

# Research into properties of wear resistant ceramic metal plasma coatings

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**Abstract.** The study considers one of the promising ways to improve the quality of wear resistant plasma ceramic coatings by implementing various powder mixtures. The authors present the study results of the nickel-ceramic and cobalt-ceramic coating properties and describe the specific character of the investigated coatings composition. The paper presents the results of the coating microhardness, chemical and adhesive strength studies. The authors conducted wear resistance tests of composite coatings in comparison with the plasma coatings of initial powder components.

## 1. Introduction

Wear resistant plasma coatings have been widely used to harden the driven elements of various process equipment. Ceramics based on aluminum oxide  $\text{Al}_2\text{O}_3$  is one of the common materials. These coatings have high hardness and wear resistance, but ceramics is also characterized by brittleness resulting in the destruction of the coating when the shock loads occur. The formation of ceramic metal compositions is a very promising approach to improve the quality of ceramic coatings. In practice this is performed by the ceramics thermal diffusion alloying with non-ferrous metals particles, electron-beam deposition of ceramic metal condensates and thermal coating spraying with plasma or detonation methods [1-6]. Thermal spraying allows for the application of both preclad with metal ceramics particles and mixtures of powder materials to form ceramic metal coatings [7-11]. Ceramics provides a high level of hardness in these compositions, and a softer metal component serves as a couplant; thus the combination generally yields an efficient ratio of coating properties.

The plasma spraying of powders in the form of mixtures is technologically less time-consuming, cheaper and more productive; it also allows for a wide range control of the coating structure by applying mixtures with different composition.

The preliminary studies on the formation of these compositions confirmed the possibility of using them as strengthening wear resistant coatings capable of sustaining considerable loads [12, 13].

The purpose of this work is to investigate the properties of ceramic metal wear resistant plasma coating formed by nickel and cobalt-ceramic powder mixtures.

## 2. Materials and methods

Two variants of initial powder mixtures with a volumetric ratio of the main and couplant components of 4/1 were used for research. The main component in both cases was the oxide ceramics on the basis



of  $\text{Al}_2\text{O}_3$  (corresponding to the composition of the 15A normal fused alumina), and the couplant was PG-12N-01 nickel powder for *composition 1* and PGN-V3K cobalt powder for *composition 2*.

The preparation of the powder mixtures was performed by mechanical mixing in a special mill to ensure uniformity. The plasma coating spraying of the samples was executed at Kiev-7 installation by 40 kW plasma torch PUN-3. The samples used were the bushes made of steel 20 with external and internal diameters of 25 mm and 15 mm, respectively, with a width of 12 mm. The spraying process was executed by the translational plasma torch motion and the rotation of the fixture with the samples. The workpieces were previously subjected to a jet-abrasive cleaning by particles of fused alumina. The samples were processed under the same conditions, which allowed the workpiece surfaces to be produced with a roughness of  $R_z = 60\ldots 80\text{ }\mu\text{m}$ .

The spraying regimes were: the plasma torch arc current was 120...180 A; the voltage was 150...160 V; the flow of plasma gas (air) was 9...12 liters/min; the spraying distance was 110 mm; the speed of the plasma torch motion was 250 mm/min; rotating frequency of the fixture with samples was 150...200 rotations per minute. The coating layer thickness was maintained within 500...540  $\mu\text{m}$ .

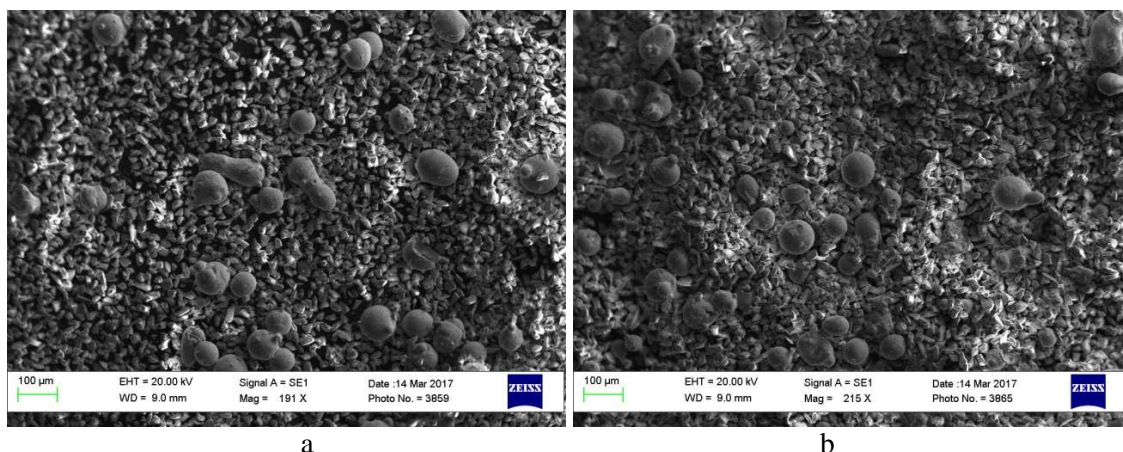
Metallographic studies were performed on a Carl Zeiss EVO50 XVP scanning electron microscope equipped with the EDS X-Act (Oxford Instruments) chemical element analyzer. The sections were prepared according to the standard technology based on material mechanical grinding and polishing [14-16]. Microhardness  $H_\mu$  of the coating was defined on the Wolpert Group 402MVD device. The load on the diamond indenter was 0.98 H.

The assessment of the adhesive strength with the "shift" method was performed on a special installation [17, 18]. A coating sample (6...7 mm wide) with the help of a press was forced by a hob through a matrix, with the coating being destroyed and removed from the substrate. The strength of the coupling was determined by the ratio of the destruction load to the area of the coating cleavage.

The test of the coating wear resistance under the sliding friction conditions was performed according to the "cutting-in indenter" scheme [19], which creates rigid loading conditions. The installation designed to implement this scheme comprises a friction pair of a rotating indenter of the VK8 hard alloy and a stationary coated sample. The load for the friction pair was 20 H. The amount of the volumetric wear was used as an integral quantitative characteristic of wear. The results of the experiments were defined as the arithmetic mean of the data received.

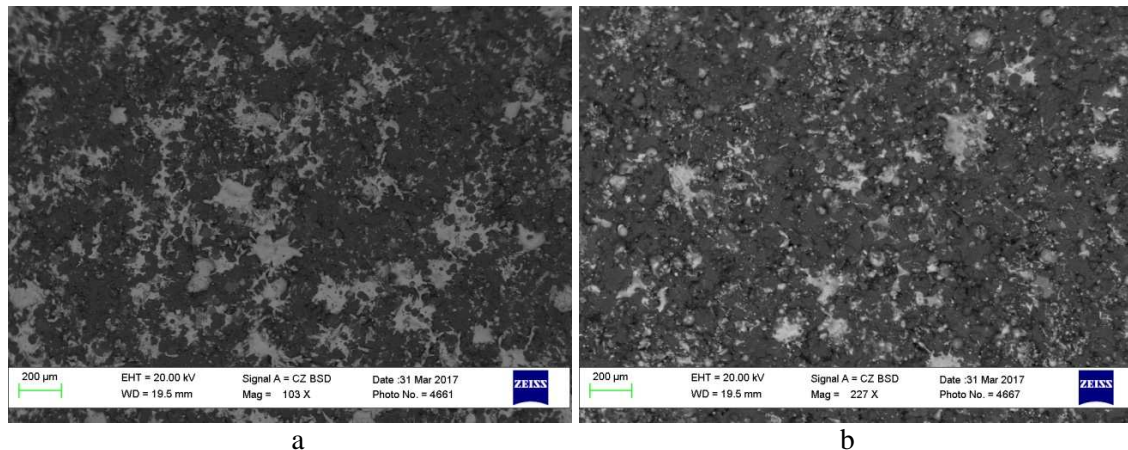
### 3. Results and Discussion

Figure 1 presents the images of the initial powder mixtures of the investigated compositions obtained by a scanning microscopy. The figures demonstrate that the particles of nickel and cobalt powders have a shape close to the spherical and large fractal dimensions in each mixture. The particles of the oxide ceramics are close to the sharp-grained form. In general, there is a steady distribution of powder particles in the mixtures.



**Figure 1.** Particles of the initial powder mixtures: a – composition 1; b – composition 2.

Figure 2 presents the surface images of the composite coatings obtained by plasma spraying. The boundaries between the individual components of the mixture are clearly expressed in both images. The light particles are nickel or cobalt components, and gray particles are oxide ceramic ones. There is a considerable change in the shape of the particles after the spraying and their uniform distribution.



**Figure 2.** Surfaces of the sprayed coatings: a – composition 1; b – composition 2.

The structural metallographic analysis of the ceramic metal coatings obtained from the powder mixtures has made it possible to determine the specific character of these compositions formation. This character is inherently similar to the mechanism of forming single-component plasma coatings. The coating is formed by the accumulation of molten powder particles that are deformed when collided with the substrate or previously deformed particles. In the structure, there is a mutual wrapping of powder particles and a low porosity (about 6...8 %) for both compositions. It should also be noted that the percentage of ceramics in the multi-component coating is noticeably lower than in the initial mixtures owing to the effect of segregation during coatings plasma spraying.

The chemical composition of the initial powder mixtures and the surface layer of the sprayed coatings were investigated to assess the effects of high-temperature plasma jets on the heterogeneous composition particles. The analysis of the obtained data established that the chemical elements composition of nickel-ceramic and cobalt-ceramic mixtures was preserved after plasma spraying at the range of adopted for the study modes, though volumetric percentage of the elements underwent certain change. The characteristic change of both compositions is the increase in oxygen percentage owing to intensive oxidation (averaging 2...5 %) with a corresponding reduction in nickel and cobalt volume. The change in the volume of the remaining chemical elements is negligible.

The microhardness in the coatings was defined separately for each of the mixture components. These compositions are characterized by nonuniform distribution of microhardness in the structure. The mean microhardness value for ceramics particles in the studied compositions is 12150...15840 MPa; for nickel powder particles in *composition 1* – 7750...9600 MPa and for cobalt powder in *composition 2* – 11060...13800 MPa.

The study of the adhesive strength of ceramic metal coatings which were deposited without a transition layer (as opposed to traditional spraying of ceramics) is essential in view of the ceramics particles presence in the transitional area.

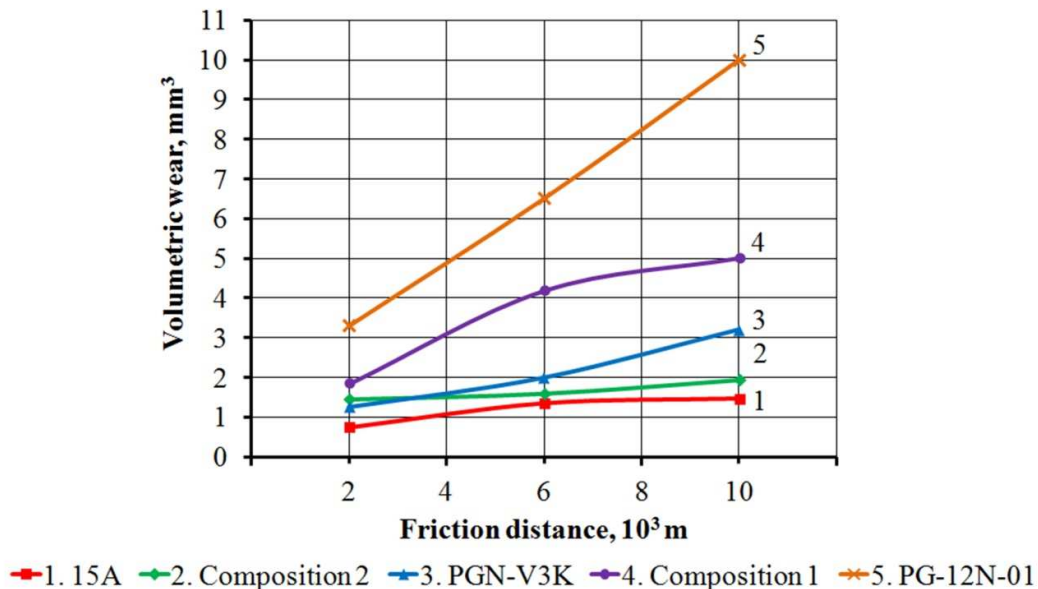
Table 1 presents the results of the adhesive strength assessment of nickel-ceramic (*composition 1*) and cobalt-ceramic (*composition 2*) mixtures compared to the standard PG-12N-01 and PGN-V3K powders.

**Table 1.** Results of the adhesive strength assessment of the coatings

	PG-12N-01	Composition 1	PGN-V3K	Composition 2
<b>Adhesion strength</b>	16.12	15.22	17.47	16.78

It follows from the analysis of the results obtained that the adhesion strength of the studied compositions is 4...6 % lower than that of the standard powder coatings. This is due to the formation of the coating structure with a new quantitative components ratio differing from the initial mixture. The adhesion reduction is clearly linked to the presence of the oxide ceramic particles in the transitional area. However, having the numerical values of the ceramic metal compositions bonding strength, it can generally be assumed that they have satisfactory efficiency.

The wear kinetics of the studied ceramic metal compositions and coatings obtained from the 15A, PG-12N-01 and PGN-V3K powders are shown in Figure 3.

**Figure 3.** Wear kinetics of the coatings samples

The results of the research showed that the most wear resistant specimens were those of the 15A oxide coating (Curve 1). A reasonably acceptable wear resistance is noted in the coating of the PG-12N-01 powder (Curve 5) and PGN-V3K (Curve 3). The wear resistance of the ceramic metal coating obtained from composition 1 (Curve 4) and composition 2 (Curve 2) is lower than that of the ceramic coatings. However, it is sufficient for these ceramic metal compositions to be used as strengthening wear resistant coating for parts of different process equipment that operates under heavy load modes.

#### 4. Conclusion

The studied composite plasma coatings generally have low porosity and uniform distribution of particles. The specific character of formation of the ceramic metal coatings from powder mixtures is similar to the mechanism of single-component plasma coatings formation. The chemical elements composition is preserved during spraying; however, there is a certain change in their volume percentage.



The basic indicators for the quality of the sprayed coatings have been defined. As a result of the studies, the authors have identified the microhardness values and its nonuniform distribution in the coating structure. The obtained values of the studied compositions adhesive strength and the wear resistance have been compared to those of the initial powder components coatings. The analysis of the results reveals that the composite coatings have a more efficient combination of physical and mechanical properties and therefore are more functional than ceramic coatings.

In general, the use of plasma ceramic metal coatings obtained from mixtures is a promising approach to improve the quality of ceramic coating and requires further experimental research.

## References

- [1] Liverani E et al. 2016 *Surface and Coatings Technology* **302** 100-106
- [2] Okovity V A et al. 2015 *Obrabotka metallov* **2** 39-45
- [3] Skeebe V Y et al. 2016 *Key Engineering Materials* **712** 105-111
- [4] Dudina D V 2017 *Obrabotka metallov* **2** 45-54
- [5] Engelkoa V et al. 2001 *Vacuum* **2-3** 211-216
- [6] Sokolov A G, Boblyov E E 2016 *Obrabotka metallov* **2** 59-69
- [7] Plotnikova NV et al. 2016 *IOP Conf. Ser.: Mater. Sci. Eng.* **156** 012022
- [8] Kornienko E E et al. 2016 *Obrabotka metallov* **4** 52-62
- [9] Aman Y et al. 2012 *Journal of Materials Science* **47(15)** 5766-5773
- [10] Kornienko E E et al. 2014 *Journal of Physics: Conference Series* **567** 012010
- [11] Kornienko E E et al. 2016 *IOP Conf. Ser.: Mater. Sci. Eng.* **156** 012020
- [12] Chesov Y S et al. 2014 *Obrabotka metallov* **4** 11-18
- [13] Zverev E A et al. 2017 *IOP Conf. Ser.: Earth Environ. Sci.* **87** 082061
- [14] Martyushev N V et al. 2017 *Journal of Physics: Conference Series* **803(1)** 012094
- [15] Lobanov D V et al. 2017 *Key Engineering Materials* **736** 81-85
- [16] Lobanov D V et al. 2017 *IOP Conf. Ser.: Earth Environ. Sci.* **87** 082029
- [17] Zverev E A et al. 2017 *Key Engineering Materials* **736** 132-137
- [18] Lobanov D V et al. 2016 *IOP Conf. Ser.: Mater. Sci. Eng.* **142** 012081
- [19] Chesov Y S et al. 2012 *Obrabotka metallov* **1** 10-13