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Influence of structural graphite surface electrospark machining conditions on erosion resistance

The study deals with the erosion resistance of graphite samples with an electrospark coating surfaced in different conditions. The purpose of the study was to identify the coating of better quality. During the experiment, three metals were used as the anode: tungsten, titanium, and vanadium. For erosivity, plasmatron was used.

Keywords: erosion resistance, electrospark alloying, erosion, plasmatron

Introduction

Wear resistance, high-temperature stability, erosion and corrosion resistances are the indispensable properties of materials operating at high temperatures, pressures, speeds, as well as in other aggressive media, which is characteristic of the products of aviation and space industry. The most heavy-duty working conditions for materials exist in booster engines and directly in nozzle clusters of rockets and boosters, where high-temperature plasma is produced by fuel combustion.

To improve resistance of parts in aggressive media, their surfaces are modified using concentrated energy flows, such as low-temperature plasma, laser, electron or ion radiation, and pulse discharges [1].

At present, such assemblies most often employ inserts made of graphite, due to a unique set of physical and chemical properties of this material. It will not dissolve in acids, has low coefficient of friction, and is conductive and heat-resistant in the absence of oxygen, with its melting point reaching 3800 °C. Accordingly, parts made of graphite can operate, without change of their performance characteristics, in such media where use of other structural materials is impossible. At the same time, the working capacities of graphite inserts in the present-day articles are close to exhaustion. Further enhancement of product characteristics is only feasible with improvement of graphite erosion resistance.

To improve erosion resistance of graphite, the method of electrospark alloying can be used as an efficient technique for modifying surfaces of structural materials [2].

The authors of this method, B. R. Lazarenko and N. I. Lazarenko [3–6], describe this process as a transfer of anode material onto cathode surface while spark (pulse) discharges are occurring in a gas medium. The method is simple to use and requires no special training of employees; no special preparation of the working surface of parts and their preheating is required too. The electrospark alloying makes it possible to form a modified layer with high adhesion and improved properties using any conducting materials. In so doing, a surface film up to 100 μm thick is formed, which enables to modify surface without considerable increase of article thickness. In some papers [7, 8] the technology of alloying steel surfaces with graphite is shown.

In this paper, the cathode is graphite and acting as anode are metals. After alloying, the surface of samples was machined with laser radiation to reduce roughness. An attempt was made to determine the influence of different modes of electrospark alloying on the erosion resistance of graphite at plasma temperature of 1800 °C.

Hence, the objective of the paper consists in determining the optimal modes of electrospark alloying of graphite surface ensuring improvement of erosion resistance.

Study subjects and methods

The experiments were carried out using plates of structural graphite MPG-7 with dimensions 4×25×25 mm. The properties of graphite samples were as follows:

• density ≥1.7 g/cm^3;
• grain size 45…90 µm;
• porosity 12…15 %.

Electrospark alloying was performed on a test installation Elitron-52A [9]. The installation is intended for hardening-and-alloying electrical-discharge machining of the surfaces of machine parts, cutting tools, dies, and other metal articles. Used as the anode were electrodes of titanium, tungsten, and vanadium, 3 mm dia., manufactured by the method of self-propagating high-temperature synthesis (SHS) [10]. Specifications of the Elitron-52A installation are as follows:

• power consumption 0.9 kW;
• supply mains voltage 220 V;
• pulse energy 0.1…6.8 J;
• pulse frequency 100 Hz;
• working current 0.3…3.8 A;
• thickness of applied coating up to 100 µm;
• applied coating roughness 2.5…16 µm;
• maximum output 4 cm^3/min.

Based on the analysis of literature [8, 11], 4 modes of electrospark alloying were selected (Table 1) as most suitable for graphite surface modification.

Table 1

Process parameters of the assigned modes of electrospark alloying

Electrospark alloying mode	Pulse energy, J	Working current, A	Output, cm^3/min
RC-1	0.5	1.5	2.0
RC-2	1.0	1.5	1.5
RC-3	3.0	1.5	2.0
RC-4	5.0	1.5	1.5

To reduce surface roughness after electrospark alloying and preserve thickness allowance of samples as required by drawing, as well as to increase coating integrity, each sample was treated on a laser installation *Bulat HTF-150* [12]. The authors of this paper had shown earlier a positive result of applying such method of hybrid machining of the surfaces of various materials by means of laser welding, which provides firm cohesion of the treated part surface. Drawing on those studies, the authors selected optimal parameters of laser machining:

• arc voltage 320 V;
• frequency 6 Hz;
• pulse duration 7 ms;
• increment by *Y* axis 0.2 mm;
• increment by *X* axis 0.35 mm;
• focusing 8 mm;
• pulse – bell-shaped.

Erosion resistance of the graphite samples with modified surface was determined under exposure to a plasma flow with constant temperature and pressure, produced by plasmatron in an inert medium (argon) [11]. During the test, the time of exposure to the plasma flow, temperature, and loss in weight of the samples were recorded. Plasma-flow machining was performed under the following conditions:

• stagnation temperature 1800 °C;
• stagnation pressure 0.5 atm;
• jet length 8 mm.

Results and discussion

The results of electrospark alloying of graphite for the MPG-7 samples are given in Table 2.

The graphs of dependencies of mass gain and roughness on the energy of pulses are given in Fig. 1 and 2, respectively.

It can be seen from the data presented in Table 2 and Fig. 1 and 2 that with an increase of pulse energy the mass of graphite samples increases accordingly. Apparently, in the process of electrospark alloying with a metal electrode, reaction C + Me → MeC is proceeding on the graphite surface, with formation of a carbide film of titanium, tungsten, or vanadium, depending on the anode material. Accordingly, the higher the energy applied, the thicker the carbide film. At the same time, with an increase of the energy of pulses, roughness of the applied layer grows too, which will tell negatively in subsequent article operation, since a non-machined surface may damage the mating part during their contact, or notches and dents may be made, affecting the specified dimensions of the article.

Table 2

Electrospark alloying results

Sample	Coating application mode	Pulse energy, J	Sample mass, g	Mass after coating application, g	Mass gain, g	Roughness Ra, µm
Ti-1	*RC*-1	0.5	4.620	4.782	0.162	0.81
Ti-2	*RC*-2	1.0	4.635	4.836	0.201	1.44
Ti-3	*RC*-3	3.0	4.590	4.907	0.317	5.80
Ti-4	*RC*-4	5.0	4.610	5.075	0.465	9.10
W-1	*RC*-1	0.5	4.615	4.765	0.150	0.83
W-2	*RC*-2	1.0	4.628	4.851	0.223	1.40
W-3	*RC*-3	3.0	4.610	4.909	0.299	5.94
W-4	*RC*-4	5.0	4.595	5.005	0.410	9.12
V-1	*RC*-1	0.5	4.621	4.770	0.149	0.79
V-2	*RC*-2	1.0	4.610	4.800	0.190	1.51
V-3	*RC*-3	3.0	4.605	4.885	0.280	5.86
V-4	*RC*-4	5.0	4.618	5.008	0.390	9.38

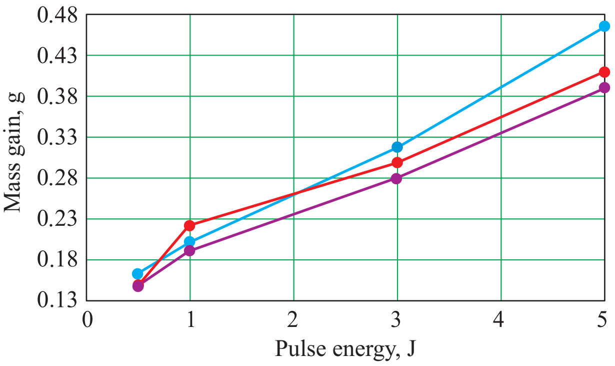

Fig. 1. Dependence of the mass gain of samples on pulse energy: –Ti sample; – W sample; – V sample

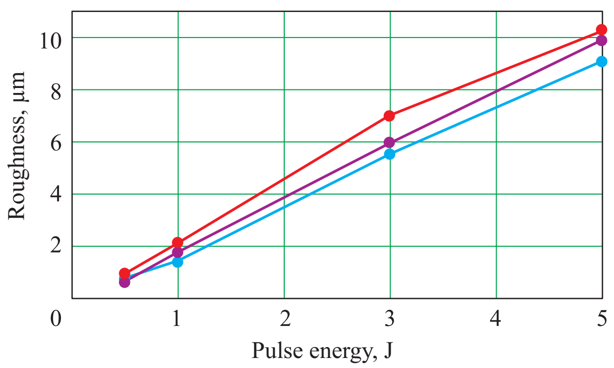

Fig. 2. Dependence of the roughness of samples on pulse energy: – Ti sample; – W sample; – V sample

It should be noted that samples alloyed with titanium had lower roughness than those alloyed with tungsten and vanadium.

Fig. 3 shows the dependencies of the temperature of samples alloyed with titanium, tungsten, and vanadium on the time of exposure to the plasmatron plasma jet. Table 3 gives the values of the loss of mass and maximum temperature of samples at the end of the experiment.

Under exposure to the plasma jet, the temperature of samples increases monotonically throughout the experiment, and the character of temperature dependence on time is similar for all samples (see Fig. 3). At the same time, modification

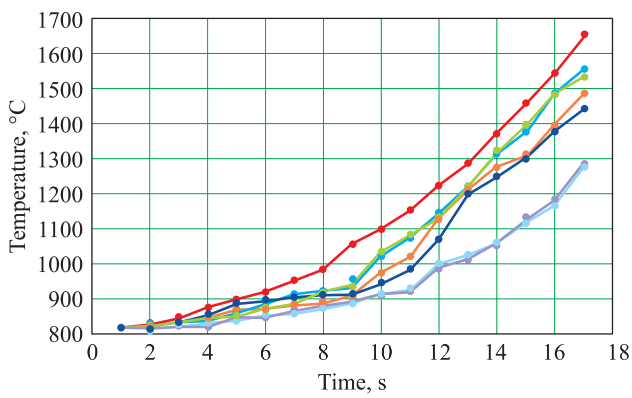

Fig. 3. Dependence of the temperature of samples on the time of exposure to plasma: – C; – Ti-1; – Ti-2; – Ti-3; – Ti-4; – W-3; – V-3

Table 3

Maximum temperature and mass loss of the samples in plasma jet

Parameters	Titanium-coated sample						
	C	Ti-1	Ti-2	Ti-3	Ti-4	W-3	V-4
Coating application mode	–	*RC*-1	*RC*-2	*RC*-3	*RC*-4	*RC*-3	*RC*-3
T_{max}, °C	1660	1560	1535	1289	1280	1489	1445
Δm, g	0.874	0.559	0.521	0.318	0.301	0.441	0.419

of graphite surface slows down the heating rate of the samples.

It can be seen that the Ti-1 and Ti-2 samples, as well as Ti-3 and Ti-4 samples, are characterised by similar dependencies of temperature on the test time. Temperatures of the samples with modified surface are systematically lower than those of the graphite sample. At that, the Ti-3 and Ti-4 samples heat up considerably slower than Ti-1, Ti-2, and C.

The W-3 and V-3 samples have similar dependencies of temperature on the test time between one another and as compared with the Ti-1 and Ti-2 samples, but they heat up faster than the Ti-3 and Ti-4 samples.

At the end of the experiment, the temperature of the Ti-1 and Ti-2 samples was 1550 and 1525 °C, i. e., by 100 and 125 °C lower than that of a non-modified graphite sample (1660 °C). The temperature of the W-3 and V-3 turned out to be lower by 80 °C on the average than that of the Ti-1 and Ti-2 samples. The temperature of the Ti-3 and Ti-4 samples at the end of the experiment was considerably lower: 1290 and 1275 °C, respectively. This is by 371 and 380 °C lower than the temperature of a non-modified graphite sample and, on the average, by 183 °C lower than that of the W-3 and V-3 samples. At the same time, the loss of mass of the Ti-3 and Ti-4 samples was by 28, 40, and 65 % less than that of the W-3 and V-3, Ti-1 and Ti-2, C samples, respectively, which testifies to high erosion resistance of the Ti-3 and Ti-4 samples.

Considering the minimum erosion resistance and low heating rate of the Ti-3 and Ti-4 samples as compared with the Ti-1, Ti-2 and W-3, V-3 samples, it can be claimed that best suited for the electrospark alloying of graphite surface are modes *RC*-3 and *RC*-4 in combination with a titanium electrode. However, if we take into account the lower roughness of the Ti-3 sample as compared with Ti-4, it can be concluded that of all the modes considered, the optimal one for electrospark alloying of graphite is *RC*-3 in combination with a titanium electrode.

Conclusion

The results of the study show that the optimal mode for the electrospark alloying of graphite surface is *RC*-3: the energy of pulses 3 J at the working current of 1.5 A, in combination with a titanium electrode.

A combination of titanium electrode with alloying mode *RC*-3 allows to obtain the maximum erosion-resistant surface with the minimum, for such resistance, surface roughness and considerably reduce the rate of part heating.

In this way, graphite surface alloying with titanium as per the *RC*-3 mode will allow to increase the time of nozzle cluster operation or reduce part thickness, while preserving the same operating time.

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Влияние режима электроискровой обработки поверхности конструкционного графита на эрозионную стойкость

Рассмотрена эрозионная стойкость графитовых образцов с электроискровым покрытием, нанесенным на разных режимах с целью выявления более качественного. В ходе эксперимента в качестве анода использовали три металла: вольфрам, титан и ванадий. Для эрозионного воздействия применяли плазмотрон.

Ключевые слова: эрозионная стойкость, электроискровое легирование, эрозия, плазмотрон.

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