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INVESTIGATION OF THE FUNCTIONAL COATINGS, OBTAINED BY GAS DYNAMIC SPRAYING, AND PROSPECTS FOR THEIR APPLICATION IN COMPUTER ENGINEERING

The paper investigates the properties of aluminum-based coatings, obtained by gas dynamic spraying. It is shown that such coatings can be used to create porous heat-removing elements for cooling the components of microprocessor equipment, provide their size reduction and significant simplification of their cooling systems.

Key words: *computer engineering, microprocessor equipment, cooling systems, gas dynamic spraying.*

Introduction

Creation of functional coatings on the surfaces of components enables significant influence on their performance and can impart such new properties to them, which are not inherent to the component material. For example, creation of aluminum-based coatings on steel components can protect them from corrosion anв change significantly frictional, electricity- and heat conduction properties of the coated surfaces.

At the Department of Wear Resistance Improvement Technologies of Vinnytsia National Technical University a test unit for gas dynamic spraying of functional coatings has been developed and manufactured. Powder particles, accelerated to high speeds, which are close to sonic speed or exceed it, collide with the substrate and interact adhesively with it at atomic level, being able to create strong cohesion with the latter and between the powder particles [1, 2]. The temperature of the deposited particle is lower than its melting point.

Gas dynamic spraying unit

Fig. 1 shows a picture of the unit for gas-dynamic spraying of functional coatings. Basic components of the unit are air heater 1 and powder sprayer 2.

Fig. 1. The unit for gas dynamic spraying of functional coatings: 1 – air heater, 2 – powder sprayer

Air heater is made of spiral-wound nichrome wire, through which compressed air is blown. Then the air enters sprayer 2, where the flow is accelerated to the speed of sound. Due to ejection, a spraying material – aluminum powder – is fed into this airflow. The powder, accelerated in the heated airflow, reaches the substrate surface and forms a uniform coating, using the received kinetic energy and heat.

The sprayer (Fig. 2) [3] consists of body 1 with needle 2 for regulation of the air flow parameters. A choke with a powder-feeding channel 3 is connected to body 1. The powder is sucked to nozzle 4 due to ejection effect. Compressed air is supplied to the sprayer through channel 5.

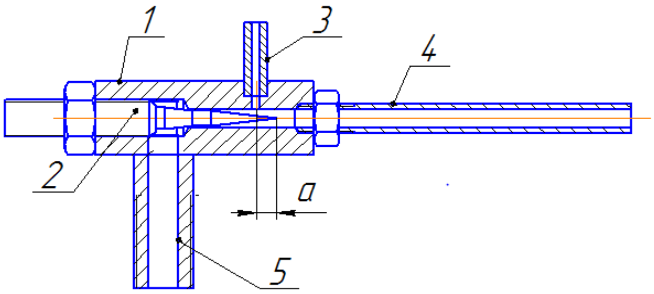


Fig. 2. Sprayer: 1 – body, 2 – needle, 3 – powder-feeding channel, 4 – nozzle, 5 – channel for feeding compressed air

The research aims at finding the following parameters: aluminum powder use factor, depending on the spraying conditions; strength of the coating spot adhesion to the substrate; porosity of the obtained coatings and evaluation of the prospects for their application in various industries, in particular, in microprocessor technology.

For the study, an aluminum powder with a particle size of 60-100 μm was used. The portion of the powder was 0.47 g, the spraying distance – 15 mm. Plates of steel 3 with a thickness of 1mm were used for the substrate. The surface of the plates was not treated before spraying.

The position of needle 2 was determined by size *a*, which took three different values. The temperature was registered at the beginning and at the end of spraying process. The air pressure was 0.57 MPa. The substrate was weighed before and after the spraying process. All the data were entered into Table 1, where *a* is the distance, which determines the position of needle 2 relative to the powder feeding channel 3; T_1 and T_2 – the temperatures at the beginning and at the end of the spraying process; M_1 and M_2 – masses of the substrate before and after the spraying process; M_s is the mass of the spraying spot; *K* is the powder use factor, is defined as the ratio between spray pattern mass and initial mass of the powder portion, multiplied by 100%. The results are shown in Fig. 3.

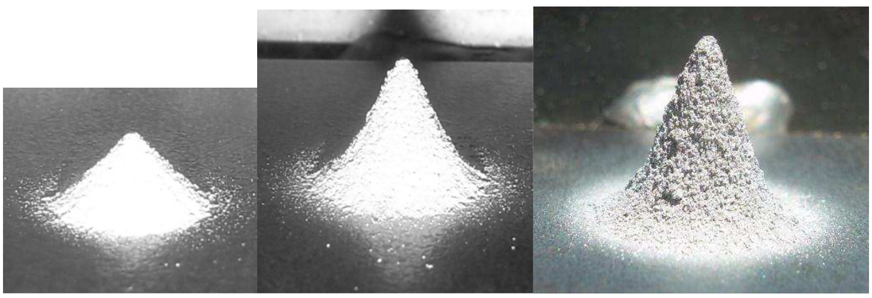
With the application of “mass-centered characteristics” function of Compass software, spray pattern mass was determined as that of a solid material for aluminum (according to state standard A0 ГОСТ 11069-2001) with the density $\rho_1 = 0{,}002700$ g / mm$^{3.}$

The coating density ρ_2 was determined as the ratio between the mass of the weighed spray pattern and its calculated volume.

Porosity j of the spray pattern was determined by formula (1):

$$J = \frac{\rho_1 - \rho_2}{\rho_1} 100\%. \tag{1}$$

that is, we determined air content in the spray pattern volume.



a b c

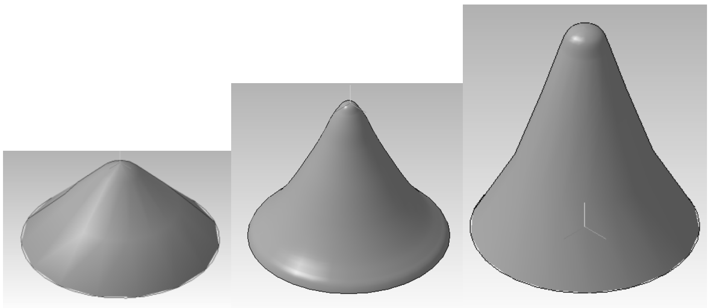
Fig. 3. Spray patterns: a – sample №1, b – sample №2, c – sample №3

Table 1

Influence of the spraying modes on the aluminum powder use factor

№ of the sample	a, mm	T_1, °C	T_2, °C	M_1, g	M_2, g	M_s, G	K, %
1	2.25	320	330	10.41	10.45	0.04	8
2	1.85	320	360	10.55	10.67	0.12	25.5
3	1.5	320	460	10.79	10.99	0.2	42.5

In order to determine density ρ_2 of the obtained coating, 3D models were developed according to the sizes of spray patterns.



a b c

Fig. 4. 3D-models of the spray patterns: a – sample №1, b – sample №2, c – sample №3

Table 2

Determination of the spray pattern porosity

№ of the sample	Spray pattern mass, calculated for aluminum A0, g	Calculated volume, mm^3	Spay Pattern mass, weighed, *g*	Spray pattern density ρ_2, g / mm^3	Spray pattern porosity J, %
1	0.097759	36.206894	0.04	0.0011	41
2	0.227543	84.275364	0.12	0.0014	52
3	0.439850	162.907247	0.2	0.00158	58

In order to determine strength of a spray pattern adhesion to the substrate, a shear-testing facility was developed (Fig. 5).

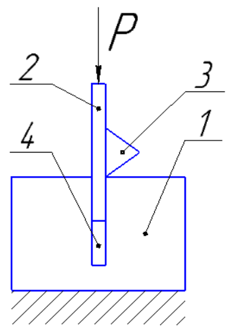


Fig. 5. The scheme of spray pattern shear testing: 1 – stop, 2 – substrate, 3 – spray pattern, 4 – slot

Substrate 2 with spray pattern 2 was placed in slot 4 of stop 1 and, with the application of hydraulic press, pressure with force P, acting on the substrate, was created. Using the known force P of the spray pattern shear and area S of its contact with the substrate, the limit strength σ_s of the spray pattern shear was found by formula (2):

$$\sigma_s = P / S. \qquad (2)$$

Taking into account that shear surface is of a sufficiently irregular shape, we used Compass software to determine shear area *S*. For this, we photographed spray patterns from above (Fig. 6) and inserted this full-scale picture into Compass-2D software. Then the spray pattern contour was drawn around with a closed Bezier curve (see Fig. 6) and contact areas of spray patterns 1, 2, 3 with the substrate was determined using the area measurement function of Compass-2D program.

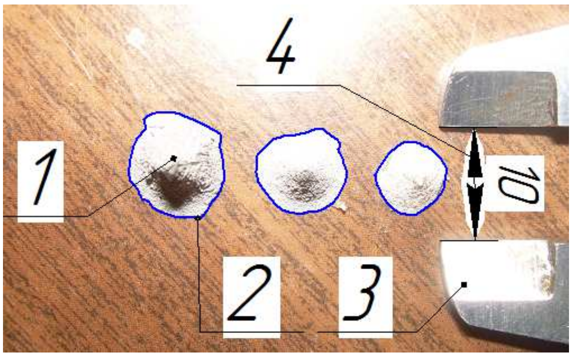


Fig. 6. Determination of the area of spray patterns contact with the substrate:
1 – spray patterns of the coating (from left to right spray patterns № 3, 2, 1 are shown), 2 – Bezier curve, 3 – caliper jaws, 4 – size between the caliper jaws for scaling factor determination

The results of measuring the areas, spray pattern shear force and ultimate shear strength are presented in Fig. 3.

Table 3

The results of measuring the areas and ultimate shear strength of the spray pattern with the substrate

№ of the spray pattern	Area of the spray pattern contact with the substrate, mm^2	Force P at the moment of spray pattern shear, *N*	Ultimate shear strength, MPa
1	29.47	173.6	5.79
2	44.69	188.2	4.12
3	58.55	151.5	2.55

Metallographic studies of the coating, made of aluminum powder, were performed. Fig.8, 9 show the corresponding microsections.

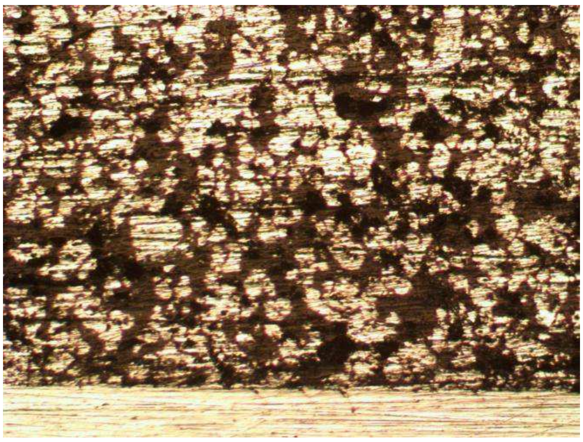


Fig. 8. Microsection of the coating, sprayed by aluminum powder (80-time magnification)

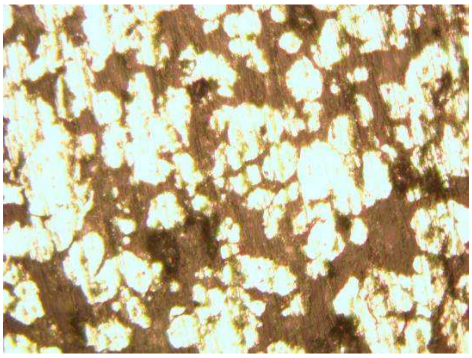


Fig. 9. Microsection of the coating, sprayed by aluminum powder (200-time magnification)

Light colors in microsections are aluminum grains, dark colors – air cavities. As it can be seen, air cavities in microsections communicate between themselves and are open. This allows the air to move freely through the cavities, combined into channels, and to ensure efficient heat exchange with the grains of aluminum.

The cooling efficiency and cooling rate of any heated object are known to improve with an increase in the surface area of these objects. For example, cooling systems of processors have special finned radiators (Fig. 10) in order to increase the cooling system surface area and prevent overheating of the processor.

a b

Fig. 10. Processor cooling systems, adapted for small-size cases:
a – DeepCool Theta 15 PWM, b – Zalman CNPS5X Performa

The investigated porous coating, similarly to the fins of the processor cooling systems, significantly increases the cooling area due to microscopic open cavities (pores) in the middle of the coating. In order to evaluate the increase in effective cooling area, we calculated the length of grain boundaries, which were in contact with the pores and, accordingly, provided heat exchange with the air in these pores. The procedure for calculating the lengths of grains consisted in encircling the grain boundaries of the microsections by the Bezier curve in the Compass program and measuring the lengths of these curves. The scheme for calculating the lengths of grain boundaries in microsections of the aluminum powder coating is shown in Fig. 11.

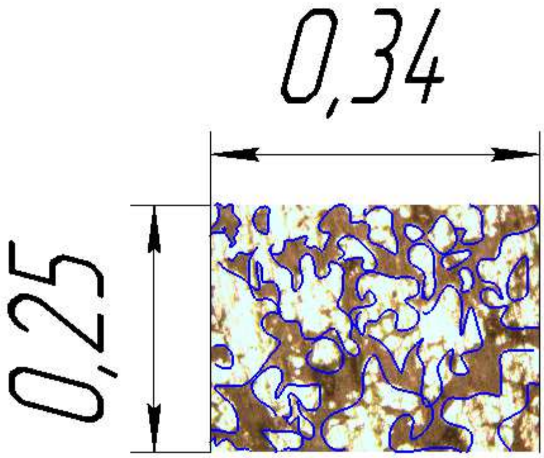


Fig. 11. The scheme for calculating the lengths of grain boundaries in a microsection of the aluminum powder coating. The size of the microsection photo: 0.34 x 0,25 mm

Total length of the boundary lines of the grains (in blue color) is 4. 8 mm (Fig. 11).

Let us consider the surface area inside the porous coating to be directly proportional to the length of grain boundaries in microsections. Then we can assume that an active surface with the area, proportional to the grain boundary lengths (the sum of which is 4.8 mm), was additionally formed on the rectilinear part of the component covered by a porous coating 0.34 mm long with the thickness of 0.25 mm. I. e, the active area, which is able to improve heat exchange, increased by 4.8 / 0.34 = 14 times. Besides, the porous coating is created from aluminum and can be applied to steel surfaces as well as to surfaces of non-ferrous metals, which can significantly reduce the cost of manufacturing cooling systems for microprocessor and other equipment.

Conclusions

As a result of the conducted research, it has been found that with an increase in the spraying temperature from 320 to 460° the powder use factor has also increased from 8 to 42.5 %. At the same time, ultimate shear strength of the spray pattern with the substrate has reduced from 5.79 to 2.55 MPa, while porosity of the obtained coating has increased from 41 to 58 %. That is, half of the coating volume is occupied by air cavities, combined into channels, through which air can move freely with corresponding heat take-off from the heated object.

The coatings obtained can be used to intensify the cooling process of objects that undergo significant heating during operation, for example, computer processors and other elements. Therefore, there appears a prospect for decreasing the weight of cooling systems by reducing or eliminating finning of the radiators.

A significant increase in the cooling area due to the creation of additional surfaces of the porous coating will lead to reduction and simplification of the design of cooling systems for processors and other computer equipment.

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