Plasma Coatings for Protection Against Hydroabrasive and Cavitation Wear

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Abstract. The results of research work on the application of coatings designed to protect the working surfaces of machine parts and mechanisms operating under conditions of hydroabrasive and cavitation wear are presented. Coatings were produced by supersonic atmospheric plasma spraying of powder materials using air as a plasma gas. The experimental list of materials was chosen taking into account the experience of the authors in protecting the details of the propulsion and steering complex of river vessels using coatings applied by subsonic thermal plasma flows.

Introduction

Cavitation erosion of propeller blades, especially high-speed ones, has been known for a long time and is a serious problem that has not been solved to date. The collapse of gas bubbles formed during cavitation leads to the formation of liquid microjets, the speed of which exceeds 120 m/s [1–3], and the pressure of the shock wave can reach 1.5 GPa [4, 5].

There are three stages of cavitation [6, 7]:

1. Vortex, which takes place in the nuclei escaping from the ends of the vortices, where the pressure reaches a critical value,
2. Bubble, in which the formation of individual bubbles is characteristic. This is the most unfavorable stage of cavitation, causing erosive wear of the part.
3. Film, in which, as the speed increases, the dimensions of the air-water cavity grow, which can close far beyond the blade. The film stage can then switch to the supercavitation regime.

The maximum wear and maximum decreasing in the propulsive qualities of propellers appears in the second stage.

The accumulated experience in the operation of such propellers has shown that erosion can be quite significant. Cavitation damage not only limits the life of the propellers, but also leads to a decrease in propulsion efficiency. propellers and, accordingly, to a noticeable increase in fuel consumption of marine engines.

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For ships that operate in shallow water significant another problem of destruction of propeller material by significant hydro abrasive and shock abrasive erosion. Intensity of destruction by the impact of a suspension of sand and gravel particles can significantly exceed cavitation erosion [8].

One of the most effective ways to reduce cavitation and hydroabrasive damage is the use of wear-resistant coatings [9].

The technology of applying coatings to protect against cavitation and hydroabrasive wear was developed in the 1980s [10]. Coatings from self-fluxing alloys of the Ni-Cr-B-Si-C system were deposited using plasma spraying with argon-nitrogen plasma followed by gas-flame reflow.

The plasma equipment used at that time in the industry did not allow obtaining high-density coatings with a sufficient level of adhesive and cohesive strength. In this regard, the technological process of applying coatings from self-fluxing alloys necessarily included the operation of subsequent reflow after spraying of the applied layer [11]. Reflow made it possible to reduce the porosity of the coatings from 8–15% to an almost monolithic structure and increase the adhesive and cohesive strength by an order of magnitude.

However, it should be noted that the technological process of melting coatings in terms of complexity, labor costs and its duration is several times higher than the process of plasma spraying.

The development and research of plasma torch (thermal plasma generators) for plasma spraying of powder materials, carried out at ITAM SB RAS, made it possible to create a new generation of plasma equipment for atmospheric spraying, which makes it possible to obtain coatings with previously unattainable properties, which made it possible to exclude the operation of their reflow.

Supersonic air-plasma spraying of coatings.

The accumulated experience in the application of various methods of thermal spraying unambiguously proves that obtaining high-quality dense coatings is possible only when using high-speed (supersonic) technologies that provide sprayed particle velocities of 600 m/s and higher [12, 13].

Of all currently known gas-thermal coating technologies, plasma spraying, due to its energy capabilities and flexibility in controlling the parameters of the spraying flow, is the most technologically advanced and high-performance method for the formation of various functional coatings. That is why the team of authors, on the basis of the previously developed electric arc plasma torch with a sectioned interelectrode insert PNK-50, developed a supersonic version of this plasma torch, which makes it possible to generate supersonic flows of thermal (air) plasma [14]. To date, we can talk about fine-tuning the design of a supersonic plasma torch to an industrial design, because. it completes the complete installation for plasma spraying of powder materials "Thermoplasma 50-04" developed and manufactured at ITAM SB RAS.

On Fig. 1 shows a photograph of supersonic air-plasma spraying of a wear-resistant coating WC/10Co4Cr (tungsten carbide on a cobalt-chromium bond) on the working surface of a hydraulic equipment part.

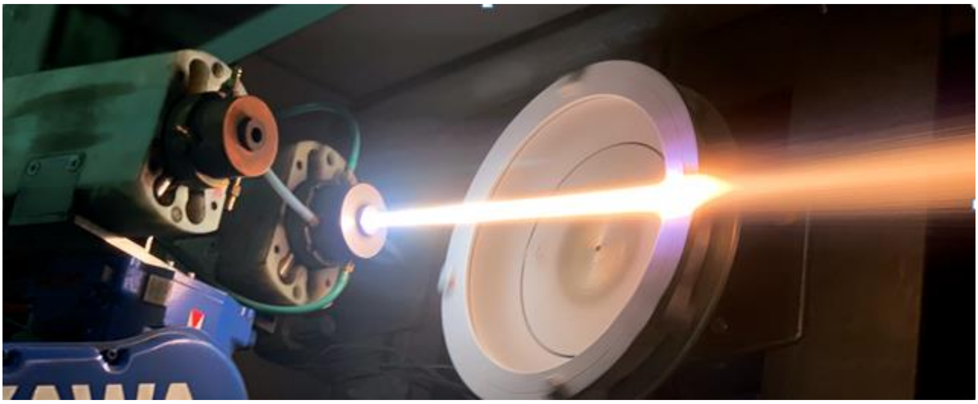

Fig. 1. Supersonic air-plasma spraying of a wear-resistant coating WC/10Co4Cr on the working surface of a hydraulic equipment part.

Powder materials selected for spraying of experimental coatings, their chemical and fractional composition are presented in Table 1.

Table 1. Characteristics of powder materials for spraying

№	powder material	Chem. composition, wt.%	Particles size, µm
1	WC/10Co4Cr	WC – 86; Co – 10; Cr – 4	15…38
2	Ni-Cr-B-Si-C	Ni – balance; Cr – 16; Si - 3,2; B - 2,7; C – 0,75	20…63
3	Ni-Al	Ni – balance; Al - 15	40…100
4	Ni-Ti	Ni – balance; Ti - 45	40…100
5	Bronze	Cu – balance; Sn – 10; P - 1	40…100

The coatings were sprayed onto flat specimens of steel No. 20 (St20) 75 × 25 × 3 mm in size. The thickness of the deposited coatings was 300–360 µm. The YASKAWA MH12 robot was used as a mechanism for moving the plasma torch relative to the sprayed surface. During deposition, the samples were cooled by compressed air.

Measurements of the microhardness of sprayed coatings showed its significant increase in comparison with the passport data of powder materials, which is explained by the formation of a subfine-grained structure. Thus, it was shown in [15] that a nickel-bonded boron carbide coating obtained using a powder material with a fraction of 40–100 µm is characterized by a nanocrystalline structure with a grain size of less than 20 nm.

On Fig. 2 shows the microhardness distribution of coatings applied by supersonic plasma flows.

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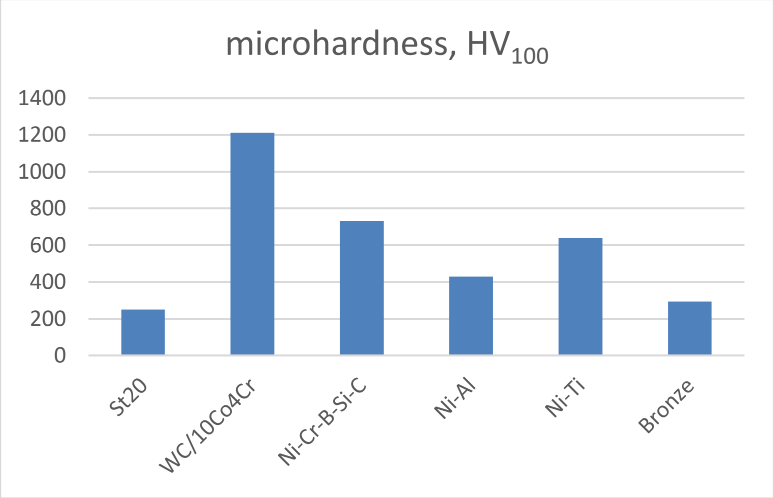

Fig. 2. Microhardness of coatings produced by supersonic air-plasma spraying.

The greatest increase in microhardness (~ 2.5 times) was obtained on a coating of bronze powder material in comparison with microhardness of the raw powder.

Wear resistance of sprayed coatings

To test samples with coatings for resistance to hydroabrasive wear, an experimental bench was made, which was a design of a plastic tank with a capacity of 100 l, a motor with a frequency converter, and a rod with a sample attachment unit (Fig. 3).

Fig. 3. Experimental bench for testing coatings for resistance to hydroabrasive wear.

Water was poured into a plastic tank and an abrasive with a volume ratio of 1 : 1 was filled in. Electrocorundum "25 A" with a fraction of 400-500 microns was used as an abrasive.

The samples on the tooling were installed in such a way that, during their rotation, the suspension of the abrasive in water flowed along the normal to the sprayed surfaces of the samples (Fig. 4).

Fig. 4. Tooling with fixed samples.

The rig with fixed samples was mounted on a rod, which was connected coaxially to the motor shaft. The length of the rod was chosen so that the tooling with fixed samples was in close proximity to the bottom of the plastic tank (at a distance of ~ 130–150 mm). The rotational speed of the tooling with samples was set using a frequency converter, and when testing samples with coatings, it was 240 rpm. In this case, the speed of movement of the far faces of the samples was 3.23 m/s, and the near ones - 0.75 m/s.

Under these conditions, the coated samples were subjected to hydroabrasive action for 16 hours, after which the erosion of the materials was determined by weighing.

On Fig. 5 shows the results of testing coatings for hydroabrasive resistance.

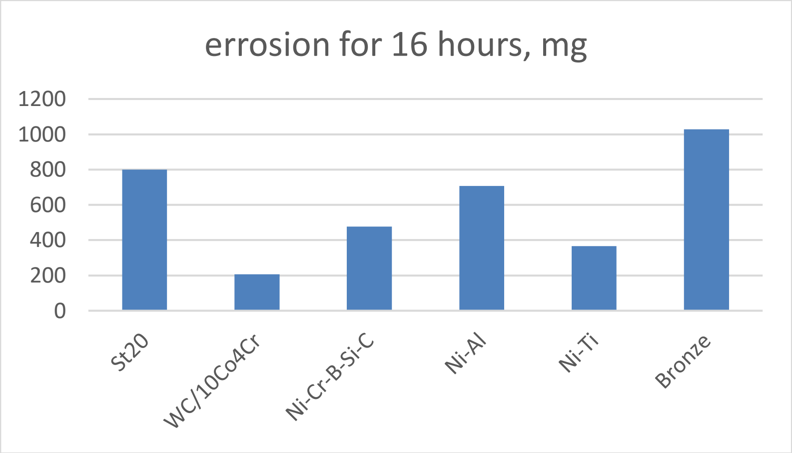

Fig. 5. Erosion of coating material and uncoated steel 20 sample after 16 hours of hydroabrasive testing.

As can be seen from the test results presented in Fig. 5, WC/10Co4Cr tungsten carbide coating has the best wear resistance under waterjet conditions.

Similar results were obtained earlier when testing the resistance of samples under conditions of dry abrasive friction according to the ASTM G65-04 standard and when testing the resistance of coatings to friction-sliding according to the ASTM G133 standard. There, the material based on tungsten carbide also showed the best results. Its wear under conditions of dry abrasive friction is 43.5 times less than the control sample made of uncoated steel 20. In this regard, for comparative tests of cavitation resistance, in comparison with a sample of steel 20 without coating, a coating based on WC/10Co4Cr tungsten carbide was chosen. The coating on the flat surface of the sample was also applied by supersonic air-plasma spraying using the YASKAWA MH12 robot. The coating thickness was ~480 µm. A drawing of the sample used in the experiments is shown in fig. 6.

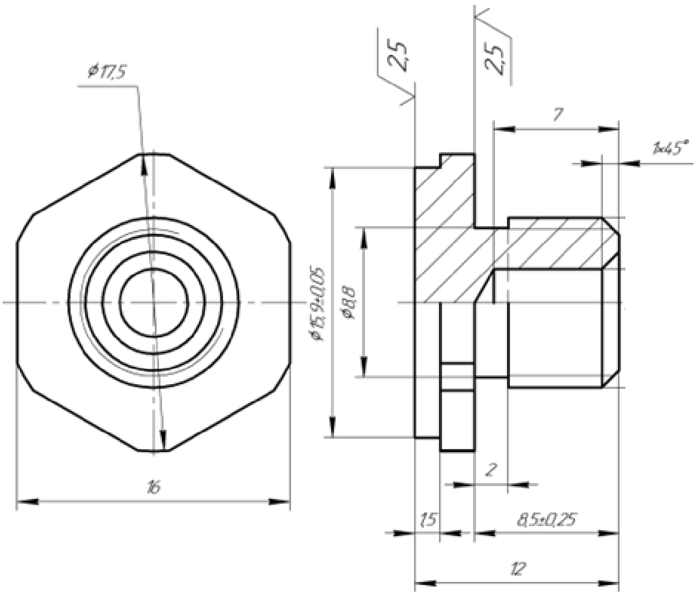

Fig. 6. Sample for testing sprayed coatings for cavitation resistance.

Tests for cavitation erosion were carried out using the laboratory ultrasonic complex "LUK-0.5 / 20-0" according to the ASTM G32 standard. To excite cavitation on the test surface, the sample was attached to an ultrasonic generator through a threaded connection and, together with it, was lowered into water to a depth of 15–20 mm (Fig. 7). The oscillation amplitude was 50 µm, and their frequency was 20 kHz.

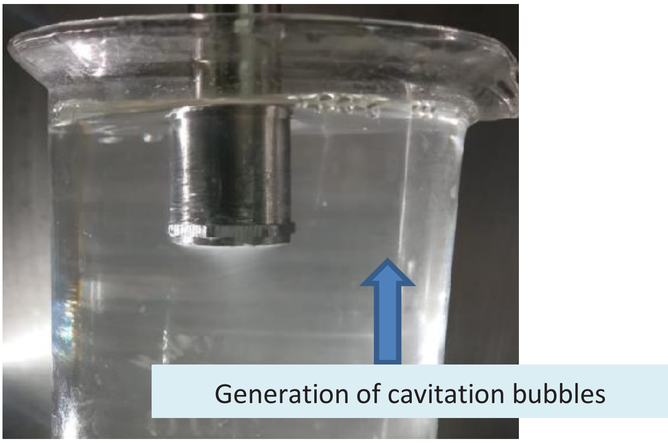

Fig. 7. Ultrasonic cavitation excitation.

The samples were tested for cavitation erosion for 14 hours, while using the laboratory scale "Ohaus PX224" (discreteness 0.1 mg) control weighing was carried out every hour and, thus, the weight loss was determined. Also, after each hour of testing, the surface roughness of the samples was measured using a Mahr Marsurf PS10 profilometer. On Fig. 8 shows the dynamics of surface erosion of a sample with a wear-resistant WC/10Co4Cr coating and a sample of steel 20 without a coating.

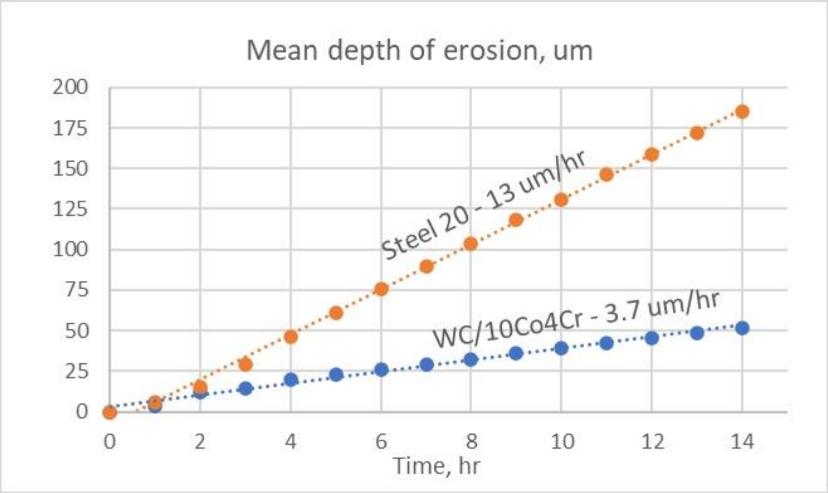

Fig. 8. Erosion dynamics of the surface of a sample with a wear-resistant WC/10Co4Cr coating and a sample of steel 20 without a coating during testing for cavitation resistance.

As can be seen from the presented results, the cavitation erosion of a sample steel 20 after 14 hours of testing is almost 4 times higher than the erosion of a surface with a wear-resistant coating WC/10Co4Cr.

On Fig. 9 shows a graph of the change in the surface roughness of the samples during testing for cavitation resistance.

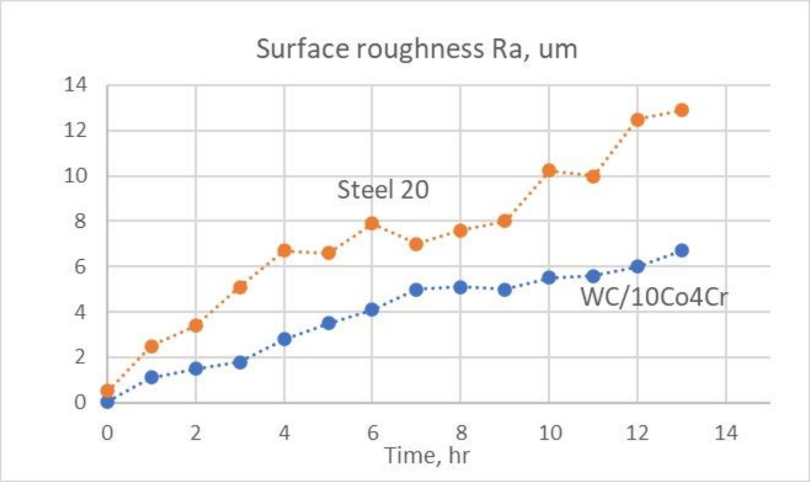

Fig. 9. Dynamics of changes in the surface roughness of a sample with a wear-resistant coating of WC/10Co4Cr and a sample of steel 20 without a coating during testing for cavitation resistance.

The graph of the dynamics of changes in the surface roughness of the samples also clearly demonstrates the effectiveness of a protective coating based on tungsten carbide. After 14 hours of testing, the surface roughness of the uncoated sample is almost 2 times higher than the roughness of the wear-resistant coating.

Thus, on the basis of the conducted studies, plasma coatings based on tungsten carbide can be recommended as protective coatings for parts operating under conditions of simultaneous hydroabrasive and cavitation wear.

Summary

Coating was produced by a supersonic modification of the PNK-50 plasma torch (development of ITAM SB RAS) on a previously optimized mode of supersonic plasma spraying using air as a plasma-forming gas.

The nomenklatura of the experimental materials was chosen taking into account the experience of the authors in protecting parts of the propulsion and steering complex of river vessels using coatings applied by subsonic thermal plasma flows.

On the basis of the conducted studies, plasma coatings based on tungsten carbide can be recommended as protective coatings for parts operating under conditions of simultaneous hydroabrasive and cavitation wear.

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