WEAR- AND HEAT RESISTANCE OF DEPOSITED METAL OF GRAPHITIZED STEEL TYPE

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Wear resistance of deposited metal of the graphitised steel type in metal-on-metal friction without lubrication at room and elevated temperatures was investigated, and its heat resistance was evaluated. It was established that the as-deposited metal alloyed with 1.4–1.6 wt.% C and 1.5–2.0 wt.% Si contains the optimal amount of graphite inclusions is characterised by high wear resistance, and has a decreased friction coefficient in metal-on-metal sliding friction at room temperature.

Keywords: *arc surfacing, surfacing materials, flux-cored wires, graphitized steels, wear- and heat resistance*

Steels and cast irons are referred to graphitized iron-carbon alloys, the structure of which has free inclusions of the different-shape graphite [1]. Application of these materials is one of the ways of improving the tribotechnical characteristics of parts of friction pairs and some types of die tools, in particular drawing dies. In this case the inclusions of graphite play a role of lubricant.

It was shown earlier [2] that the deposited metal of a graphitized steel type can be produced at content of carbon of above 1.6 wt.% and silicon of above 2.0 wt.%. For graphitizing the deposited with content of not less than 1.5 wt.% C and 1.1 wt.% Si it is recommended to use the heat treatment instead of high-temperature annealing: directly after surfacing the part is placed into furnace at 400 °C temperature, and after holding for 2 h it is slowly cooled. Modifying the deposited metal by aluminium and calcium allows activating the process of graphitization.

The present work is aimed at the investigation of wear resistance of the deposited metal of a graphitized steel type in metal-on-metal friction without lubrication at room and elevated temperature, and also evaluation of its heat resistance. The multilayer surfacing of specimens was performed under the layer of AN-26 flux using three experimental flux-cored wires. Chemical composition of deposited metal and its hardness after surfacing and annealing are given in Table 1.

The investigations of wear- and heat resistance were carried out in a modular-type installation, developed at the E.O. Paton Electric Welding Institute [3].

Investigations of wear resistance of deposited metal in metal-on-metal friction at room temperature were carried out in a test installation friction module, which was equipped additionally by a system of specimens positioning with respect to a rotary shaft-counterbody. Tests were performed by the method of wiping-out craters using the shaft–plane scheme without an additional feeding of lubricant into the friction zone.

The shaft-counterbody of 40 mm diameter and 12 mm height was manufactured of steel 45 of *HRC* 42 hardness. The test specimens of 3 × 15 × 25 mm size were cut out from the deposited metal so, that the test plane of the specimen could enter the upper layers of the deposited metal (Figure 1). As a reference the specimens of deposited metal (steel of 20KhGS type), produced by using the flux-cored wire PP-AN194, were used.

During tests the specimen was pressed with a definite force against the counterbody by the plane having 3 × 25 mm size in design. The following test condition was selected: rate of sliding of 1 m/s; loading of 30 N; frequency of rotation of shaft-counterbody of 30 rpm; friction path — 113 m. This condition provides the stabilization of tribotechnical characteristics of all the test specimens. The application of positioning system made it possible to test each deposited specimen not less than three times on the new region of friction surface of the specimen and friction path of the counterbody.

During testing the deposited specimen the friction force, wear of deposited specimen in the volume of wiped-out crater and counterbody were determined from the difference of its mass before and after the test. The coefficient of friction was calculated as a quotient from division of friction force value by load at an error of not more than 5 %.

Table 1. Chemical composition (wt.%) and hardness of metal deposited by experimental flux-cored wires

Grade of flux-cored wire	Elements, wt.%					*HRC*	
	C	Si	Mn	Al	Ca	After surfacing	After annealing
PP-Np-Op-1	1.5	1.15	0.60	–	–	43	26
PP-Np-Op-2	1.8	1.46	0.58	–	–	49	20
PP-Np-Op-3	1.5	1.45	0.49	0.09	0.02	43	38

Note. Metal, deposited by wire PP-Np-Op-3, was subjected to annealing at 400 °C for 2 h, the rest metal — to annealing at 680 °C for 6 h.

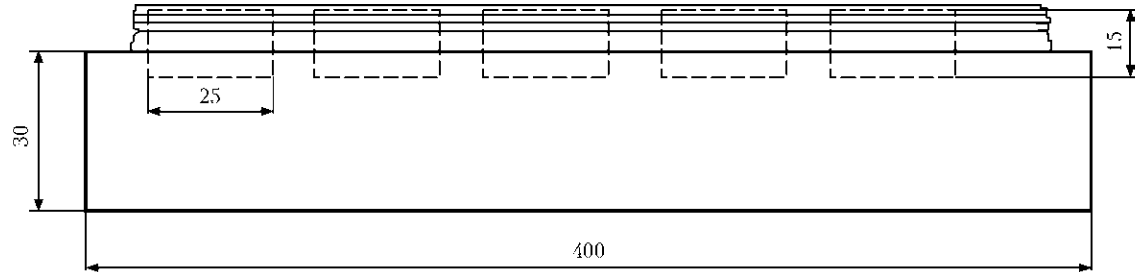

Figure 1. Scheme of cutting out of specimens for tribotechnical investigations of deposited metal

Wear *m* of counterbody was determined from loss of its mass as a result of testing at an error of not more than 0.0005 g. The error of determination of wear of specimen and counterbody did not exceed 1 %.

Results of carried out tests are presented in Table 2. The best wear resistance was in specimens of metal, deposited by experimental flux-cored wires PP-Np-Op-1 and PP-Np-Op-2, which possessed the optimum combination of hardness and free inclusions of graphite [2]. Heat treatment contributed to increase in content of free inclusions of graphite in the deposited metal structure [2], but simultaneously it decreased its hardness and, respectively, also wear resistance of deposited metal of both tested types.

Metal, deposited by the flux-cored wire PP-Np-Op-3 with modifying additions of aluminium and calcium, was also characterized by a sufficiently high wear resistance. Annealing at 400 °C for 2 h led to the reduction in hardness and wear resistance of deposited metal of this type.

The graphitized steels as compared with low-alloy steel 20KhGS have the lower coefficient of friction and with a higher content of graphite inclusions, formed as a result of annealing, the value of friction coefficient is lower. Addition of calcium and aluminum allows decreasing the temperature of a graphitizing annealing and coefficient of friction of metal deposited by the flux-cored wire PP-Np-Op-3, the value of which after annealing at 400 °C is at the same level with the friction coefficient value of ordinary graphitized steels after annealing at the higher temperatures.

The tests of wear resistance of deposited metal of graphitized steel type in metal-on-metal friction at high temperature were performed by shaft–plane scheme without additional feeding of lubricant into the friction zone. For comparison, the specimens deposited by the flux-cored wire PP-Np-25Kh5FMGS were tested as a reference.

Specimens of 40 × 10 × 17 mm size were manufactured from deposited templets, in this case the area of friction plane was 10 × 40 mm, and the thickness of deposited layer was 8–10 mm.

The wearing ring was heated by oxy-natural gas flame. Owing to a strictly definite consumption of natural gas and oxygen the temperature of a wearing ring was maintained constant (950–980 °C) and controlled periodically using an optical pyrometer.

Wear tests in metal on metal friction at elevated temperature were carried out for 1 h at 175 N load; rate of rotation of the ring-counterbody was 30 rpm. As a counterbody the 120 mm diameter ring of hardened steel 45 was used. Temperature of surface of test specimen in the wear zone was equal approximately to 600 °C. During tests the specimen realized the reciprocal movement in vertical plane at 20 mm amplitude of oscillations and 62 min^{-1} frequency of oscillations. Test results (mean value of three specimens) are given in Table 3.

The tests showed that the wear resistance of metal, deposited by the flux-cored wire PP-Np-Op-1, not subjected to heat treatment, is higher than that of metal, passed the annealing, that can be explained by a significant reduction in hardness as a result of annealing. It should be noted that the presence of a large amount of free graphite in the structure of deposited metal of this type hinders the transfer and sticking of metal on the counterbody. Decrease in heat treatment temperature reduces the wear of deposited specimens

Table 2. Wear resistance of deposited metal of graphitized steel type at room temperature

Grade of flux-cored wire	Heat treatment	Wear of specimen, mm^3/km	Wear of counterbody, g/km	Coefficient of friction
PP-Np-Op-1	Directly after surfacing	0.00203	0.00205	0.62
	Same after tempering at 680 °C for 6 h	0.06020	0.00210	0.57
PP-Np-Op-2	Directly after surfacing	0.00204	0.00207	0.60
	Same after tempering at 680 °C for 6 h	0.07230	0.00101	0.51
PP-Np-Op-3	Directly after surfacing	0.00302	0.00310	0.59
	Same after tempering at 400 °C for 2 h	0.00801	0.00204	0.52
PP-AN194 (reference)	Directly after surfacing	0.08900	0.00450	0.65

Table 3. Wear resistance of deposited metal of graphitized steel type at elevated temperature

Grade of flux-cored wire	Heat treatment	Wear $m \cdot 10^4$, kg/km	
		Specimen	Counterbody
PP-Np-Op-1	Directly after surfacing	16.579	+17.452
	Same after annealing at 680 °C for 6 h	29.602	59.488
	Same after annealing at 400 °C for 2 h	23.352	36.879
PP-Np-Op-2	Directly after surfacing	12.723	89.562
	Same after annealing at 680 °C for 6 h	25.945	132.765
	Same after annealing at 400 °C for 2 h	15.132	93.453
PP-Np-Op-3	Directly after surfacing	7.984	168.656
	Same after annealing at 400 °C for 2 h	7.277	147.761
PP-Np-25KhFMGS (reference)	Directly after surfacing	4.287	142.102
Note. + denotes the increase in mass of counterbody as a result of metal sticking.			

Table 4. Test results on heat resistance of deposited metal of graphitized steel type

Grade of flux-cored wire	Heat treatment	Number of heating–cooling cycles	
		Before appearance of the first cracks	Before appearance of net of fire cracks
PP-Np-Op-1	Directly after surfacing	5	240
	Same after annealing at 680 °C for 6 h	3	190
	Same after annealing at 400 °C for 2 h	5	210
PP-Np-Op-2	Directly after surfacing	8	180
	Same after annealing at 680 °C for 6 h	4	140
	Same after annealing at 400 °C for 2 h	7	160
PP-Np-Op-3	Directly after surfacing	4	110
	Same after annealing at 400 °C for 2 h	5	80

and counterbodies, however this characteristic still remains higher than that in specimens directly after surfacing.

The metal, deposited by the flux-cored wire PP-Np-Op-2, possessed somewhat better characteristics of wear resistance. Metal, modified by aluminium and calcium, is characterized after surfacing or low-temperature annealing by a higher wear resistance, which is at the level of that of the known chrome-molybdenum die steel 25Kh5FMGS.

Heat resistance is one of the most important characteristics of materials designed for the restoration and strengthening of tools for hot deformation of metals. The test procedure should envisage the optimum sizes and shape of the deposited specimen, temperature and rate of its heating and cooling close to service

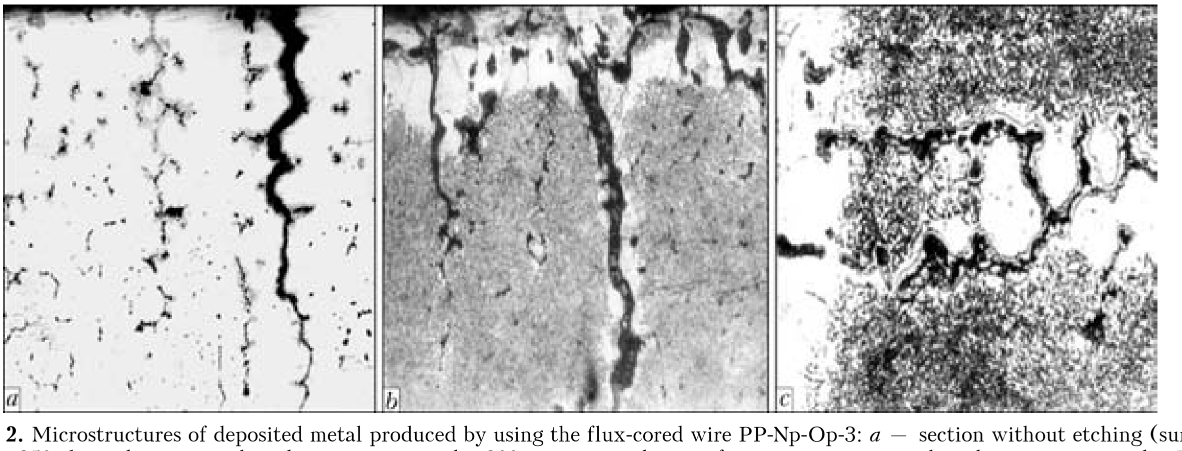

Figure 2. Microstructures of deposited metal produced by using the flux-cored wire PP-Np-Op-3: *a* — section without etching (surface layer), ×250; *b* — the same with etching in nitric acid, ×200; *c* — central zone of specimen section with etching in nitric acid, ×500

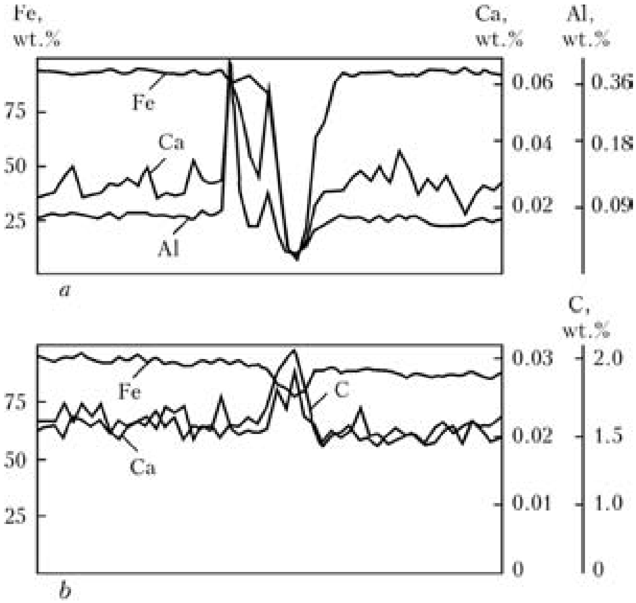

Figure 3. Distribution of main alloying elements Ca, Al (*a*) and Ca, C (*b*) in deposited metal produced by using flux-cored wire PP-Np-Op-3

values, environment condition, etc. The specimen should have first of all the sufficient mass to provide the gradient of temperatures, simulating the full-scale conditions, during the process of its heating.

Heat resistance tests of deposited specimens were performed using the following procedure: 30 × 40 × × 40 mm size of specimen, heating of deposited surface of specimen by a gas cutter up to 800 °C (15 mm heating spot, 40 × 40 mm specimen surface being heated), cooling of heated surface by a water jet down to 60 °C. Cycles of heating–cooling were repeated until appearance of a net of fire cracks, visible with a naked eye. Heat resistance was estimated coming from the number of heating–cooling cycles until the appearance of the first cracks and reaching a certain degree of cracking, i.e. the appearance of a net of fire cracks. Test results (mean values from 3–5 specimens of each type of deposited metal and kind of heat treatment) are given in Table 4.

Metal, deposited by the flux-cored wire PP-Np-Op-1, has the best characteristics of heat resistance, they are lower in metal, deposited by the wire PP-Np-Op-2, and the lowest characteristics are in metal, deposited by the wire PP-Np-Op-3. Here, the net of fire cracks in specimens, deposited by flux-cored wires PP-Np-Op-1 and PP-Np-Op-2, is much less developed than in specimens, deposited by the flux-cored wire PP-Np-Op-3.

Structure of specimen metal, deposited by the wire PP-Np-Op-3 after heat resistance tests (80 cycles) was investigated (Figure 2). The non-etched section has numerous cracks, the maximum depth of which reaches 1500 μm (Figure 2, *a*). After etching in nitric acid the surface decarburization of the last layer of deposited metal (Figure 2, *b*) for the depth of up to 250 μm was observed. The decarburized layer has a microhardness *HV*0.5 1680 MPa, while the hardness of neighboring non-decarburized areas was *HV*0.5 3030–3680 MPa. Clusters of inclusions of dark grey color were formed in metal of test specimen (it is supposed to be graphite) which are located along the boundaries of ferrite grains and have hardness *HV*0.5 1480 MPa (Figure 2, *c*).

To define the causes of the earlier appearance of a net of fire cracks, the X-ray microanalysis of specimen, deposited by wire PP-Np-Op-3, was made after tests for heat resistance. The examinations were made at the depth of about 1.5 μm from the surface of deposit in parallel to it in the automatic condition at 1.02 μm interval along the front of fire crack (Figure 3).

It was found that near the fire crack the content of carbon, aluminium and calcium is abruptly increased. It allows assuming that the fire cracks are passed through the inclusions of free graphite, the appearance of which was contributed by modifying the deposited metal with aluminium and calcium. In the deposited metal in the zone of cracks the mass fraction of elements is varied within the following ranges, %: 0.2–9.6 C; 0.23–2.44 Al; 0.01–0.319 Ca; 1.48–1.99 Si; 0.137–0.66 Mn.

It was established that the metal, alloyed with 1.4–1.6 wt.% C and 1.5–2.0 wt.% Si, directly after surfacing has an optimum content of graphite inclusions and is characterized by high wear resistance in sliding friction of metal on metal at room temperature. The additional heat treatment for increasing the content of graphite inclusions to improve the wear resistance is, probably, not rational. As compared with a low-alloy steel 20KhGS the graphitized steels have the lower coefficient of friction. With higher content of inclusions of graphite in the steel structure, the coefficient of friction is lower. The investigations of heat resistance of deposited metal of a graphitized steel type showed that this metal should be used for strengthening the parts and tools, which are subjected to moderate cyclic, thermal and load effects.

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