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Напыление покрытий плазмотроном с подачей порошка спутно плазменному потоку

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Эффективность использования энергии плазмы при нанесении покрытий во многом определяется конструкцией плазмотрона. Основное отличие разработанного плазмотрона ПМ-1 заключается в подаче транспортирующего газа с порошком спутно плазменному потоку, что позволяет обеспечить более эффективный и равномерный прогрев напыляемого материала. В данной работе представлены результаты измерения коэффициента использования материала (КИМ), являющегося важной и показательной характеристикой плазмотронов, показывающей их экономичность и производительность, рассчитаны затраты на электроэнергию и проведены исследования напыленных образцов на термоудар.

Ключевые слова: плазмотрон, технологический режим, теплозащитное покрытие, образцы, напыление, плазменная струя, коэффициент использования материала.

Spraying plasmatron coatings with powder supply to plasma flow

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The efficiency of using plasma energy when applying coatings is largely determined by the design of a plasmatron. The main difference of the developed plasmatron PM-1 is the supply of transporting gas with powder to the plaza flow, which allows us to ensure more efficient and uniform heating of the material being sprayed. This paper presents the results of measuring a material usage factor (MUF), which is an important and indicative characteris-

tic of plasmatrons, showing their economy and productivity. The authors calculated the cost of electricity and conducted studies of the sprayed samples for thermal shock.

Keywords: plasmatron, technical regime, heat-protective coating, samples, spraying, plasma jet, material usage factor.

Introduction. The purpose of the paper is to refine the technical regimes of applying thermal protective coatings using the PM-1 plasmatron and to compare the characteristics of the applied coatings with those obtained on the F4 plasmatron. The use of coatings that protect against high-temperature exposure, erosion and abrasive wear, exposure to neutron fluxes, allow preserving structures from destruction to a greater extent. For this purpose, many aerospace enterprises widely use plasma spraying of coatings [1–13].

The advantages of the plasma spraying method are the following characteristics:

1. high temperature of the jet, which makes it possible to apply refractory materials;
2. significant performance capacity;
3. simplicity of technology;
4. relatively low cost;
5. good indicators of adhesion strength of coatings to the substrate;
6. the ability to process parts of various configurations and dimensions.

The process is multifactorial and allows us to control the quality of coatings in a wide range based on optimization of spraying modes.

Experimental part. The efficiency of using plasma energy in coating deposition is largely determined by the design of a plasmatron. The design of the PM-1 plasmatron with a gas feeding circuit with powder in cocurrent to the plasma flow is presented in [1]. The preliminary studies on the PM-1 plasmatron showed some of its advantages over the standard F4 plasmatron. But for the PM-1 plasmatron, the main technological parameters of its operation were not determined, and not all characteristics of the applied coatings were investigated.

Table 1 shows power input to the F4 plasmatron, which is in the range from 20 to 52 kW.

Table 1

Calculated power values

Current strength, A	Arc voltage, V	Power, kW
200	113.221	22.6442
300	100.254	30.0762
400	91.964	36.7856
550	83.585	45.97175
650	79.499	51.67435

Since the PM-1 plasmatron is not fully studied for its energy parameters, we set a task to test it at lower current densities (up to 200 A). The main difference of the PM-1 plasmatron is the supply of the transporting gas with the powder in cocurrent to the plasma flow, which allows us to ensure more efficient and uniform heating of the material being sprayed. In the F4 plasmatron, the powder is fed under the nozzle section. As a spray material, we applied the powder of aluminum oxide (Al_2O_3); the material of sample pieces was steel

45. To smooth thermal expansion coefficients, we used a sublayer of the following composition (40% Al_2O_3 + 60% NiCr).

The main parameters of spraying on the PM-1 and F4 plasmatrons are presented in Tables 2 and 3.

The plasmatrons were installed on a six-axis manipulator called KUKA. The motion of the plasmatrons was carried out along the calculated trajectory shown in Fig. 1.

To exclude repeated overturns of the samples, we calculated and selected the scheme with the reverse motion of the plasmatron. In this way, the coating is applied in an even layer.

Table 2

Input parameters of spraying with the PM-1 plasmatron

Current strength, A	Arc voltage, V	Argon consumption, l/min	Hydrogen consumption, l/min	Plasmatron motion speed, m/s	Powder feeder pressure, bar	Distance from the nozzle exit to the sample surface, mm
200	150	40	4	0.2	4	90

Table 3

Input parameters of spraying with the F4 plasmatron

Current strength, A	Arc voltage, V	Argon consumption, l/min	Hydrogen consumption, l/min	Plasmatron motion speed, m/s	Powder feeder pressure, bar	Distance from the nozzle exit to the sample surface, mm
650	150	30	6	0.2	4	90

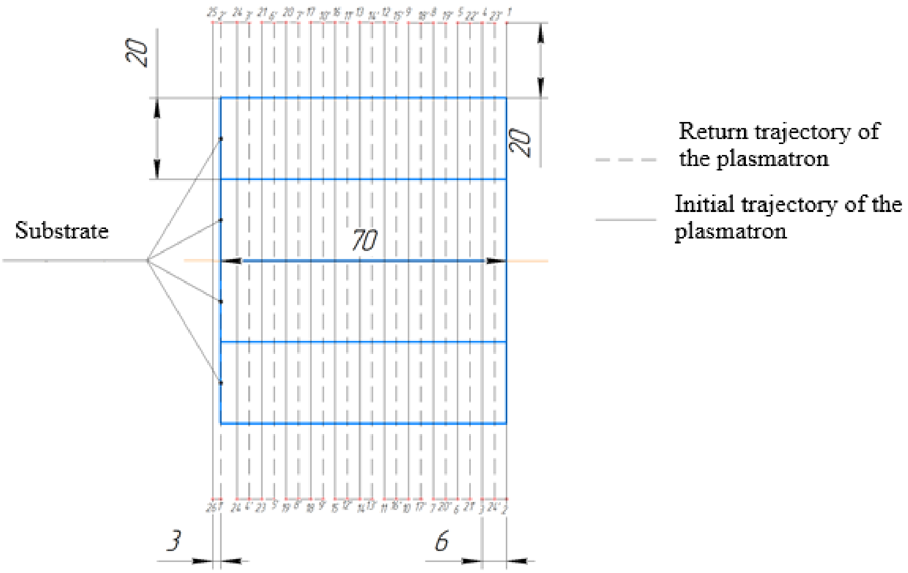

Рис. 1. Оптимальная траектория плазмотрона
Fig. 1. Optimal trajectory of the plasmatron

Previously conducted comparisons of the quality of the obtained coatings being sprayed with different plasmatrons were carried out according to three main properties characterizing the quality of coatings, namely: adhesive strength to the base, thickness and porosity [1].

This paper presents the results of measuring the material usage factor (MUF), which is an important and indicative characteristic of plasmatrons showing their efficiency and productivity.

When comparing the PM-1 and F4 plasmatrons, according to the research results obtained earlier, it was decided to test the PM-1plasmatron at low energy parameters (up to 200 A), and F4 at high-energy parameters (up to 550 A). The PM-1 plasmatron shows good results due to its design and powder feeding method, even at low capacities.

Spraying time for each sample is 60 seconds. Knowing the initial weight of the sample and its final weight after spraying, we determine the amount of material being applied to the sample. Comparing with the total weight of the powder consumption at different technical regimes of the powder feeder, we determine the material usage factor.

The material usage factor was calculated according to the following formula

$$\text{MUF} = ((m_2 - m_1) / m_2) \cdot 100\ \%,$$

where m_1 is the mass of the sample before plasma spraying; m_2 is the mass of the sample after plasma spraying.

To determine the dependence of the powder consumption at different values of the rotation speed of the disk in the feeder, special experiments were carried out, the results of which are shown in Fig. 2.

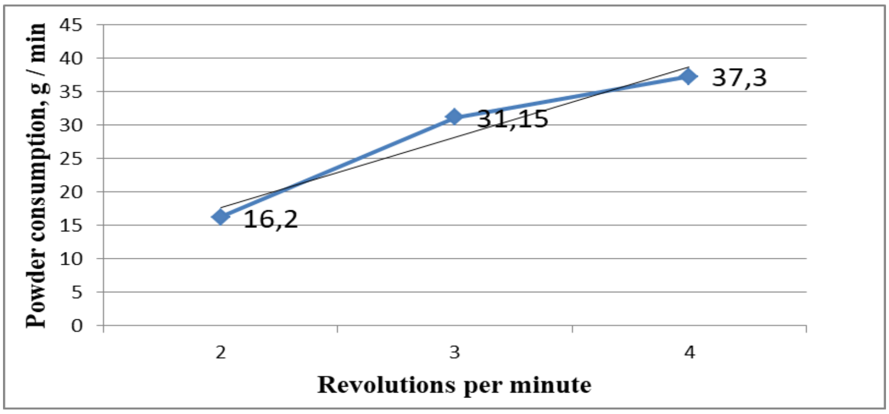

Рис. 2. График зависимости расхода порошка от частоты вращения диска

Fig. 2. Graph of dependence of powder consumption on disk rotation frequency

We chose 6 samples, 3 of which were used for spraying 'peaks' with the PM-1 plasmatron, the other 3 - with the F4 plasmatron. For spraying the samples with the PM-1 plasmatron, we chose the technical regimes presented in Table 2. When determining the MUF, a sublayer was not sprayed on the samples.

In the F4 plasmatron at 200 A, the powder does not melt; consequently, the comparison results will be inadequate; therefore for the F4 plasmatron we selected the regimes indicated in Table 4, and for the PM-1 - 200 A (Table 5).

Table 4

The obtained MUF results for the F4 plasmatron

Spraying time of aluminum oxide = 60 sec					The difference of the sprayed aluminum oxide, gram	Material usage factor,%
Sample number	Current strength, A	Weight, gram		Disk revolutions, r/min		
		After abrasive processing	With a sprayed layer of aluminum oxide			
1	550	143.6	147.61	2	4.01	21.22
2	550	157.63	167.13	3	9.5	29.87
3	550	143.28	158.56	4	15.28	37.54

Table 5

The obtained MUF results for the PM-1 plasmatron

Spraying time of aluminum oxide = 60 sec					The difference of the sprayed aluminum oxide, gram	Material usage factor,%
Sample number	Current strength, A	Weight, gram		Disk revolutions, r/min		
		After abrasive processing	With a sprayed layer of aluminum oxide			
4	200	157.54	166.03	2	8.49	44.92
5	200	159.05	176.15	3	17.1	53.77
6	200	163.13	185.96	4	22.83	56.09

The MUF measurement results are shown in Fig. 3. The graph shows that when spraying with the PM-1 plasmatron, the MUF is on average 15–18% higher than when spraying with the F4 plasmatron. The results of calculating the cost of electricity when spraying with the PM-1 plasmatron show that they are approximately 2 times lower than the cost of F4.

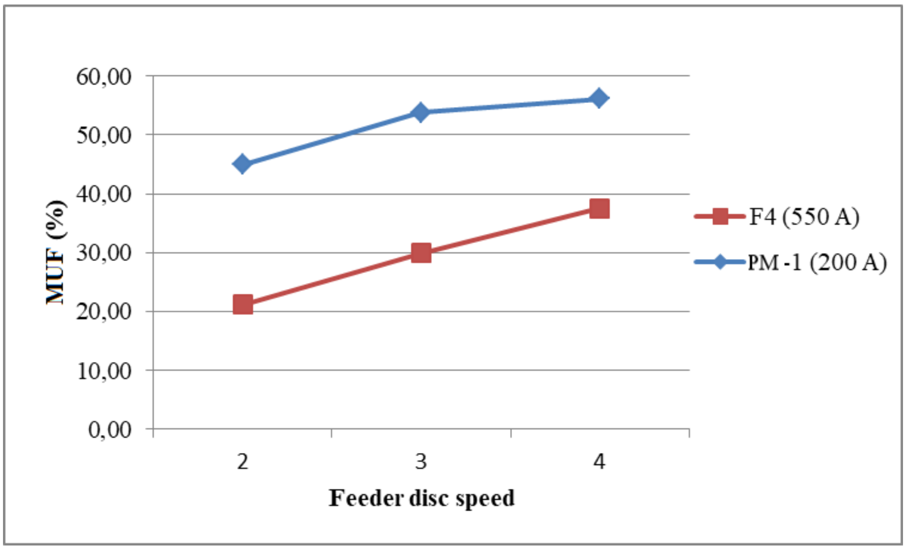

Рис. 3. График зависимости КИМ от числа оборотов питателя

Fig. 3. Graph of dependence of MUF on the number of revolutions of the feeder

Table 6

Electricity costs

	The cost of 1 kW/h is taken equal to 4 rubles.			
Plasmatron	Current strength, A	Arc voltage, V	Power, kW	Economic costs for 1 hour of plasmatron operation, rubles.
PM-1	200	150	30	120
	300	150	45	180
F4	550	150	82.5	330
	650	150	97.5	390

The tests of the sprayed samples for thermal shock were carried out as well. The temperature required for heating the coating and the sample itself is not less than 700 °C. We had 10 heating-cooling cycles. Heating was performed in an electric furnace. Upon completion of each cycle, the coatings were checked for defects and general condition. During the work, we found small shearing distortions of the coating (Fig. 4) along the edges and changing the coating color. In general, all the samples with the Al_2O_3 coating sprayed with the F4 and PM-1 plasmatrons passed the heat resistance tests, while the defects were minimal.

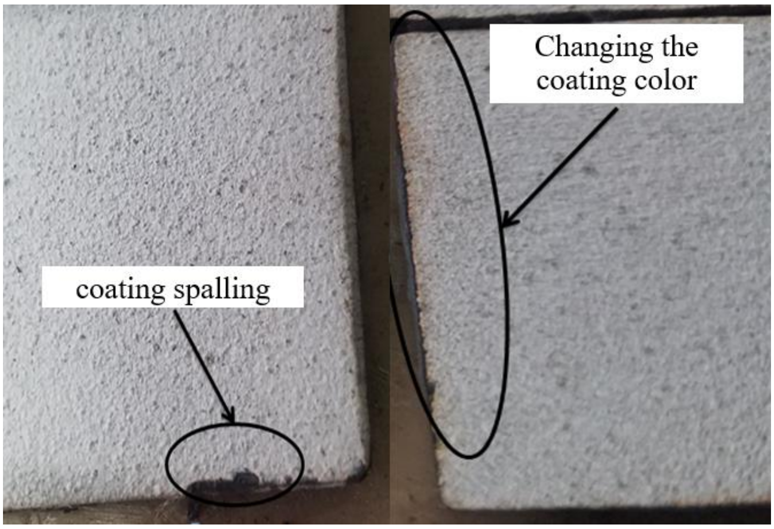

Рис. 4. Дефекты при испытаниях на жаропрочность
Fig. 4. Defects obtained during heat resistance tests

Conclusion. The results of our work complement the advantages of the PM-1 plasmatron in comparison with the F4 plasmatron, namely, MUF increased by 15-18%, electricity costs are about 2 times lower, with the same thermal shock resistance of coatings.

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