ADVANCES IN MATERIALS SCIENCE, Vol. 21, No. 2(68), June 2021

DOI: 10.2478/adms-2021-0013

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FABRICATION AND CHARACTERIZATION OF Zr MICROPLASMA SPRAYED COATINGS FOR MEDICAL APPLICATIONS

ABSTRACT

This paper presents new results of studying the influence of parameters of microplasma spraying (MPS) of Zr wire on the structure of Zr coatings. The coating experiments were accomplished in a two level fractional factorial design. Individual particles of sprayed Zr wire and their splats on the substrate were collected under various spraying parameters (amperage, spraying distance, plasma gas flow rate and wire flow rate) and evaluated by Scanning Electron Microscopy (SEM) to establish the effect of particle size and shape on the coating microstructure. The particles were characterized by measurement of their sizes and the obtained results were evaluated in terms of their degree of melting. This was compared with the experimentally observed coating microstructure type and finally correlated to the investigated coating porosity to select the specific MPS parameters of Zr coatings depositing onto medical implants from Ti alloy. It was found that the main parameters influencing the size of the sprayed Zr particles and the porosity of the Zr coatings are the plasma gas flow rate and amperage. It was demonstrated that it is possible to control the porosity of Zr microplasma coatings in the range from 2.8% to 20.3% by changing the parameters of the MPS. The parameters of microplasma spraying of Zr wire were established to obtain medical implant coatings with porosity up to 20.3% and pore size up to 300 μm.

Keywords: *zirconium coatings; titanium implants; microplasma spraying (MPS); porosity; splats; scanning electron microscopy (SEM)*

INTRODUCTION

Currently, technologies for the production of patient-oriented medical implants have been actively developed in order to speed up patients' recovery after surgery, reduce the risk of post-surgery complications associated with implant rejection, and ensure a long service life of the implant [1, 2]. Modification of the implant surface (etching, micro-arc oxidation, deposition of thin films or coatings made of biocompatible materials, etc.) can improve not only mechanical properties of an implant, but also enhance its biological activity and osteoconductivity at the cellular level, as well as increase antibacterial properties of an implant surface [3, 4]. The development of modern technologies for the production of biocompatible coatings follows the path of creating functionally gradient coatings [5] and

compositionally gradient coatings [6, 7]. Thus, different combinations of various materials and coating methods are used to achieve optimal for a particular implant chemical and physical properties of the surface. In this case, the challenge remains the choice of coating material and method of production, as well as obtaining a coating with the desired microstructure.

One of the surface properties important for orthopaedic and dental implants that can be modified is the porosity of implant surface layers. A number of studies of the influence of average pore size, volume porosity, thickness, and other parameters of biocompatible coatings made of various materials on the osseointegration of implants have shown that the use of thick (from 50 μm to 700 μm) porous coatings allows the implant to be securely fixed in tissues by increasing the area of contact with bone tissues [2, 4, 8, 9]. Such coatings have a structure similar to bone, which allows for the invasion of bone tissue into the pores of the implant.

Authors have different opinions on the optimal pore size for an implant. Tumilovich M.V. *et al.* [8] provided some data from laboratory animal studies to determine the strength of adhesion to adjacent bone tissues of cylindrical implants with a porous coating of titanium powder. It was shown that after 2-3 months, the shear strength reaches a maximum of 26-27 MPa in the range of pore sizes from 100 μm to 300 μm, while at larger pore sizes the strength of bone adhesion to the implant decreases. It was noted that the amount of adhesion strength is affected by the morphology of the sprayed titanium particles, and the best results were achieved when using sponge particles. Kalita V.I. *et al*. [9] provided experimental data on animal (canine) osseointegration of intraosseous implants with coatings of titanium and hydroxyapatite (HA). The authors [9] assumed that the size of open pores of 300 μm to 500 μm is optimal for the effective integration of the bone tissue. HA coatings with the thickness of 80 μm to100 μm were deposited onto Ti coatings by plasma spraying of HA powder. The mean thickness of the Ti coatings varied from 24 μm to 40 μm; the porosity made 15–20%; and the pore size ranged from 0.4 μm to 10 μm. The dynamics of osteointegration of implants was evaluated by the shear strength of the "bone–coating on implant" interface. The experiment showed that the shear strength values of the interface between the Ti-coated implants and the osseous block 16 weeks after the implantation was 4.25–4.81 MPa, while for implants with an additional plasma hydroxyapatite coating it exceeded 6.19 MPa 4 weeks after the implantation. Liu W. *et al.* [4] recommended to ensure the presence of pores of different sizes (in the range from less than 20 μm to more than 100 μm) in the materials of endoprosthesis implants; at that the pores should be interconnected. Matassi F. *et al.* [2] pointed that the pore size of 100-200 μm in titanium samples is the best for stimulating cell adhesion and reducing bacterial attachment compared to larger pores of 355-500 μm, or with completely dense samples.

The surface roughness of implants also affects the response of cells and tissues; the increased roughness expands the surface area of implant adjacent to bone, thereby improving implant fixation in bone [10-13]. Jemat A. *et al.* [11] worked on the effect of surface roughness role in providing an effective surface for bone-implant contact. The results showed that a combination of high surface roughness ranging from 0.44 to 8.68 μm and mechanical properties of titanium could lead to successful dental implants with better osseointegration. Nicholson J.W. [12] reviewed the topic of titanium alloys for dental implants and found that roughening the surface with some additional processing step was effective in improving the osseointegration properties of titanium alloys and noted the success of using thermal plasma spraying methods for this purpose [13].

Currently, there is an increased interest in using Zr as a material for medical implants [14, 15]. Due to its high strength and chemical stability, Zr is promising as an orthopedic

biomaterial. Methods of thermal plasma deposition allow obtaining coatings from a high-melting-point material, such as Zr [1, 16]. The formation of a thermal plasma coating is characterized by the ingress of a large number of particles more or less melted in the plasma jet, forming so-called splats, between which pores are formed. Herewith the porosity and roughness of the coating surface depend on the size, speed and degree of melting of the particles forming it [1]. The pore size is affected by both the actual size of the coating particles and their shape [7, 8, 17]. Understanding the mechanisms of coating formation allows selecting specific parameters of thermal plasma spraying to obtain the desired microstructure of the coating. Currently, thermal spraying methods are widely used in applications related to the metalworking industry [7, 16], but for the biomedical field, it is an innovative issue with the potential that is currently being studied [1, 7, 13, 16].

One of the factors that prevent the introduction of thermal plasma deposition technologies in the production of biocompatible coatings is the possible heating of an implant during the process of coating deposition with a jet of high-temperature plasma, which can lead to changes in its shape and mechanical properties. The use of Microplasma Spraying (MPS) technology allows avoiding volumetric heating of the implant due to the low power of the process (up to 2 kW).

The small size of the spraying spot on the plasma-coated surface (with a diameter of 5 mm to 15 mm) reduces the loss of spraying material when coating small-sized products, which include most parts of endoprostheses. The use of robotic MPS allows for precision coating deposition on complex-shaped implant parts, such as parts of elbow and hip replacements. In our previous papers [18-22], it was shown that robotic microplasma spraying can produce coatings on medical implants made of biocompatible titanium and hydroxyapatite materials with the desired porosity and roughness, meeting the requirements of international standards for implants for surgery in terms of coating adhesive strength [23], crystallinity and purity [24].

The objectives of this study were to evaluate the effect of MPS parameters on the sizes of sprayed Zr particles and to establish correlation between Zr coating porosity and MPS parameters. This evaluation was required to select specific MPS parameters to form porous Zr coatings on Ti substrates with the desired porosity suitable for biomedical applications. A better understanding of MPS processes is promising for obtaining functional coatings with the desired structure and properties by controlling MPS parameters.

MATERIALS AND RESEARCH METHODS

The production and research site, where experimental medical implants from titanium alloys are manufactured by CNC machines, operates at D. Serikbayev East Kazakhstan Technical University [18, 20, 21]. Titanium alloys are the preferred material for the production of orthopedic and dental prostheses. However, the biocompatibility of titanium implants can be increased by surface treatment [12, 25], in particular, by spraying coatings of unalloyed titanium, tantalum, or zirconium, etc. Robotic microplasma spraying of Zr coatings on titanium alloy substrates was performed using a microplasmatron MPS-004 (E. O. Paton Institute of Electric Welding, Ukraine) [26] mounted on an industrial robot manipulator Kawasaki (RS010L, Kawasaki Heavy Industries, Japan). Microplasmatron MPS-004 uses argon as a plasma-forming and shielding gas. The coating thickness varied from 150 μm to 500 μm due to changing the MPS parameters (amperage, spraying distance, plasma gas flow rate and wire flow rate) and change in the number of passes of the plasma jet. The speed of linear traveling of the microplasmatron along the substrate was chosen to be 50 mm s^{-1}. This

speed was chosen experimentally to ensure plasma spraying of the coating with a uniform thickness. Experiments have shown that this speed of linear traveling of the microplasmatron does not lead to disturbances in the plasma jet flow due to air resistance and, therefore, ensures the stability of the spraying process in all runs. The use of a robot manipulator allows spraying coatings with a steady speed of movement of the microplasmatron along the surface of an implant, as well as moving the microplasmatron along a predetermined trajectory accurately observing the distance of spraying and the perpendicular alignment of the plasma jet to the surface of the substrate.

The coatings were deposited by MPS of 0.3 mm diameter wire from Grade 702 unalloyed zirconium (UNS R60702) onto substrates from Grade 5 ELI titanium alloy (ASTM B348-13) [27].

The samples of medical Ti alloy of Grade 5 ELI were cut with thicknesses of 3 mm from rods with a diameter of 50 mm and 30 mm on CTX 510 ecoline computer numerical control (CNC) machine (DMG MORI AG, Germany). The specimen dimensions were chosen to provide sufficient substrate thickness compared to the coating to avoid overheating of the substrate during the MPS of coatings. These specimen dimensions are also optimal for further studies, both for placement in the SEM chamber and for the preparation of cross-sections. To manufacture the medical implants (parts of the elbow and hip joint components) the CTX 510 ecoline CNC turning and milling machine and DMU 50 CNC milling machine (DMG MORI AG, Germany) have been used [18, 20]. Before MPS, for the substrate surface activation [28], the substrate surface was subjected to gas abrasive blasting treatment followed by cleaning. The gas abrasive surface treatment was carried out by a Contracor ECO abrasive blasting machine (Comprag Group GmbH, Germany) using normal grade A14 electrocorundum at a compressed air pressure of 0.6 MPa, for further information refer to our paper [22].

The coating experiments for MPS of Zr wire were accomplished in a two level fractional factorial design (2^{4-1}). The experimental conditions in fractional factorial designs have been selected to provide a balanced design [29]. Experiment planning was carried out according to a linear model, that is, the contribution of each factor (parameter) was assumed to be equal, and it was also assumed that the factors did not affect each other. The maximum and minimum values of the parameters at which the process is technically feasible and the contribution of each factor is independent, that is, the factors (parameters) do not affect each other, were chosen experimentally, based on the previous studies [18, 19].The interpretation of the experimental results was carried out by the methods of regression analysis using Excel to calculate the coefficient of determination for the model. The following parameters were selected as variable parameters: amperage (I, A), plasma gas flow rate (Q, slpm), spraying distance (H, m) and wire flow rate (Vw, m/min). The coating parameters are summarized in Table 1.

Due to the great complexity of the experimental measurement of the temperature and, consequently, the degree of heating of individual Zr wire particles at the moment of their impact on the substrate, the method for analyzing SEM images of particles and splats was used for a comparative assessment of their degree of heating. The application of this method for the characterization of the microplasma spraying of biocompatible titanium coating can be found in the previous paper [19]. The oxidation level of the coatings was not measured in this study.

In order to study the size and morphology of particles formed by MPS of Zr wire, samples were taken by collecting particles in a 0.5 × 0.5 × 0.2 m water bath installed under the stream of the sprayed material. For the study we used the particles obtained in the corresponding MPS runs (Table. 1), collected in water at room temperature.

Table 1. *Parameters of MPS of Zr wires*

Run number	Parameters/Settings			
	Amperage I, A	Plasma gas flow rate Q, slpm	Spraying distance H, mm	Wire flow rate V_w, m/min
1	26	4.0	120	4.8
2	26	4.0	40	2.9
3	26	2.7	120	2.9
4	26	2.7	40	4.8
5	16	4.0	120	2.9
6	16	4.0	40	4.8
7	16	2.7	120	4.8
8	16	2.7	40	2.9

The particles of the sprayed Zr wire after collision with the substrate were studied using splat tests [30, 31]. MPS of Zr wire onto the plates of polished Ti alloy was performed in the plane perpendicular to the axis of the plasma jet. The speed of the linear movement of the plasma jet was set at 50 mm s^{-1}. As a result, single particles of the sprayed material (splats) were fixed on the substrate and deformed upon contact with the substrate surface. The visual analysis of the splats was carried out by scanning electron microscopy (SEM); the splats were classified according to their appearance and their spraying runs (Table. 1).

The study of the microstructure and assessment of coating thickness were performed using a metallographic microscope BX-51 (OLYMPUS, Japan) and a scanning electron microscope JSM-6390LV (JEOL, Japan) with an energy dispersion analysis add-on unit (EDX) INCA ENERGY (Oxford Instruments, UK). The SEM study of Zi particles was performed using Philips SEM 515 (Philips, the Netherland).

The SEM images of splats and coatings cross sections and surfaces have been captured with the beam accelerating voltage of 20 kV in a low vacuum mode via the Back Scattered Electron Detector (BSD). The SEM images of Zr particles have been obtained with the beam accelerating voltage of 20 kV in a high vacuum mode.

To assess the porosity of coatings the images of their microstructures were processed using image processing programs ATLAS.ti (ATLAS.ti Scientific. Software Development GmbH) and ImageJ (the National Institutes of Health and the Laboratory for Optical and Computational Instrumentation LOCI, University of Wisconsin, USA). The measurements were made on the polished cross section of the coatings in accordance with the standard ASTM E2109-01 (2014) [32].

RESULTS

The results of measuring the Zr particle sizes and the coating porosity for different spraying parameters (Table 1) are shown in Fig. 1.

The SEM images of Zr splats and surfaces of Zr coatings sprayed by runs 1, 4, 7 and 8 are given in Fig.2. For comparison Figure 2 shows the images of microstructures obtained in runs that provide the minimum (Run 1) and maximum (Run 8) particle size, as well as the minimum (Run 4) and maximum (Run 8) porosity of the coating.

The SEM images of cross-sections of coatings sprayed in all 8 runs are given in Fig.3.

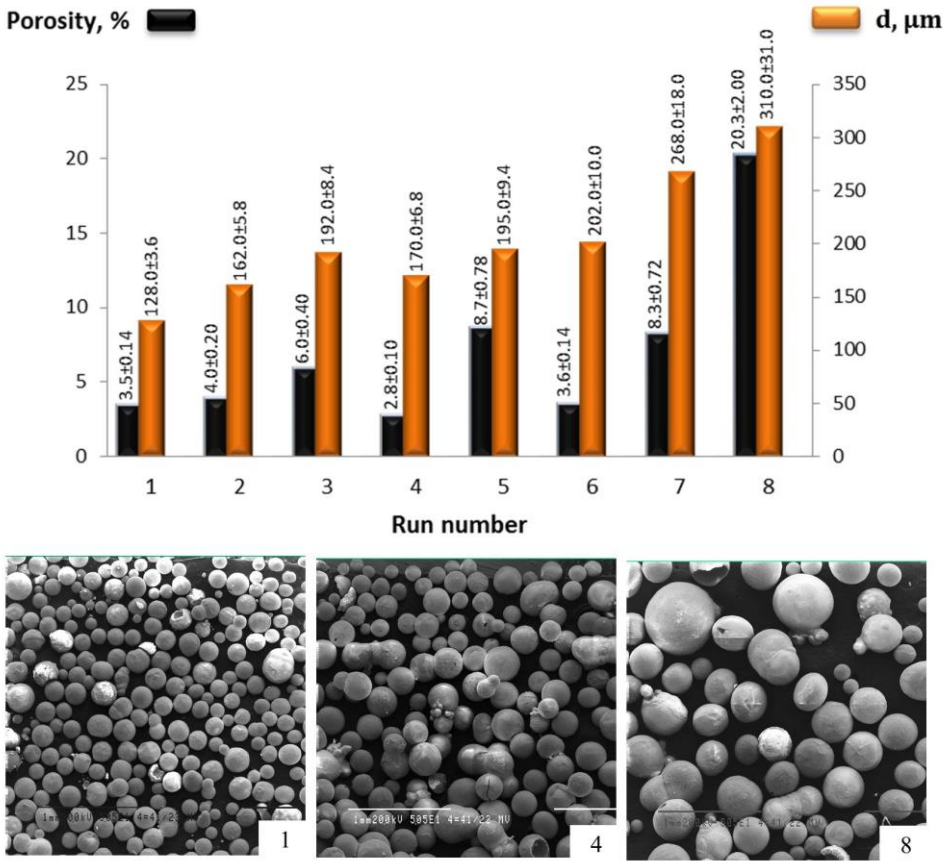


Fig. 1. The dependence of the particle size of the sprayed wire and the porosity of the coatings on the combination of MPS parameters in runs 1-8 (Table1) with SEM images of Zr particles

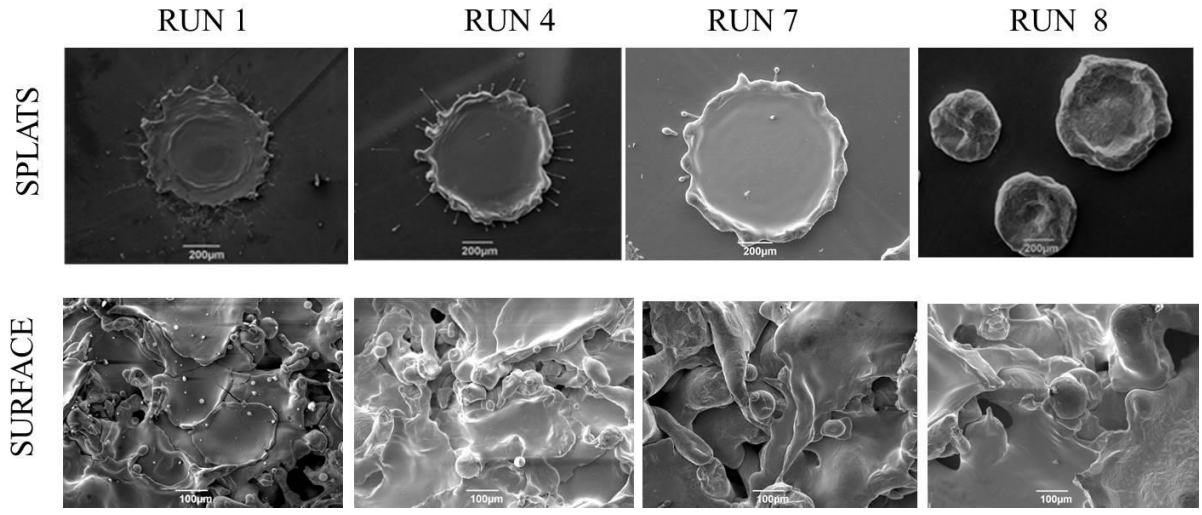


Fig. 2. SEM images of individual splats and surfaces of Zr coatings sprayed in runs 1, 4, 7 and 8 (Table 1)

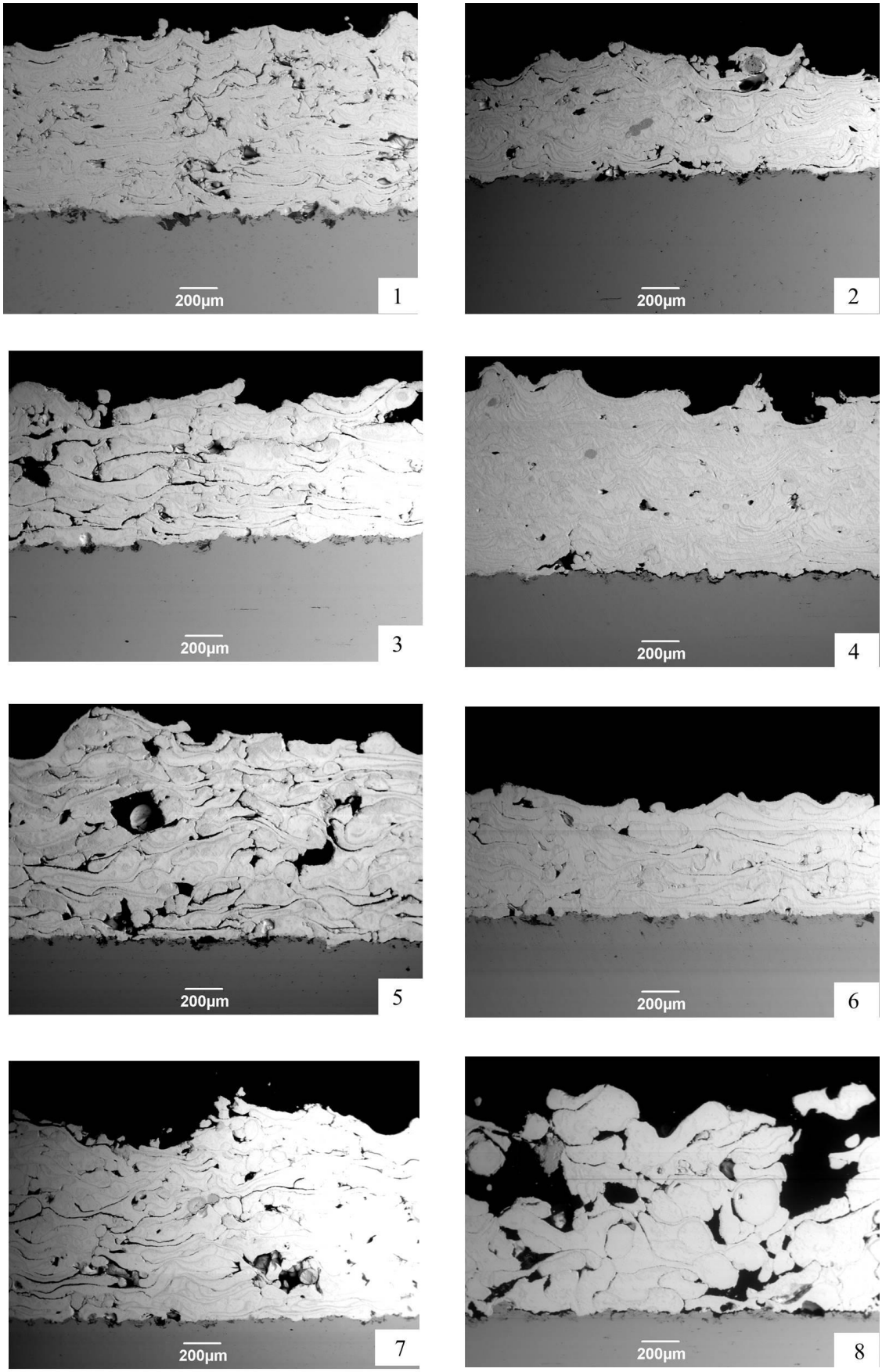


Fig. 3. SEM images of Zr coatings sprayed by runs 1- 8 (Table 1)

DISCUSSION

As can be seen in Fig.1, the particle sizes are significantly dependent on the MPS parameters and it follows that the main way to control the size of the sprayed particles is a change of the current and the plasma gas flow rate. Thus, the minimum average particle size (128.0±3.6 μm) was obtained in the case of a combination of the maximum values of these operating parameters (Run 1, Table 1). This is associated with a decrease in the surface tension of the melt during the overheating of particles and an increase in the dynamic pressure of the plasma jet. The combination of the minimum values of the current and the plasma gas flow rate (Run 7 and Run 8, Table 1) leads to the formation of particles with maximum sizes of 268.0±18.0 μm and 310.0±31.0 μm, respectively (Fig. 1). It is also noteworthy that the use of Run 8 leads to the formation of spongy particles with a rough and microporous surface, whereas the use of Run 4 leads to the formation of smooth spherical particles (Fig.1).

The appearance and structure of the splats varies depending on the interactions of the sprayed particles with the substrate. The interaction is generally defined by the velocity of the particles at impact and also the degree of heating of the particles in the plasma jet. It is possible to correlate the temperature and velocity of the particles before the collision with the substrate to the resultant structure of the coating. The profile and cracks on the surface of the splat correlate with the stress state of the coating [7, 30, 31]. The examination of the Zr particles splats obtained in runs 1, 4, 7 and 8 (Table 1) showed that the samples are completely melted and have formed a disk (Fig. 2). This form of splats means that the particles were in a molten state before colliding with the substrate. At the same time, the fact that the splats characteristics of Run 4 (Fig. 2) have more metal splashing at the edges of the splats suggests that they were formed by a less viscous melt. Therefore, at the moment of collision with the substrate, the particles obtained in Run 4 had a higher temperature than the particles obtained in Run 1. The higher particle temperature characteristic of Run 4 is due to the shorter deposition distance compared to Run 1.

As can be seen in Figure 2, the splats obtained in different runs have similar area but different thickness. The splat thickness was not measured in this experiment, but it can be estimated from the lamellae thickness in Fig. 3. The beginning of the process of solidification of the particles at the moment of their impact with the substrate is shown in Figure 2 (Run 7). The splats obtained in Run 7 (Table 1, Fig. 2), were formed by the particles that have cooled before their interaction with the substrate and were in the process of solidification, which is caused by a great distance of deposition. Such splats are characterized by greater thickness and the presence of a characteristic “bulge” (thickening) at the edges. The thicker splats (about 100 μm thick) are formed in Run 8 (Table 1, Fig. 2). The increase in the thickness of the splats in Run 8 is due to the minimum velocity of the particles during their interaction with the substrate. The minimum particle velocity in Run 8 is caused by the large size of the sprayed particles, low gas flow rate and low spraying distance. This also leads to a decrease in the speed of the sprayed particles. Particles of Zr wire, melted by a plasma jet, move towards the substrate during plasma spraying. On the one hand, the size of these particles depends on the set spraying parameters. On the other hand, both the set spraying parameters and the size of the particles affect the speed and the degree of heating of particles in the plasma jet. Before interacting with the substrate, the particles of molten metal can either heat up, being in the high-temperature zone of the plasma jet (the initial section of the plasma), or, more likely, cool down by going to the low-temperature zone (the end of the plasma jet). The size of the sprayed particles and the degree of their heating in the plasma jet can be varied by spraying parameters. It can be assumed that a porous coating with a high surface roughness can be obtained due to large particles moving at a low speed, as in Run 8. In the previous

study of characteristics of coatings obtained by the MPS of Ti wire [18], the surface roughness of Ti coatings (Ra) varied from 12 μm to more than 50 μm depending on the combination of spraying parameters (I, Q, H, V_w,). The maximum surface roughness (more than 50 μm) corresponded to a run with a combination of the minimum values of variable MPS parameters, similar to Run 8 in this study (Table 1)

A dense coating with a relatively low surface roughness can be obtained by high speed small and completely melted particles, as in Run 4. The thicker splats (about 100 μm thick) and the largest pores (up to 300 μm) are formed in Run 8 (Table 1, Fig. 2). The analysis of the cross sections of the Zr coatings (Fig.3) showed that the coatings obtained by Run 8 have the highest average porosity of 20.3%, while Run 4 makes it possible to obtain dense coatings with an average porosity of 2.8% (Fig. 1). Thus, the thick (about 100 μm), slightly deformed splats (as in Run 8) allow forming coatings with high porosity (%) and largest pores. Such characteristics of the coating on the implant could facilitate the growth of bone tissue into the coating, and therefore could provide a reliable and long-term fixation of the implant in the bone.

The regression analysis of the dependency of porosity (%) (Fig.1) versus process parameters (Table 1) can be obtained as follows:

$$Porosity\ (Zr)\ =\ k_1 + k_2 I + k_3 Q + k_4 H + k_5 V_w \qquad (1)$$

The numerical values and units of measurements of the coefficients in the regression equation (1) were calculated as follows: k_1= 42.8, k_2= -0.615 (A^{-1}); k_3= - 0.055 (lpm^{-1}); k_4= - 0.013 (mm^{-1}); k_5= - 2.766 min/m.

The coefficient of determination for equation (1) was 0.92. Such a small error of the model allows concluding that the effect of spraying parameters on the coating porosity is described by a linear model with a good approximation, and also confirming the correct choice of model factors, i.e. plasma spraying parameters.

As noted by Szala *et al.* [33], the selection of plasma spraying parameters for obtaining coatings with the required properties is a multi-criteria decision problem. Szala *et al.* [33] applied a new approach, namely, the fusion of artificial neural network and genetic algorithm for selection of atmospheric plasma spray parameters in the design of ceramic coatings [17, 34] with specified hardness, porosity and superior cavitation erosion resistance. The selection of MPS parameters applied in our study can contribute to further large-scale research of obtaining coatings with controlled microstructure and properties by modelling of thermal spray process parameters.

Thus, we have demonstrated the possibility of controlling the porosity of microplasma coatings made of zirconium wire in the range from 2.8±0.10 % to 20.3±2.00 % by changing the MPS parameters.

The carried out analysis of SEM images allowed us to identify 3 groups of microstructures of coatings, depending on the spraying parameters (runs), i.e. on the degree of heating particles when they collide with the substrate:

Group 1. If the particles are completely melted when approaching the substrate, then the structures shown in Fig. 3 can be formed in runs 1, 2, 4, 6. The degree of heating of the particles depends on their speed, the temperature before colliding with the substrate, the degree of their deformation and crushing when placed in the coating layer.

Dense structures from disc-shaped splats that have a characteristic lamellar structure are formed from completely molten spherical particles (Fig. 3, runs 1, 2, 6).

Overheating of the material above the melting point leads to the fact that the material fills the

cavities and splashes more easily due to the lower viscosity of the melt. Correspondingly, a structure with a greater degree of mixing of the material and a less correct shape of the lamellae is formed (Fig. 3, Run 4).

Group 2. If on approaching the substrate, together with the molten particles, there are particles that have begun to solidify (data from the splat test, Fig. 2, Run 7), then the structures characterized by lamellae of greater thickness than in the structures of Group 1 are formed, with the presence of pores and granular inclusions of fixed solidified particles (Fig. 3, runs 3, 5, 7). When the particles that have started to solidify hit the surface of the substrate, the thermal and kinetic energy is not enough for their complete deformation, which, with a significant number of particles, leads to the formation of granular-disk-shaped and granular structures with the presence of pores (Fig. 3, Run 5).

Group 3. If coatings are formed from particles that have begun to solidify at a low speed (data from the splat test, Fig. 2, Run 8), then such particles form a coating with a structure characterized by a large number of large pores ranging in size from 100 μm to 300 μm (Fig. 3, Run 8). The presence of pores of this size in the coatings of endoprostheses can contribute to the invasion of blood vessels into the pores of the coating, positively affecting the formation and nutrition of bone tissue, and therefore the fixation and osseointegration of an endoprosthesis in the human body [2, 3, 8, 12].

Thus, such parameters of MPS of Zr wire as in Run 8 (Table 1), namely: the amperage: 16 A, the plasma gas flow rate: 2.7 slpm, the spraying distance: 40 mm, the wire flow rate: 2.9 m/min, result in the formation of coatings with porosity up to 20.3±2.00 % (Fig.1) and pore sizes up to 300 μm (Fig. 3).

Thus, the influence of MPS parameters on the microstructure of the emerging coating was established. By varying the parameters of microplasma spraying, it is possible to obtain coatings with controlled porosity in the range from 2.8±0.10 % to 20.3±2.00 % and pore sizes in different ranges, from 2 μm to 10 μm in dense coatings (Run 4, Fig. 3) and from 100 μm to 300 μm in the porous ones (Run 8, Fig 3). These are rather wide ranges, which is promising for increasing the biocompatibility of a microplasma-coated titanium implant. For comparison, Kalita V.I at al. [35] reported on the possibility of forming three groups of micropores in titanium wire coatings obtained by the technology of plasma off-angle spraying: 1) from 35 μm to 150 μm, 2) from 6 μm to 30 μm and 3) from 1 μm to 6 μm and on the successful results of osseointegration of titanium knee implants with these coatings in dogs. Our further research will be aimed at analyzing the surface roughness and the adhesive strength of zirconium microplasma coatings, selecting the composition of multilayer coatings with various layers porosity, and investigating the biocompatibility of the resulting coatings.

SUMMARY

The effects of MPS parameters on the sizes of sprayed Zr particles and the correlation between the porosity of Zr coatings and the MPS parameters have been specified. It has been established that the main parameters controlling the size of the sprayed Zr particles and the porosity of the Zr coatings are the amperage and the plasma gas flow rate.

The possibility of controlling the porosity of microplasma coatings made of zirconium wire in the range from 2.8% to 20.3% by changing the parameters of the MPS was ascertained. The following parameters of MPS of Zr wire for the formation of coatings with the porosity up to 20.3% and pore sizes up to 300 μm have been elicited: amperage: 16 A, plasma gas flow rate: 2.7 slpm, spraying distance: 40 mm, wire flow rate: 2.9 m/min.

The advantages of applying SEM for analysis of the structure of microplasma sprayed Zr coatings have been shown. The analysis has been successful in assessment of the relation of the morphology and structure of coatings to the processing parameters of the MPS.

The results of the research are of significance for a wide range of researchers developing the technologies of thermal plasma spraying of biocompatible coatings.

ACKNOWLEDGEMENT

The work was supported by the National Academy of Science of Ukraine under Grant number 0117U004951

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