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INVESTIGATION OF SURFACE ADHESION PRODUCED BY HIGH-SPEED FLAME SPRAYING

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Peculiarities of surface adhesion based on nickel, produced by high-velocity spraying on steel base with different surface morphology have been analysed. It is shown that ultrasound final polishing builds up wavy submicrorelief providing the reliable adhesive connection between covering and base. Ultrasound finite polishing is suggested as a method of preparing surface for high-speed flame.

Introduction

In the last 10–15 years the high-velocity oxygen fuel method of gas-thermal coating has been effciently developed and improved in the world [1–3]. In comparison with gas-flame and plasma methods the process of high-velocity oxygen fuel spraying possesses a number of advantages. Coatings produced by this technique are of high density, adhesive and cohesive strength, fine and homogeneous microstructure, low residual voltages [1]. Oxidation of high-velocity oxygen fuel coating at high temperature is rather less than it is of subsonic one [3]. The values of density and adhesive strength of such coating are comparable with those of explosion and exceed sufficiently those parameters of plasma coating [1, 3].

The modern equipment available at Yurga Machine-Building plant has permitted for developing technology of hydrocyllinder support shaft with reinforcing coating. However, quality control of the produced coating did not give the complete account on interaction of the process parameters, produced structure and coating characteristics. Therefore, the purpose of the given paper is to investigate the interaction of coating with the base at different techniques of surface preparation before spraying.

1. Materials and methods of investigation

Coating was applied by means of high-velocity oxygen fuel device for antiwear, high-temperature, heat-reflecting sealing coating [3], Fig. 1.

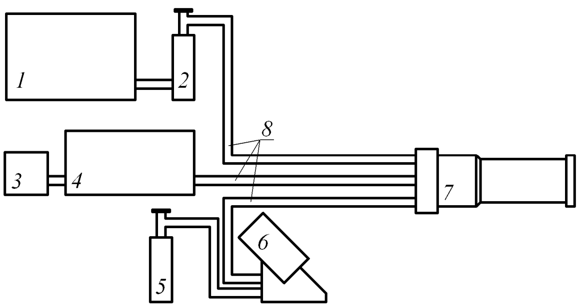

Fig. 1. *Scheme of installation: 1) gas bottle (propane); 2) vaporiser; 3) condenser; 4) receiver; 5) gas bottle (nitrogen); 6) powder feeder; 7) burner; 8) pipes and cables*

The installation includes: burner, powder feeder, vaporiser, control board and a number of accessories. Structurally the burner consists of four main parts: ready-fitted combustion chamber, gas dispenser, «secondary» propane dispenser, ready-fitted nozzle frame. Powder feeder provides exact dosing and continuous feeding of powder into the burner. Powder is fed under the pressure of carrier gas, for which nitrogen or argon may serve. Vaporiser serves as a phase transforming means of propane from liquid into gas. Inside the vaporizer propane is prepared for necessary parameters of pressure and temperature. Spraying is performed under the automatic mode. The control board with touch screen provides distance adjustment, regulation and stability of the process parameters.

Specifications of the installation: velocity of gas outflow at the burner nozzle section is 800 m/sec; the flow of fuel gas (propane) is 250 l/min; the flow of carrier gas is (nitrogen) 40 l/min; oxidizer flow (compressed air) is 7...9 m^3/min; the capacity in spraying metals and alloys is up to 18 kg/h; the thickness of evaporated layer is 0,03...10 mm; the coating porosity is less than 1,0 %; the total power input is not more than 5 kW.

As an evaporated material the powder on the basis of nickel ПР-Н65Х25С3Р3 (Fe – 5 wt. %; C – 1,5 wt. %; Cr – 26 wt. %; Si – 2,3 wt. %; B – wt. 3 %; Ni – the rest) with the particle size 30...50 mkm was used [4]. The sample spraying was performed at distance – 200 mm; with the spraying angle 90°; linear velocity of the burner motion 21 mm/sec. Coating was formed in layers of 500...800 mkm thick on the cylindrical samples of the steel 20.

The surface pre-treatment was performed in several ways. Turning was carried out at TUM-35 machine tool at the number of spindle revolutions – 900 rev/min and feed – 0,07 mm/rev. The subsequent polishing was made at the same machine-tool using the polishing sheet Mirka ecowet of P1000 grit. Ultrasonic treatment was performed by the device of final polishing UZGK-02 of 200 W capacity; of the indenter hold-down pressure 70...75 H; the indenter vibration frequency 24 kHz. The number of the shaft revolutions of lathe was 100 rev/min; the feed was 0,2 mm/rev [5]. The spray-abrasive treatment was carried out in a special chamber by shot-blaster that direct the electrocorundum particles of 1,5...2 mm porosity in the compressed puff with the pressure 0,5...0,6 MPa and the velocity 15...30 m/sec onto the work surface.

The presented study is based on the optical analysis of the surface morphology with high accuracy of measurements performed at the profilometric complex MICRO MEASURE 3D station. The state of the base surface before spraying and after coating detachment has been investigated. With the help of graphic program the square of grip points of the base with coating [6].

2. Results and discussion

At gas-thermal spraying in air the pre-treatment of the part surface before spraying is of great significance, since the state of surface is responsible for the quality of adhesive bond at the «coating-base» boundary [7–10]. High-velocity spraying specifies the specific conditions for particle precipitation of the material on the base with super-high velocity that provides high forward pressure in flowing particles over the base, and hence, does not require complex morphology of the base surface. From the above mentioned facts, in the paper some methods of the surface preparation before spraying are suggested. After turning, along with the traditional method of spray-abrasive surface treatment the technique of polishing surface preparation and ultrasonic final treatment has been suggested. The ultrasonic final treatment consists in plastic deformation of the base surface layers by the instrument vibrating with ultrasound frequency [5]. The formed in this treatment cellular microrelief, fine-grain, with high defect density of crystal composition structure, and internal compressions may provide the reliable adhesive bond [11].

The surface relief after turning has a definite periodicity set by the turning modes, Fig. 2, *a*. The results of profilometric analysis has shown that the roughness width on the tops amounts 0,13 mm with $R_{мах}$~9 mkm height, the roughness R_a=1,15 mkm, Fig. 2, *b*. The surface morphology is defined by the quality of turning.

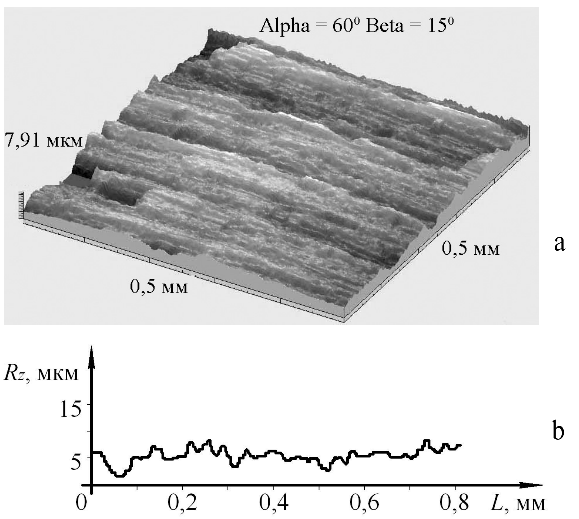

Fig. 2. *State of sample surface of steel 20 after turning: a) morphology; b) profilogram*

As the results of profilometric analysis showed, the sample surface after spray-abrasive treatment is presented by morphology consisting of a group of craters formed by the corundum particles after the strike on the surface, Fig. 3, *a*.

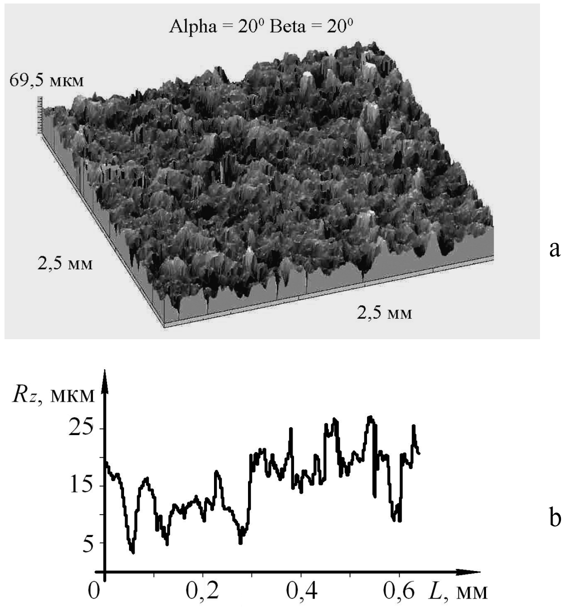

Fig. 3. *State of sample surface of steel 20 after spray-abrasive treatment: a) morphology; b) profilogram*

In the course of repeated influence of abrasive particles on the sample surface the equalization of its roughness occurs (R_a=4,38 mkm) owing to chipping-off the original micro asperities and overlaying the craters, Fig. 3, *b*. The formed relief has a sawtooth structure with the asperity height up to 34 mkm.

After turning and polishing the asperities of microroughness are smoothed to $R_{мах}$~6 mkm, due to which the support surface increases. The roughness decreases to R_a=0,85 mkm, Fig. 4.

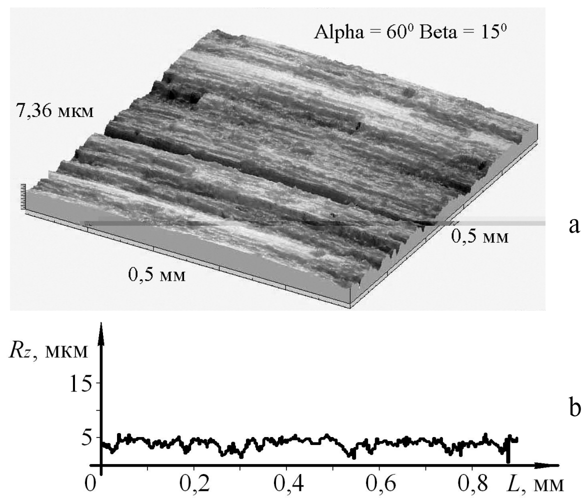

Fig. 4. *State of sample surface of steel 20 after polishing: a) morphology; б) profilogram*

Ultrasonic final polishing results in formation of microrelief on the base surface conditioned by the relative motion of the smoothing tool and the sample

(R_a=0,7 mkm), Fig. 5. The formed microroughness profile in the direction of tool feed has the wavy structure with the roughness width 0,2 mm and the height R_z~4 mkm. Along the tool motion the submicrorelief set by repeated discrete pulse action of the tool is formed. The periodicity of the formed submicrorelief amounts approximately 5 mkm, Fig. 5, *b*.

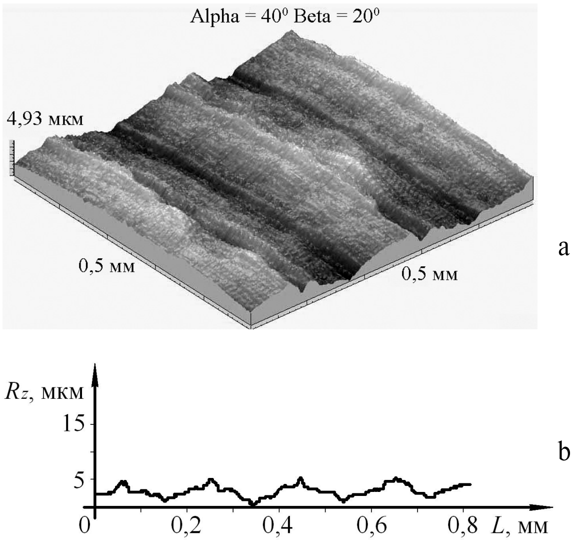

Fig. 5. *State of sample surface of steel 20 after ultrasonic final treatment: a) morphology; b) profilogram*

On the basis of the profilometric analysis it was stated that the maximum effective contact area is formed at spray-abrasive treatment of the base. In this case the surface relief is shown by a group of sawtooth asperities, not oriented in the space. After polishing and ultrasonic final treatment the maximum effective area is less and nearly the same. However, geometry of polished profiles differs significantly. After polishing the directed traces of cutting instrument remain on the sample surface. They are not removed in the process of polishing and form sharp marks. After ultrasonic final treatment the relief of the turning surface is smoothed and the submicrorelief consisting of the traces of ultrasonic device multiple strikes is formed.

After mechanical detachment of the sprayed surface from the involved surfaces the iterated profilometric analysis with estimation of grip point area of the coating with the base.

In all cases, when detaching the coating from the base the surface has the following view: the grip points of the sprayed particles with the base alternate with the areas of the secondary oxidation. In profilograms the increase in total value of roughness due to asperities formed by the sprayed particles remained after coating detachment, Fig. 6.

The value of the total roughness includes the roughness of the areas having original relief and coated with non-detached particles. Thus, on the basis of surface roughness values after detachment one can estimate qualitatively the adhesion between the coating and the base, prepared by different techniques.

In Fig. 6, *a*, the profilogram of the base surface after detachment with preparatory spray-abrasive treatment is presented. When comparing with Fig. 3, *b*, it is seen that a part of the profile is formed by the base relief, the other one – by the sprayed particles. The roughnes of the formed surface R_a amounts 6,99 mkm.

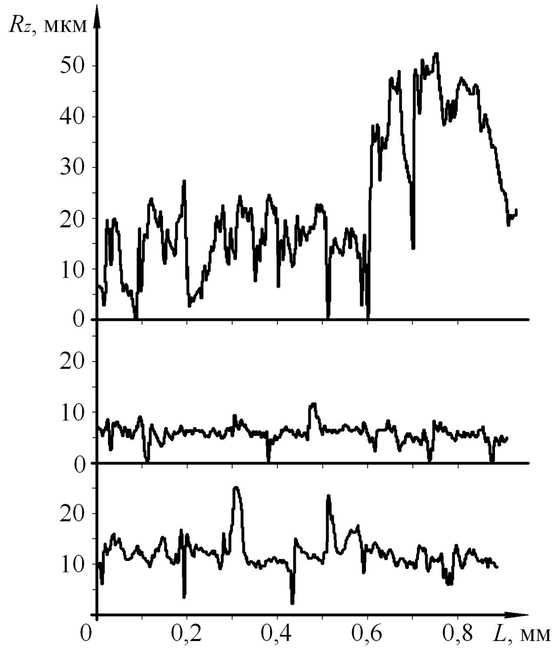

Fig. 6. *Profilograms of the base surface after coating detachment: a) spray-abrasive treatment; b) polishing; c) ultrasonic final treatment*

The profiles of the base surface formed after coating detachment applied on the polished and ultrasonically treated surface have a complex view, Fig. 6, *b*, *c*. In the picture of the formed profiles it is difficult to distinguish the areas formed by the base relief and that of sprayed particles. Nevertheless, the total roughness in both cases increases. Moreover, on the surface of ultrasonically treated surface it is twice as much.

The quantitative estimation of sprayed surface adhesion was performed by estimation of the total area of grip points of the sprayed particles and the base. It is known that the more is the grip point area of the sprayed particles and the base, the higher is the adhesive strength of coating [10].

Table. *Results of estimation of adhesion between the coating and the base*

Technique of the preparatory surface treatment	Original roughness of the base R_a, mkm	Roughness after coating detachment R_a, mkm	Total area of particle and base grip points, %
Spray-abrasive	4,38	6,99	53
Polishing	0,85	1,05	24
Ultrasonic final treatment	0,7	1,97	38

With the help of graphic program it was determined that when detaching the coating sprayed on the base after spray-abrasive treatment the grip point area is approximately 53 %, that corresponds to high indexes of adhesive strength between the coating and the base [9, 10]. On the surface of the polished base the grip point area is approximately 24 %, but on that with the ultrasonic treatment it is approximately 38 %. The results of analysis in sample surface morphology after coating detachment and the values of the total grip point area of the coating and the base are listed.

Thus, the estimation of the base surface state after coating detachment has shown that preparatory spray-abrasive treatment results in formation of strong bond at the «coating-base» composition boundary due to realisation of some activation channels and increase in contact area. Minimum roughness of the base surface treated by ultrasound as well as formation of wavy submicrorelief and modified structure of the surface layer provides the uniform influence of pulse and forward pressure of liquid drops of evaporated material on the base and promote the mechanical activation channel over the whole surface of the base [8–10]. The formed at the boundary adhesive bond between coating and the polished by ultrasound base meets the engineering requirements.

Conclusion

On the basis of the conducted investigation of the base surface morphology before and after coating and its detachment it has been determined:

1. All investigated techniques of base surface preparation before spraying: spray-abrasive treatment, polishing and ultrasonic final treatment form at the boundary between coating and base effective adhesive bond. In this case the maximum square of grip points between coating and base is formed on the surface after spray-abrasive treatment, but minimum one is after polishing the base surface.
2. Ultrasonic final polishing forms the wavy submicrorelief and modified structure on the base surface, providing the formation of reliable adhesive bond between coating and base. Ultrasonic final polishing is suggested as a method of surface preparation before high-velocity oxygen fuel coating.

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