -  | 10.80 | 1.98 | 75.40 |
| 3             | 55.01      | 34.97 | 3.81| 4.11 | 2.10 | -    | -    |
| 4             | 54.19      | 33.91 | 2.76| 7.38 | 1.77 | -    | -    |

The correlation of data on chemical composition (Tables 1 and 2) reveals that in the cermet coating there is an increase in oxygen content at the expense of intensive oxidation in the process of plasma spraying. There is also a decrease in the percentage of the basic elements of the powder mixture, namely of aluminum and nickel. The change in the proportion of other chemical elements is negligible.

4. Conclusion

The results of the conducted research testify that the application of high-energy fusion by of high frequency currents and formation of cermet coatings of powder mixtures lead to the increase of nickel plasma coatings wear resistance.

Special attention should be given to the temperature mode during the coatings fusion, as overheating leads to a sharp decrease in wear resistance and insufficient impact does not significantly affect the parameter.

The conducted research of the chemical composition has shown that after nickel-ceramic powder mixture plasma spraying at the chosen modes, the coatings preserve the structure of the initial mixture chemical elements with a certain change in their percentage. The increase in the percentage of oxygen and the reduction in aluminum and nickel, which are due to the high level of energy exposure of the plasma jet to the heterogeneous particles of the powder mixture, characterize the investigated processes.

Deposition of wear resistant coatings made of powder mixtures involves the issue of determining the efficient modes of plasma spraying due to the heterogeneity of powder components. The technology of nickel self-fluxing powder materials deposition allows one to achieve a significant increase in wear resistance of machine parts in the conditions of sliding friction.

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