

# Defining efficient modes range for plasma spraying coatings

**E A Zverev, V Yu Skeebea, P Yu Skeebea, I V Khlebova**

Novosibirsk State Technical University, 20, Prospekt K. Marksa, Novosibirsk, 630073, Russia

E-mail: [skeebea\\_vadim@mail.ru](mailto:skeebea_vadim@mail.ru)

**Abstract.** The article outlines an approach for ensuring the quality of wear-resistant plasma coatings of high-chromium powder material. Based on the results of theoretical and empirical research, the authors received a plasma coating process model, which takes into account the influence of spraying modes on the main indicators of quality: adhesive strength, porosity, and the level of residual stresses. The authors recommend relevant functional dependencies, which enable determining the combination of the process mode parameters to ensure efficient indicators of the plasma coating quality.

## 1. Introduction

The majority of the machine elements of modern technological equipment perform in heavily loaded modes and often fails due to the working surfaces wear. With this in mind, there is a growing interest in wear resistant coatings, since their application gives the greatest economic effect. Coatings are most often applied to substrates of lower quality as well as widely used in restoration of worn parts [1 - 6]. Plasma spraying is a widely spread and effective method of industrial coating. Its advantages are high performance, process manageability, ease of implementation technology, relatively low cost, as well as the ability to process elements of various configurations and dimensions. Obviously, the modes of spraying directly affect the type of the coating structure which predetermines the complex of its physico-mechanical and performance properties [7 - 11].

Selecting the modes of plasma spraying implies solving complex and controversial problem, since the quality of the coating structure depends on many factors [12 - 15]. Spraying modes determine the energy state of the sprayed particles (temperature and speed). Generating a favorable structure option requires an increase in the particle temperature in the plasma jet, i.e. the increase in the degree to which the powder is melted. This, however, raises the level of residual stresses in the structure of the coating and negatively affects its strength. Besides, the increase in plasma energy leads to the burning-out of alloying elements or individual powder particles. Thus, the mentioned conditions necessitate determining the optimal mode range for the implementation of the plasma spraying process.

The most important indicators of the coating structure quality are adhesive strength (coating adhesion with the substrate) -  $\sigma_{ad}$ , porosity  $Po$  and the level of residual stresses  $\sigma_{rs}$ .

The objective of this study is to establish numerical correlation between the quality of coatings and the technological parameters of plasma spraying process.



## 2. Materials and methods

Plasma installation "Kiev-7" was used to conduct basic research of the coating. Spraying was carried out by 40 kW powered plasma torch PUN-8. Widely spread in industry high-chromium cast iron PG-S27 with fractional size 50... 100  $\mu\text{m}$  was chosen as a coating material.

The spraying process was executed by the translational plasma torch motion and the rotation of the work-holder with the samples. Bushes made of steel 20 were used as samples. The specimens were previously subjected to jet-abrasive cleaning (with fused alumina as a working material), which is required for the surface activation, such as its cleansing from dirt, oils and oxidation films, as well as the required roughness values:  $R_z = 50 \dots 75 \mu\text{m}$ . In addition, immediately prior to the spraying process, the workpieces were heated up to temperatures of approximately  $150^\circ\text{C}$  to improve the adhesion of the coating to the substrate. The coating layer thickness value was within 600 ... 630  $\mu\text{m}$  with the view of avoiding the residual stresses growth.

When assessing the coatings adhesive strength, the authors applied the method of "shift", an installation being constructed specially for it. Porosity was measured by metallographic method by *NIKON Eclipse MA100* optical microscope. When determining the level of the coatings residual stress of the first kind, the authors used non-destructive "build-up" experimental and calculated method requiring the plate deformation at the time of spraying the covering layer.

The plasma torch arc current  $I$  (range of variation values -116... 160 A) at a voltage of  $U = 140\text{ V}$ , plasma-forming gas flow rate (air)  $G$  (13... 27 l/min) at a pressure of  $P = 0.4\text{ MPa}$  and spraying distance  $L$  (80... 160 mm) were set as operated mode parameters to build a model of the process in the form of regression equations *ceteris paribus*. Mass flow of powder was  $G_{\text{pow}} = 1.5\text{ kg/h}$ . Spraying was carried out by rotating the samples with linear velocity  $V_{\text{sam}} = 12\text{ m/min}$  and plasma torch speed of motion (feeding)  $S = 300\text{ mm/min}$ .

Since preliminary research has shown that the relationship between input (evaporation regimes) and output (coating quality indicators) is non-linear, the orthogonal centrally-composite second order plan was adopted as the experiment plant.

## 3. Results and discussion

As a result of the experiments, the authors obtained the mathematical model of plasma spraying based on regression equations of the following type

$$\sigma_{\text{ad}} = 130.62 - 2.316I + 3.878G - 0.086L + 0.009I^2 - 0.124G^2 + 0.007IG. \quad (1)$$

$$Po = -159.45 + 4.48I - 7.308G - 0.714L - 0.018I^2 + 0.159G^2 + 0.003L^2 + 0.008IG. \quad (2)$$

$$\sigma_{\text{rs}} = 161.22 - 3.713I + 0.018I^2 + 3G - 0.099G^2 + 1.06L - 0.003L^2 - 0.004IL. \quad (3)$$

This model made it possible to assess the extent of each factor impact and identify their quantitative relationship. With the increased current strength, adhesive strength increases and porosity reduces. This is due to the rise in the jet temperature, resulting in the decreased number of unmelted particles. Reaching the critical current strength results in overheat and burning-out of particles in plasma jet.

Increase in gas flow affects positively only up to a point. This is due to the complex influence of flow magnitude on the state of the plasma jet: with the increase in gas consumption, plasma velocity grows (as well as the kinetic energy of the powder particles), but at the same time the thermal power of the jet decreases which has a negative effect on the temperature of the particles. Within the investigated range of spraying modes, the coatings adhesion strength and porosity change within 9.8 ... 26.4 MPa and 4 ... 26%, respectively.

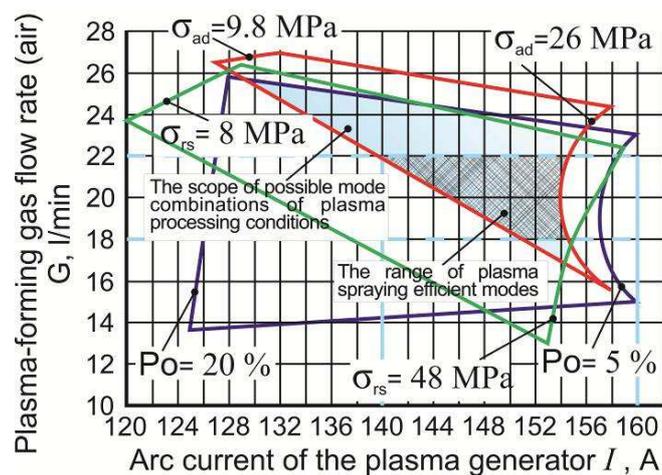
The analysis of experimental data has shown that the sign of residual stresses is not changed in the spraying process. The magnitude of the tensile stresses mainly depends on the temperature of samples heating, the biggest influence being that of plasma torch current arc. The increase in the arc current

strength is accompanied by the increased substrate temperature. This is due to the fact that with the increased current strength plasma jet thermal power grows as well.

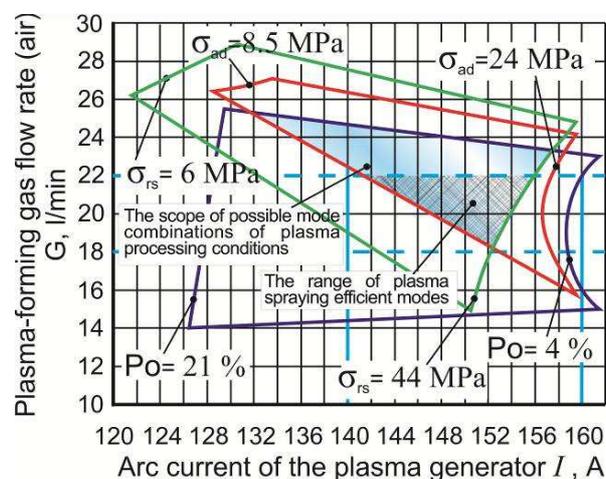
At the same time, with increased plasma gas flow the situation is reverse, namely the sample temperature reduces because of the decrease in the total heat of plasma. The spraying distance has nearly the same impact: its increase leads to the decrease in the substrate temperature. Within the investigated range of plasma spraying coating modes the residual stress level was within 7.0 ... 60 MPa.

Metallographic analysis showed that the spraying modes produce a significant effect on such characteristics of coatings structure as porosity and pore size, number of unmelted particles and the degree of their deformation as well as discontinuity flow of the transition border. The more in-depth exploration of structures at the micro level was called for by the fact that the powder particles undergo significant thermal loads during plasma spraying. The research has demonstrated that chemical and phase composition changes after spraying are insignificant, which testifies to the efficiency of the selected modes.

The modes of plasma spraying can be defined with the help of the graphical correlation of the coatings quality indicators which are constructed according to equations (1) - (3). Figures 1 and 2 show the possible combinations of conditions for plasma treatment modes at different spraying distance value.



**Figure 1.** Defining plasma spraying modes at distance  $L = 110$  mm



**Figure 2.** Defining plasma spraying regimes at distance  $L = 125$  mm

Producing high quality coatings requires choosing the formation sub-field of low porosity structure which helps to ensure a minimum roughness of coatings after grinding. Spraying modes are determined with the view of the possible residual stresses minimization. The covering of the required thickness is applied in layers. The thickness of the layer applied in one pass is adjusted by the powder consumption variation with the help of trial samples. A single layer thickness should not exceed 0.2 mm in order to avoid a sharp increase in residual stresses.

#### 4. Conclusion

As a result of the complex analysis, the authors defined the range of plasma spraying efficient modes:  $I = 140...155$  A,  $G = 18...22$  l/min,  $L = 118...120$  mm, which ensures the formation of coatings with the appropriate combination of quality indicators:  $\sigma_{ad} = 22.8... 24.0$  MPa,  $Po = 7.5... 9.0\%$  and  $\sigma_{rs} = 35.0... 39.0$  MPa.

The proposed methodology has been tested and its efficiency has been confirmed while strengthening the intensely wearing parts of the mounting, which is used in the manufacture of special backings system of rails fixing on the railroad switch. The technology has been introduced at public corporation "Novosibirsk Switch Plant".

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#### References

- [1] Plotnikova N V, Skeebe V Y, Martyushev N V, Miller R A and Rubtsova N S 2016 *IOP Conference Series: Materials Science and Engineering* **156(1)** 012022
- [2] Ivancivsky V V, Skeebe V Y, Bataev I A, Lobanov D V, Martyushev N V, Sakha O V and Khlebova I V 2016 *IOP Conference Series: Materials Science and Engineering* **156** 012025
- [3] Liverani E, Lutey A H A, Ascari A, Fortunato A and Tomesani L 2016 *Surface and Coatings Technology* **302** 100-106.
- [4] Kornienko E E, Lapushkina E J, Kuzmin V I, Vaschenko S P, Gulyaev I P, Kartaev E V, Sergachev D S, Kashapov N, Sharifullin S and Fayrushin I 2014 *Journal of Physics: Conference Series* **567** 012010
- [5] Ivancivsky V V, Bataev I A, Martynova T G, Vakhrushev N V and Cha G O 2016 *Obrabotka metallov (tekhnologiya, oborudovanie, instrumenty) (in Russian)* **3(72)** 41-51
- [6] Dhakar B, Chatterjee S and Sabiruddin K 2017 *Materials and Manufacturing Processes* **32(4)** 355-364
- [7] Zverev E A, Skeebe V Yu, Martyushev N V and Skeebe P Yu 2017 *Key Engineering Materials* **736** 132-137
- [8] Kornienko E E, Nikulina A A, Belousova N S, Lazurenko D V, Ivashutenko A S and Kuz'min V I 2016 *IOP Conference Series: Materials Science and Engineering* **156(1)** 012020
- [9] Kornienko E E, Mul' D O, Rubtsova O A, Vaschenko S P, Kuzmin V I, Gulyaev I P, Sergachev D V 2016 *Thermophysics and Aeromechanics* **26(6)** 919-927
- [10] Chesov Y S, Zverev E A, Ivancivsky V V, Skeebe V Yu, Plotnikova N V and Lobanov D V 2014 *Obrabotka metallov (tekhnologiya, oborudovanie, instrumenty) (in Russian)* **4(65)** 11-10
- [11] Kornienko E E, Nikulina A A, Bannov A G, Kuz'min V I, Mildebrath M, Bezrukova V A, Zhoidik A A 2016 *Obrabotka metallov (tekhnologiya, oborudovanie, instrumenty) (in Russian)* **4(73)** 52-62
- [12] Cartier M 2003 *Handbook of surface treatments and coatings* (New York: ASME Press) p 464
- [13] Fauchais P L, Heberlein J V R and Boulos M 2014 *Thermal Spray Fundamentals. From Powder to Part* (New York: Springer US Publ.) p 1566
- [14] Vardelle M, Vardelle A and Fauchais P 1993 *Journal of Thermal Spray Technology* **2(1)** 79-91
- [15] Kharlamov M Y, Krivtsun I V, Korzhyk V N, Ryabovolyk Y V and Demyanov O I 2015 *Journal of Thermal Spray Technology* **24(4)** 659-670