Evaluation of Tribological Properties of Hard Coatings Obtained on Steel C45 by Electro-Spark Alloying

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Abstract. It was shown that under dry contact conditions, under normal load of to 2 MPa, all coatings demonstrated a significant increase in wear resistance compared to that of the substrate. However, among them, the Mo coating showed the highest wear resistance: ~20 times higher than that of the uncoated steel. That was caused not only by the Mo high microhardness and the lowest initial roughness, but also by the structure of this coating. Meanwhile, the Ti + SiC samples displayed the highest microhardness among investigated coatings. A correlation was established between the microhardness of the coating and the friction coefficient: the larger the microhardness of the coating, the higher is the coefficient of friction. An X-ray analysis of the coatings obtained by ESA on steel with compositions (Ti + Al + C), (Ti + AlN) and (Ti + SiC) revealed phases of titanium carbide, titanium nitride, intermetallic compound $AlFe_3$, and small amounts of aluminum nitride, silicon dioxide and titanium dioxide. This could explain the high microhardness (from 6.8 up to 13.8 GPa) of the obtained coatings.

Introduction

Currently, the engineering industry is increasingly using a very large range of metals and alloys, which every year becomes more and more expensive. Therefore, the formation of surfaces with high hardness and high tribological properties with less expenditure of metals and alloys is an important task. It is known that one of the simplest methods of forming surfaces with high tribomechanical properties is the electro-spark alloying (ESA) of metals and alloys with electrodes of various materials [1-5]. In this paper, we studied the tribomechanical properties of electro-spark coatings obtained with hard alloy electrodes and materials that synthesized carbides, intermetallic compounds, oxides, and other substances on steel C45 (St. C45).

Experimental

Tribological tests of thin coating samples were carried out on an automated reciprocating tribometer equipped with a specially designed device for recording friction force. Coatings were deposited on the samples of St. C45 with dimensions of 5x8x6 mm, namely, on the face with dimensions of 5x8 mm. The tribological properties of the coatings from Mo, Ti + Al + graphite, Ti + AlN, and from Ti + SiC, which were applied by ESA on an EFI-10M installation, were determined. In tests, a counterbody made of hardened steel U8 (HV = 7800-8000 MPa) with dimensions of 2x40x90 mm was used and its surface was ground with subsequent polishing on a fine abrasive paper with grit M40.

Tribological testing of coatings was carried out at a specific load of 2 MPa under dry friction conditions. All test time consisted of 4 periods: the first 30 minutes (2250 cycles - sliding distance of

135 m), the second 45 minutes (3375 cycles - the sliding distance of 202.5 m), the third 75 minutes (5625 cycles - the sliding distance of 337.5 m), and the fourth all for 75 minutes. The counterbody was reciprocating with an amplitude of 30 mm. The average speed of the movement of the counterbody during the test was 0.075 m/s or 75 cycles per minute.

Measurements of wear of prismatic samples were carried out by the gravimetric method using the analytical balance ADV-200M. The error in measuring the mass of the sample was 0.05 mg. Before weighing, the wear products were carefully removed from the surface of the samples and then the samples were washed, rubbed with alcohol and dried in a drying oven at a temperature of 100ºC. After drying, the samples were weighed on the analytical balance. Each sample was weighed at least 2-3 times.

The friction force F arising from the mutual displacement of the contacting surfaces was recorded using a strain gauge dynamometer. The deformation of the elastic element of the strain gauge dynamometer was converted using a standard strain amplifier into an electrical signal, which was inserted into a computer through a specially designed unit. After each minute of the test, the friction force was recorded 3000 times within 3 seconds. With the help of a special program, the values of the friction force were converted into the values of the friction coefficients. The measured values of the friction coefficients were subjected to statistical processing and the average value of F was determined after each minute of testing.

The main reason for the wear of materials is the adhesion setting of the contacting surfaces, accompanied by a scuffing and seizing of friction units. Such processes are usually implemented with the functioning of friction devices under conditions of high contact pressures, friction without lubrication or with insufficient lubrication, as well as when working in the region of elevated temperatures. In this regard, to assess the resistance to contact destruction of electro-spark coatings, their tribological characteristics were measured under conditions of friction without a lubricant (dry friction).

The roughness of the samples before and after the tribological tests was determined on a Surtronic 25 profilograph. The initial microhardness of the samples coated with different materials was determined on a PMT-3 microhardness tester. The friction surface of the samples was studied with a NEOPHOT-30 optical microscope.

For a better comparison of the wear resistance of the coatings, we determined the true wear volume (V_u) of each type of coatings in mm^3 (taking into account the density of each type of coatings) and then their linear wear (h) µm was found (taking into account the surface of each type of coatings). Both the wear intensity (I_h) of the coatings in mkm/m for each wear period and the average wear intensity ($I_{h\ aver}$) for the entire wear period were then determined.

Results and Discussion

Table 1 show the wear intensity (I_h) of the coatings in the test periods 1-4 and the average wear intensity $I_{h\ aver}$ after a total test time of 225 minutes (or after a sliding distance of 1012.5 m). Looking at table 1, it can be noted that the lowest wear intensity of 0.0031 µm/m had the Ti+AlN coating in the second test period and highest wear intensity of 0.178 µm/m had the uncoated steel also in the first test period. The coating of Mo had the lowest wear intensity in the first, the third and the fourth period - 0.0143, 0.0039, and 0.0089 µm/m, respectively. In the first test period, the wear intensity increased in the direction Mo→Ti + Al + graphite→Ti + SiC→Ti + AlN→St. C45, in second test period - Ti + AlN→Mo→Ti + SiC→Ti + Al + graphite→St. C45, in the third test period - Mo→Ti + SiC→Ti + Al + graphite→Ti+ AlN→St. C45, and in the fourth test period - Mo→Ti + SiC→Ti + AlN→Ti + Al + graphite→St. C45. From table 1 it is clear that the lowest average wear intensity for the entire test period had the Mo coating. The average wear intensity increased in the direction Mo→Ti + SiC→Ti + AlN→Ti + Al + graphite→St. C45. Therefore, after calculating the average wear intensity of the coatings, the highest wear resistance was rightly the Mo coating, and the Ti + SiC coating rankeds second.