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Effect of the detonation-spraying mode on the tribological properties of NiCr-Al_2O_3 coatings

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The article presents the study results of detonation spraying parameters on the phase composition and tribological properties of NiCr-Al_2O_3 powder coatings. The spraying was carried out at a ratio of the acetylene-oxygen mixture O_2/C_2H_2=1.856. The detonation barrel filling volume with an explosive gas mixture varied from 30% to 68%. It is determined that the phase composition of the NiCr-Al_2O_3 coatings varies depending on the degree of detonation barrel filling. With an increase in the detonation barrel's filling volume, the intensity of the NiCr diffraction peaks is decreased, and the intensity of the α-Al_2O_3 reflexes is increased, which indicates an increase in the content of the Al_2O_3 phase. When low filling volume, there is determined a low coating density and uneven roughness. The tribological test results showed that with an increase in the detonation barrel filling volume, there is a decrease in the wear volume, which confirms the increase in the coatings wear resistance. Determined that the lowest friction coefficient was recorded in the sample obtained at the barrel filling volume 68%. The coatings' high wear resistance is associated with an increase in the alpha phase volume fraction of α-Al_2O_3 and coatings density.

Keywords: detonation spraying, coating, phase, wear resistance, roughness.

Introduction

At present, an actual task is to increase the reliability and durability of products, the performance characteristics of which are determined by the properties of their working surfaces. One of the most promising ways to improve the performance properties and increase the durability of products is to apply functional coatings on their surfaces using various spraying technologies [1-4].

One of the promising methods of coating, intended to work in the hardest conditions under the action of extreme loads and temperatures, is detonation spraying [5]. This method allows obtaining a coating with less heating of sprayed part, which avoids the deformation during the spraying process, as well as to exclude adverse phenomena that accompany the process when heating part, such as surface satiation of the part with gases. A popular application of the detonation spraying method is the spraying of powders of various systems: Ni-Cr; Cr_3C_2-NiCr; NiCr-Al; WC-Co; NiC-Al_2O_3; etc. to obtain functional coatings working under extreme conditions (high temperature and pressure, intense friction wear, alternating loads, etc.) [6, 7].

Metal-ceramic composites based on NiCr-Al_2O_3 have attracted a lot of attention because of their exceptional mechanical properties and wear resistance and their thermal and chemical stability at high temperatures, which makes them excellent candidates for the manufacture of antifriction materials [8, 9]. Also, aluminium and chromium oxides have the same crystal structure and form solid solutions over the entire composition range, contributing to achieving a good bond between Al_2O_3 and Cr [10]. Thus, in this work, the tribological properties of NiCr-Al_2O_3 were investigated since it is expected that these composites can form a synergistic lubricating tribolayer tested for wear.

This work aims to study the structural and phase features and assess their influence on coatings' tribological properties metal-ceramic coatings based on nickel-chromium-NiCr with aluminium oxide Al_2O_3 obtained at different detonation barrel filling volumes.

Materials and research methods

The CCDS2000 detonation system was used for obtaining coatings, which has a system of electromagnetic gas valves that regulate the supply of fuel and oxygen (Figure 1), as well as control the purge of the system. As a combustible gas was used acetylene-oxygen mixture, which is the most popular fuel for detonation spraying of powder materials [11, 12]. The spraying was carried out at a ratio of the acetylene-oxygen mixture O_2/C_2H_2=1.856. The detonation barrel filling volume with an explosive gas mixture varied from 30% to 68%. Nitrogen was used as a carrier gas.

As the substrate was chosen Stainless steel 12Kh18N10T. The samples were sandblasted before coating. For spraying, was used powders of 80% nickel-chromium NiCr and 20% aluminum oxide Al_2O_3. Powder particle size is up to 22-45 μm.

Research of the phase composition of samples were carried out by x-ray diffraction analysis using X'PertPro diffractometer using CuKα-radiation. The shooting was carried out in the following modes: tube voltage U=40 kV; tube current I=20 mA; exposure time 1s; shooting step 0.02° [13]. We photographed the surface of the coatings at 5$\times$ optical magnification using a metallographic microscope (Altami MET 5S model The surface roughness of the coatings was estimated according to GOST 2789-73 (ASTM D7127-05) using the Ra parameter

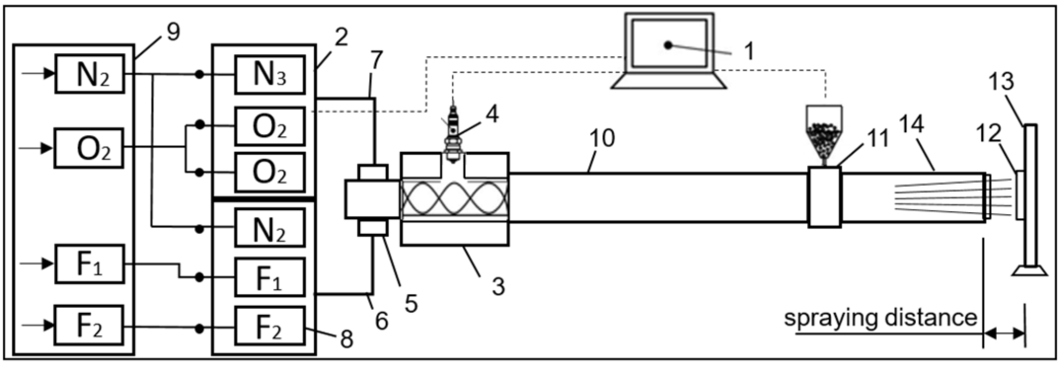

Figure 1. Principled schematic diagram of the CCDS2000 detonation complex: 1 - control computer, 2 - gas distributor, 3 - mixing-ignition chamber, 4 - spark plug, 5 - barrel valve, 6 - fuel line, 7 - oxygen line, 8 - gas valves, 9 - gas supply unit, 10 - indicated part of the barrel, 11 - powder dispenser, 12 - workpiece; 13 - manipulator, 14 - the muzzle of the barrel.

by profilometer model 130. Tribological tests for sliding friction were performed on a high-temperature tribometer TRB3 using the standard "ball-disc" technique (international standards ASTM G 133-95 and ASTM G 99). As a counterbody was used a ball with a diameter of 3.0 mm, made of SiC-coated steel. The tests were carried out at a load of 10 N, and a linear velocity of 3 cm/s, a radius of wear curvature of 4 mm, the friction path was 41 m. The volume of material ΔV removed by the counterbody from the surface during the test was selected as a parameter that characterizes the coatings' wear process. It was determined taking into account the microgeometry of the friction track profile [14]. In the test scheme, when the counterbody repeatedly passes the path l (the length of one circle) and, approximating the section of the friction track with a ball with area S, the volume of the worn out material can be determined by the formula:

$$\Delta V = lS, \tag{1}$$

where, ΔV is the loss of sample volume, mm^3, l is the length of the track, mm, S is the cross-sectional area of the track of the wear, mm^2.

Results and discussion

Figure 2 shows the diffractograms of the $NiCr/Al_2O_3$ coating system obtained at barrel filling volume with an explosive gas mixture of 30%, 45%, 60% and 68%. The results of XRD analysis of the $NiCr/Al_2O_3$ system coatings showed that the coating as the main phases consists of NiCr phases and α-Al_2O_3 as the phase. The figure shows that, depending on the barrel filling degree, the coatings phase composition changes. With the increase of the barrel filling volume, a decrease in intensity of the diffraction peaks NiCr and increase the intensity of the reflexes of α-Al_2O_3, which indicates that increasing the content of Al_2O_3 phase at high temperatures detonation. As the amount of explosive mixture increases, the temperature increases too, up to which the particles are heated during movement inside the barrel. The highest temperature of the detonation products is reached in acetylene-oxygen mixtures containing about 50 vol.% of C_2H_2 [15].

Micrographs and the measuring roughness results of the coatings are shown in Figure 3. The coating surface has a non-uniform structure and match to the

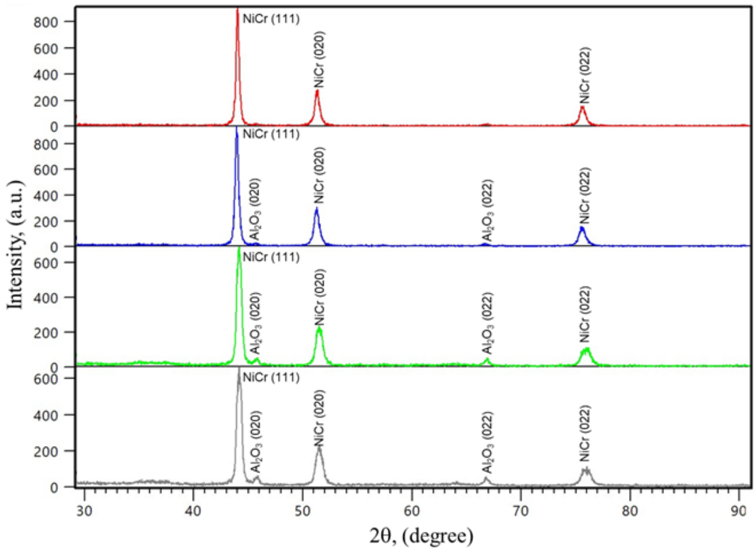

Figure 2. Diffractograms of NiCr/Al_2O_3 system coatings obtained at different filling volumes of detonation barrel: a) 30%, b) 45%, c) 60%, d) 68%.

roughness class 2-3. The roughness parameter of the coatings obtained when filling barrels with 30%, 45%, 60% and 68% have the values respectively R_a =12.4, 14.1, 12.4 and 12.6. When the filling volume is decreased the coating density is decreased and thus the coatings surface roughness is deteriorates [16].

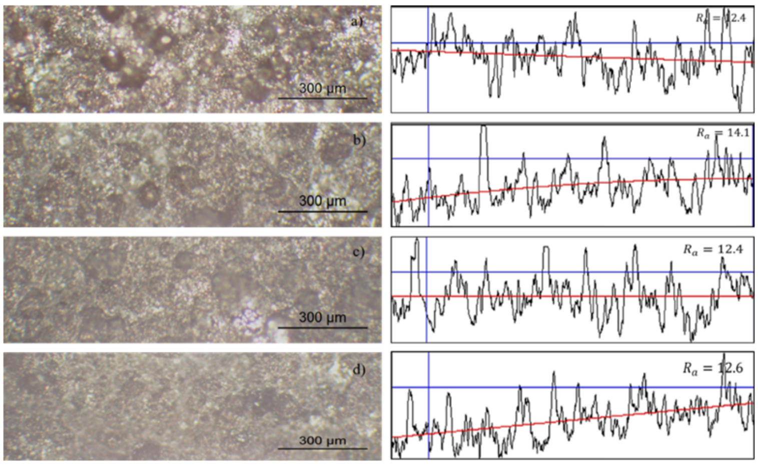

Figure 3. Micrographs and roughness of NiCr/Al_2O_3 coatings at different filling volumes of detonation barrel: a) 30%, b) 45%, c) 60%, d) 68%.

Figure 4 shows the curves of the friction coefficient of NiCr/Al_2O_3 coatings at different barrel filling volumes. The tribological tests results of the coatings showed that the barrel filling volume and the coatings structure do not significantly influenced the coatings wear resistance. However, it should be noted that the lowest friction coefficient was recorded in the samples obtained at the barrel filling volume 68%.

Figure 5 shows the coating wear volume. The tribological test results showed that with an increase in the barrel filling volume is observed decreasing the wear volume, which confirms the increase in the coatings wear resistance. Based on the XRD analysis results, it can be argued that the reason for the coatings high wear resistance is associated with an increase in the alpha phase volume fraction

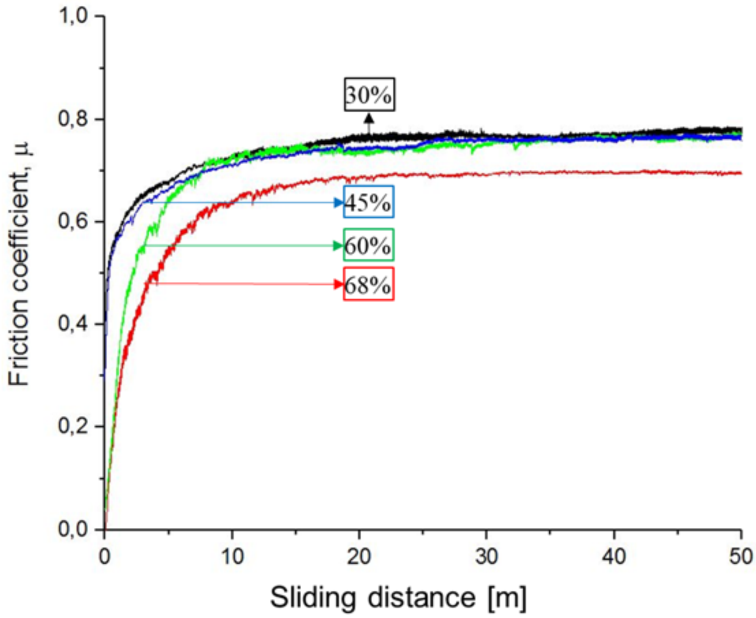

Figure 4. The friction coefficient of the $NiCr/Al_2O_3$ coatings, with different filling volumes of detonation barrel.

of α-Al_2O_3 and the coatings density [17, 18].

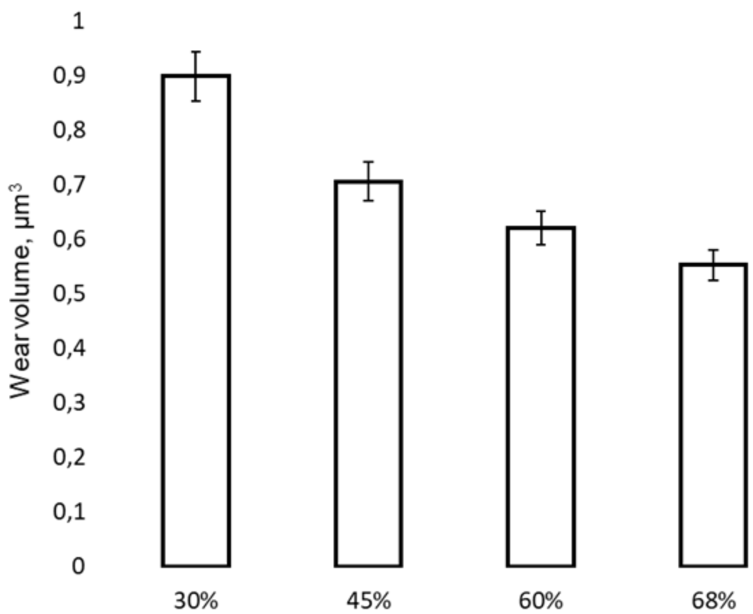

Figure 5. The $NiCr/Al_2O_3$ coatings wear volume at different filling volumes of detonation barrel.

Conclusion

The most promising direction for improving the properties of detonation coatings is the development of composite coatings based on ceramic (Al_2O_3) and metal materials. Based on the study results of the influence of the detonation barrel filling volume with an explosive gas mixture on the phase composition of $NiCr/Al_2O_3$ coatings, is developed mode of oxide detonation formation coating, which provides an increase in the content of the α-Al_2O_3 phase, which allows to increase its wear resistance. As the amount of explosive mixture increases to 68%, there is a significant reduction in the wear volume and an increase in the $NiCr/Al_2O_3$ coatings wear resistance. Thus, by varying the detonation spraying modes, it is possible to form coatings with specified values of different properties and with a consistent change in the content of metal and ceramic components in the coating composition.

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