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THE HIGH QUALITY OF HYBRID SPRAYED COATINGS FOR POWER PLANT APPLICATION

Abstract. The article presents the factors affecting the quality of coatings and their impact on the derived properties of materials. We describe the stages of designing innovative coating obtained by using thermal spraying. We presented mapped hybrid system and possibility of use of selected laboratory results to obtain coatings. Presented, selected research of the structure and resistance to corrosion and erosion confirm that coating materials received using modern method are characterized by high quality performance.

Keywords: the design of quality of the coating, spray coating method, a hybrid method

PROJEKTOWANIE WYSOKIEJ JAKOŚCI POWŁOK NATRYSKIWANYCH HYBRYDOWO DLA ZASTOSOWAŃ W ENERGETYCE

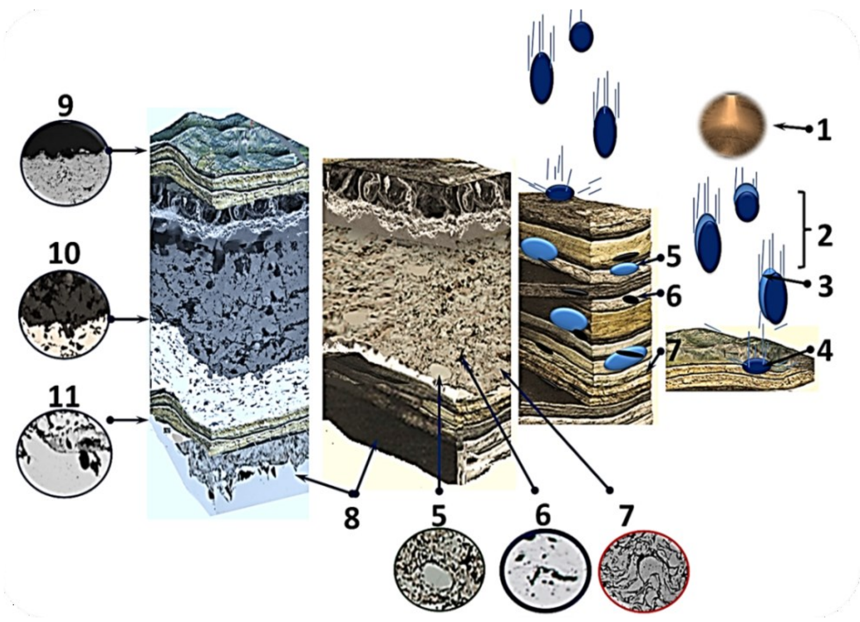
Streszczenie. W artykule przedstawiono czynniki wpływające na kształtowanie jakości powłok oraz ich wpływ na otrzymywane własności użytkowe materiałów. Opisano etapy projektowania powłoki otrzymanej innowacyjną metodą natrysku cieplnego. Przedstawiono zmapowany system hybrydowy oraz wybrane wyniki badań laboratoryjnych otrzymanych powłok. Prezentowane, wyselekcjonowane badania struktury i odporności korozyjno-erozyjnej potwierdzają, że materiały powłokowe otrzymane nowoczesną metodą charakteryzuje wysoka jakość użytkowa.

Słowa kluczowe: jakość powłok, metody badań powłok, metoda hybrydowa natrysku

1. Introduction

Protective coatings must have a compact design, very low porosity, temperature stability and required relatively high thickness. Very important is the technology of applying which must provide them adequate structure and good adhesion to the substrate[1]. In order to improve the stability of the system components we could apply various types of coatings, from the paint through the fused coating thermal sprayed coatings. For installations operating under the circumstances of corrosion and erosion (for example for power boilers) coating is produced frequently in the type[2]:

- HVOF – high velocity oxy fuel allowing currently receive the best quality of coatings.
- ARC characterized by high efficiency and satisfactory quality of coatings.



Description:

1 – heat source (arc, flame);
2 – giving the speed of the particle;
3 – oxide coating;
4 – blow particles into the ground;
5 – not molten particles;
6 – pores;
7 – the oxide layers;
8 – the base material;
9 – surface roughness;
10 – transition zone in the coating layered;
11 – transition zone between the coating.

Fig. 1. Diagram of spraying process and coating materials
Source: Szczucka-Lasota B., Węgrzyn T., Stanik Z., Piwnik J., Sidun P.: Selected parameters of micro-jet cooling gases in hybrid spraying process. "Arch. Metall. Mater", Vol. 61, No. 2, 2016, p. 621-624.

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[1] Hernaś A.: Materials and technology for the ultracritical boilers and west combustion. SITPH, Katowice 2009; Moskal G., Swadźba L., Hetmańczyk M., et al.: Characterization of microstructure and thermal properties of Gd2Zr2O7-type thermal barrier coating. "Journal of the European Ceramic Society", Vol. 32, No. 9, 2012, p. 2025-2034; Łukaszkowicz K., Dobrzański L.A.: Structure and mechanical properties of gradient coatingsdeposited by PVD techniques onto the X40CrMoV5-1 steel substrate. "Journal of Materials Science", No. 43, 2008, p. 4300-4307.

[2] Pasternak K.: Zarys zarządzania produkcją. PWE, Warszawa 2005, s. 213; Song Y., Lv Z., Liu Y., Zhuan X., Wang T.J.: Effects of coating spray speed and convective heat transfer on transient thermal stress in thermal barrier coating system during the cooling process of fabrication. "Applied Surface Science", Vol. 324, No. 1, 2015, p. 627-633; Wielage B., Pokhmurska H., Student M., Gvozdeckii V., Stupnyckyj T., Pokhmurskii V.: Iron-based coatings arc-sprayed with cored wires for applications at elevated temperatures. "Surf. Coat. Tech", No. 220, 2013, p. 27-35; Hanson T.C., Settles G.S.: Particle Temperature and Velocity Effects on the Porosity and Oxidation of an HVOF Corrosion-Control Coating. "Journal of Thermal Spray Technology", Vol. 12(3), 2003, p. 403-415; Tarasiuk W., Szczucka-Lasota B., Piwnik J., Majewski W.: Tribological Properties of Super Field Weld with Micro-Jet Process. "AMR", No. 1036, 2014, p. 452-457.

The main issue during the thermal spray coating is the kinetic energy of the process. Source temperature needed to melt the metal particles may cause excessive heating of the coating and the substrate (Fig. 1) leads to thermal cracking or exfoliation of the coating during its operation. Therefore, to form the entire coating with a sufficient thickness, we use during spraying process a gap between the stitches and cooling with compressed air. This increases material consumption and energy consumption of the process and decrease the quality of the final product. The molecules are oxidized, sprayed in the stream of gas, and consequently the coating has an excessive amount of oxides in a volume and a higher porosity[3]. To prevent this you must properly select materials and carefully design technological process.

The aim of this article is to provide a method for the design of high-quality coatings with special emphasis on innovation on a global scale using hybrid method. The new method was adapted from the technological welding process using a micro-jet process of thermal spray coatings.

2. Quality of coatings

The quality of the protective coatings, resulting from the materials and technology regulations, affects their useful properties – and these determine their applicability in specific technical conditions (Fig. 2).

Under the conditions of corrosion and abrasive wear durability of the coating will depend on many factors. The following should be considered as the most important[4]:

- coating structure (morphology, tightness, porosity, thickness, hardness, homogeneity of the structure – Fig. 2),
- condition of the coating surface (the degree of development of surface – roughness, modification and surface finish, for example used seals),
- chemical composition and phase coatings influencing the resistance to the conditions of data use,
- existing operating conditions (type of atmosphere gas: oxygen, sulfur, chlorine and alkali, forming sediments, pressure, temperature, and the fluctuation in the environment, the trajectory of the particles, their phase composition, size and shape, the concentration of dust in the gas stream, etc.).

[3] Ibidem.
[4] Hanson T.C., Settles G.S.: op.cit., p. 403-415.

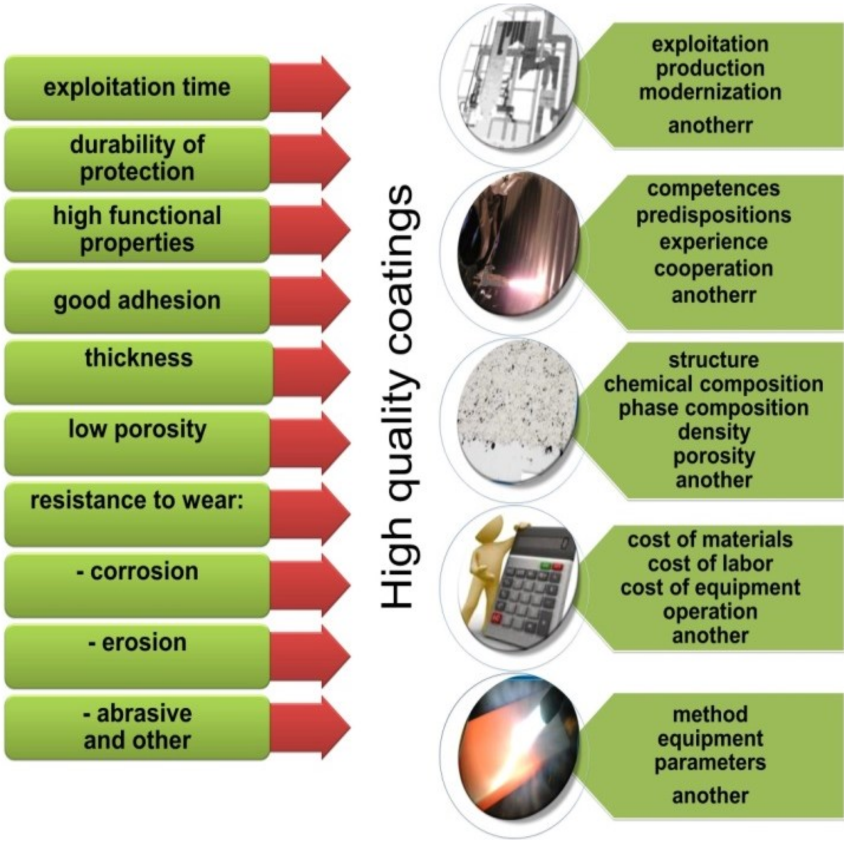

Fig. 2. Quality of coating

Obtaining assumed structure or coating material having a predetermined chemical composition and the phase is not a simple task. It requires to apply the appropriate starting material, the preparation, the use of appropriate technology and equipment for coating, choose the process parameters, perform proper finishing.

In addition, the technology should be accepted in the terms of technological and economically justified. The choice of technology regulations should take into account (Fig. 1):

- the availability of used equipment and materials endearing performance capabilities, ease of use, acceptability of the cost of materials and applications,
- the type and shape of the protected area (eg. the shape of the structure turbine blades partly determines the type of technology used, as in some cases cannot be complied recommended distance of thermal sprayed surfaces),
- technical environment (the possibility of using the technology for a given object, the method of surface preparation),
- efficiency of the process – the preparation of coatings time must be short as far as possible, the coatings are produced during equipment downtime,
- qualifications and experience of persons engaged in protection.

A properly selected material and technology and also the professional staff with appropriate privileges are a guarantee to provide a coating with appropriate thickness, uniformity and adhesion of the structure to the ground.

Newly developed hybrid technology involving the use of cooling by means of a suitably designed snap-type micro-jet cooling allows[5]:

- Modifying the classical methods of spraying, because the device is compatible with existing hardware for thermal spray coating by ultrasonic methods. Therefore it does not require the complete replacement of existing equipment and only the addition of a properly constructed snap.
- Use an appropriate, selective and precise cooling immediately after spraying shortens the time of formation of the coating, which translates into material consumption and energy consumption of the process.
- The type and shape of the protected area is mainly determined by access of the pistol with an attachment to the sprayed surface. In that regard, the new technology can present additional problems compared with conventional spray methods supersonic.
- New technology allows both spraying particles of molten metal and ceramic particles over large surfaces. The main limitations stem from the type of spray gun supersonic.

These advantages of the hybrid method suggest that the new technology is fully justified economically.

3. Designing quality coatings in the product life cycle

Designing quality coatings must take into account projected, designed and planned of processes, which the coating will be subject in the entire life cycle.

The projected and programmed processes are both processes predicted how the material will be subject during use and the processes associated with the demand for the product. Forecasting the life cycle of the product as coatings designed to protect the installation of boilers, is difficult due to the unpredictability of the emergence of new situations[6]. For example one such event was the introduction of the energy package in Poland, according to which in conventional boilers began incinerating waste and biomass. Work environment in which the coating was thus drastically changed. Working conditions have become more aggressive.

[5] Szczucka-Lasota B., Węgrzyn T., Stanik Z., Piwnik J., Sidun P.: op.cit., p. 621-624; Moskal G., Swadźba L., Hetmańczyk M. et al.: op.cit., p. 2025-2034; Łukaszkowicz K., Dobrzański L.A.: op.cit., p. 4300-4307; Węgrzyn T., Piwnik J., Wieszała R., Hadryś D.: Control over the steel welding structure parameters by micro-jet cooling. "Archives of Metallurgy and Materials", Vol. 57, No. 3, Iss. 1, 2012, p. 679-685; Węgrzyn T. Piwnik J., Hadryś D.: Acicular ferrite in micro welding technologies. "Archives of Metallurgy and Materials", Vol. 59, No. 2, 2014; Hadryś D., Węgrzyn T., Piwnik J.: The Effect of different micro-jet streams number on plastic properties of welds. "Arch. Metall. Mater". Vol. 60, No. 3A, 2015, p. 1617-1621.

[6] Oksa M., Turunen E., Suhonen T., Varis T. Hannula S.-P.: Optimization and Characterization of High Velocity Oxy-fuel Sprayed Coatings: Techniques, Materials, and Applications. "Coatings", Vol. 1, No. 1, 2011, p. 17-52; Hernaś A., Chmiela B., Szczucka-Lasota B.: Untypical bromine corrosion in boilers co-firing biomass. "Journal of Achievements in Materials and Manufacturing Engineering", Vol. 54, Iss. 1, 2012.

Example coatings which have not passed the test in a real environment were presented, among others, in another publications[7].

The chemical composition of the corrosive environment is currently difficult to determine, since it is subject to fluctuations as a serious problem during the research project. The emergence of new elements interferes with the course of the current corrosion processes. An example would be the appearance of different types of corrosion, including bromocorrosion, described in another publications[8].

However, the increased aggressiveness of the environment led to: an increase in demand for new coating to protect existing energy installations and the actions of competitors introducing to the market its own products and technologies (Fig. 3).

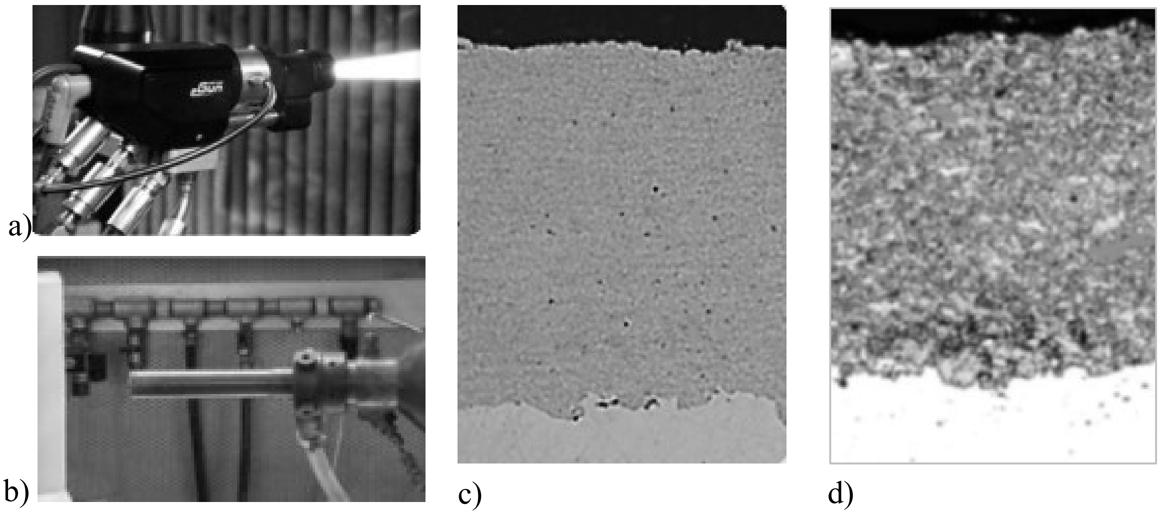

Fig. 3. New guns of thermally spraying systems a) e-gun; b) gun in cold spray system and structures quality of coatings after spraying by; c) ultrasonic e-gun method; d) cold impulsed technique
Source: Tarasiuk W., Szczucka-Lasota B., Piwnik J., Majewski W.: Tribological Properties of Super Field Weld with Micro-Jet Process. "AMR", No. 1036, 2014, p. 452-457; Szczucka-Lasota B., Węgrzyn T., Stanik Z., Piwnik J., Sidun P.: Selected parameters of micro-jet cooling gases in hybrid spraying process. "Arch. Metall. Mater.", Vol. 61, No. 2,2016, p. 621-624.

During the design process we should also plan on what time produce a coating and which method to use, depending on the materials, the structure, parameters, cost etc. To determine what processes will be impotent for the coating during the entire life cycle of the product and what impact the individual stages will have on the environment.

[7] Szczucka-Lasota B., Węgrzyn T., Stanik Z., Piwnik J., Sidun P.: op.cit., p. 621-624.
[8] Altkorn J. (red.): Podstawy marketingu. Instytut Marketingu, Kraków 2004, s. 144-147.

4. Designing quality coatings – obtained by hybrid method

It was assumed, that the coatings produced using hybrid method must have a set of beneficial features, for example: corrosion resistance in an oxidizing environment, erosion resistance, the abrasive resistance, the appropriate thickness (about 450-550 μm), porosity (max. 3%), compactness, imposing uniformity, the appropriate chemical composition, hardness, adhesion to the substrate.

It was considered that the design of appropriate coatings can be divided into five main phases (Fig. 4), which precedes the stage of pre-project activities. This step resolved decision problems associated with optimal shaping of the quality of the proposed coating process for its preparation and application. The complex work related to the preparation and planning of material resources, human resources and definition of requirements aimed to ensure the optimal quality of the designed shell.

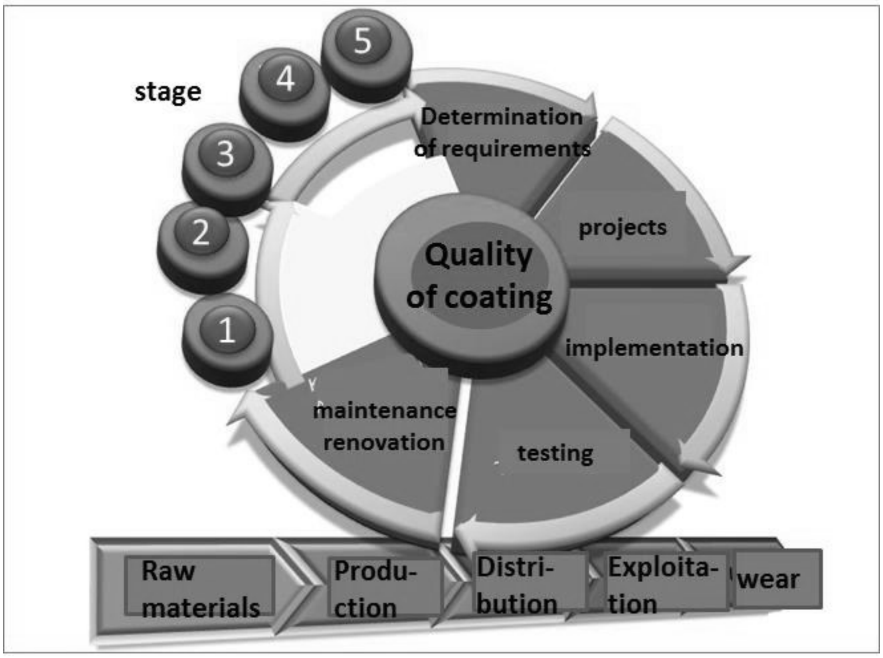

Fig. 4. Designing optimal performance of coatings
Source: Own work.

The design phase coatings obtained using hybrid method.

The first two phases included the research and design, organizational and material. At this stage, forming a coating we chosen, inter alia:

- materials – powders of nickel-chromium obtained in the process of SHS self high temperature synthesis modified hard carbide phases as the most suitable for producing coatings characterized by high resistance to corrosion and erosion;

- devices and methods for the preparation of coatings. HVOF method is chosen to produce a compact, low porous coatings with good adhesion to the substrate has been modified by attachment micro-jet adapted to the spraying process. The diameter of the spray cooling was 4 cm.

The coating where prepared by spraying methods. Designing of coating quality in hybrid method took place through the interaction of the two processes: HVOF spraying and micro-jet cooling process.

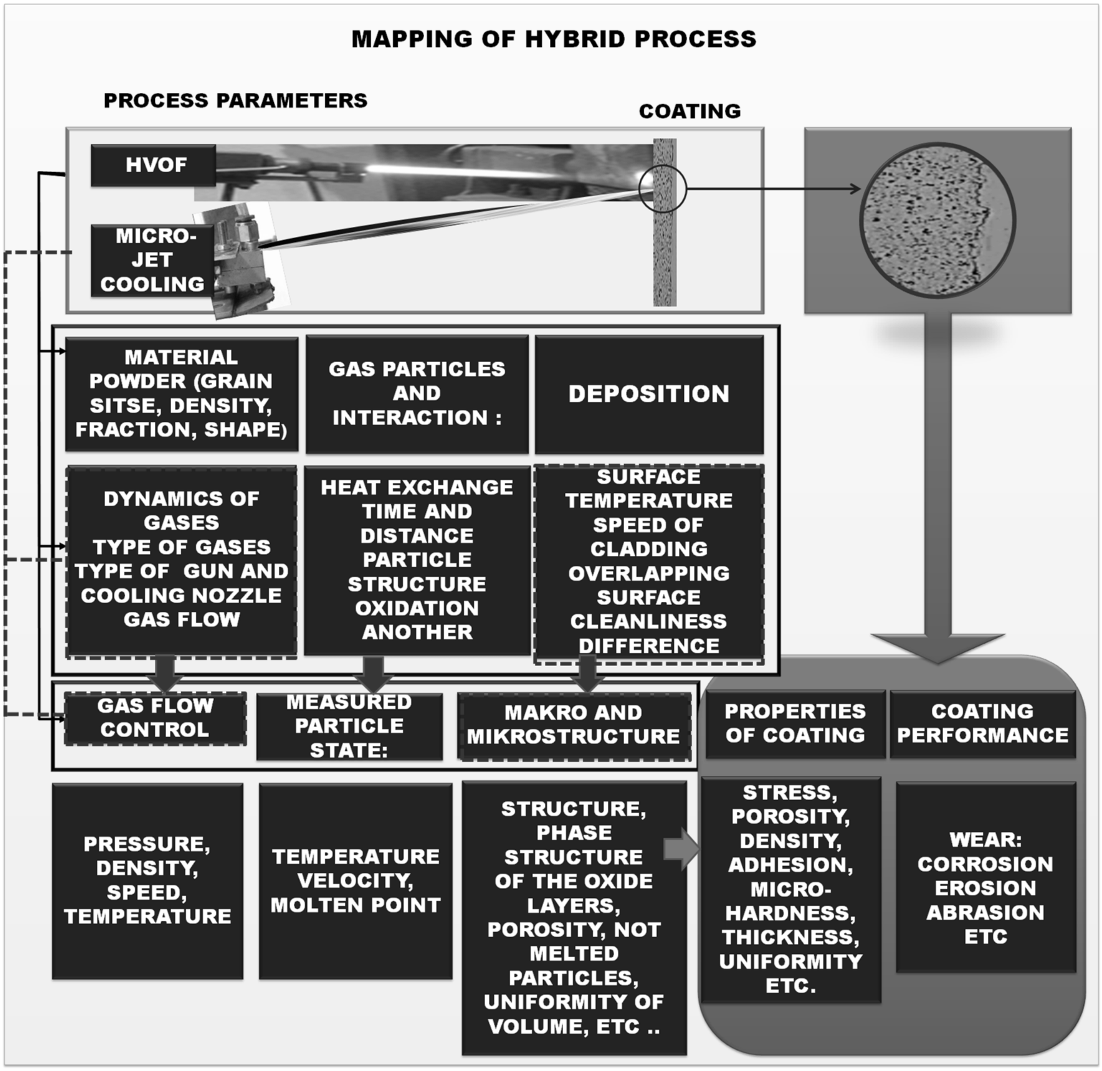

Fig. 5. Designing quality of the coating in hybrid process – system mapping
Source: Own work.

Hybrid method, in fact, uses the phenomenon of heat transfer from the shell by a cooling medium (Fig. 5). Controlled of the structure of a coat enabled the development of its properties. The main factors influencing the useful properties of coatings, such as corrosion resistance and erosion were compactness and uniformity of structure (Fig. 6) and its hardness. A coating of high density (low porosity) and a set of appropriate thickness are having superior corrosion resistance properties as compared to coatings with a more advanced structure with a higher degree of porosity.

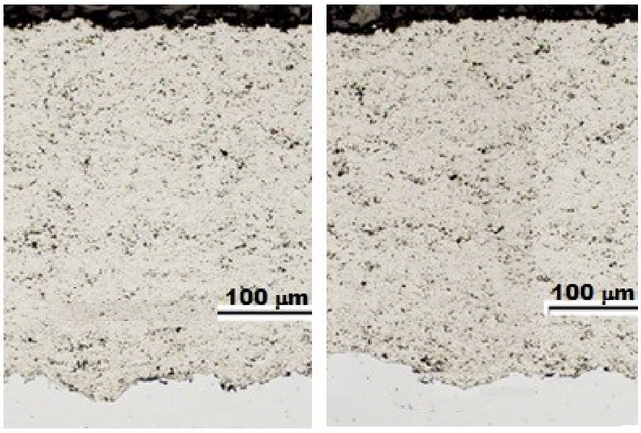

Fig. 6. Selected structure of coatings obtained by hybrid method
Source: Szczucka-Lasota B., Węgrzyn T., Stanik Z., Piwnik J., Sidun P.: Selected parameters of micro-jet cooling gases in hybrid spraying process. "Arch. Metall. Mater.", Vol. 61, No. 2, 2016, p. 621-624.

Therefore, the formed coating, characterized by finely dispersed structure with a porosity of approx. 2% warranted has the correct structure. The appropriate structure of a thickness of 450-500 μm, uniform in volume confirmed the good choose of the process parameters.

Sprayed samples for laboratory tests were prepared to determine their quality parameters. Examples of the results of testing four samples obtained by hybrid shower are presented in Fig. 8 and table 1.

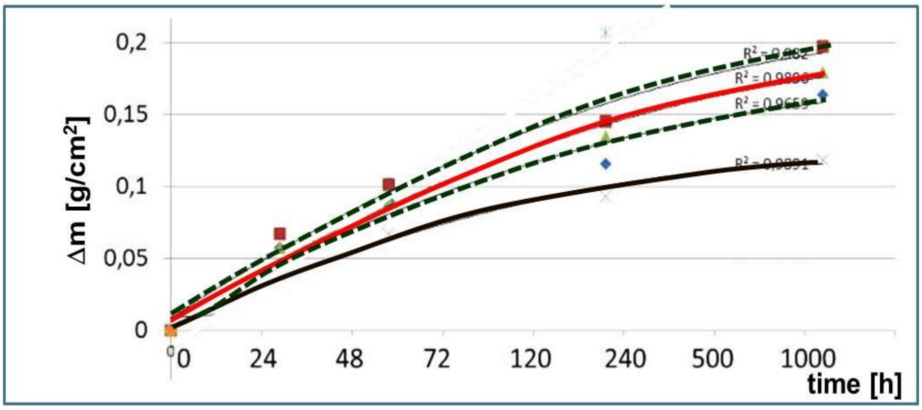

Fig. 8. Mass change of samples obtained by hybrid method – oxidation test 650^{0}C, 1000 h

Table1

The results of the erosion test at high temperature – abrasive corundum, the angle of incidence 30^0

Signify of coating	Erosion test/mass [g]: m_1 (mass of sample before test) m_2 (mass of sample after test)		
	temperature 650^0C		
	m1 [g]	m2 [g]	mI [g] (m1-m2)
Sample 1	35.2431	35.2297	0.01344
Sample 2	34.2672	34.2546	0.01257
Sample 3	34.1107	34.0978	0.01290
Sample 4	35.7413	35.7315	0.00979

The samples were characterized by high resistance to corrosion and erosion. Oxidized in accordance with the parabolic law and tested showed erosive weight changes comparable to literature data about coatings HVOF sprayed using classical system[9]. The results indicate that the high quality of the tested coatings.

It should be noted that in the laboratory is not always possible to use accurate simulation of the conditions of operation in the case of some power equipment. In this case, the usefulness of the coating may only be determined when the exploitation process is monitoring. Especially is it difficult for coatings for use in power boilers incinerating waste, as mentioned in section 3 of the article.

The third phase includes activities related to the adjustment of results of laboratory tests for large-scale production. In this phase, the results must be corrected by empirical research laboratory analysis to ensure adequate capacity and stability of the coating process on a real object. Therefore, the aim is to obtain a sufficient quality of the produced coatings, consistency of results and optimization of the process. Current activities related to the developed hybrid method are at this stage.

Further studies will provide testing coatings on real object, this is called a fourth phase of the coatings control. For coatings produced using hybrid method this stage is planned in 2020.

An important factor taken into account when designing the quality of coatings is that they can be maintained and regenerated. It affects their whole life time and safety of operation until the material is completely consumed. The determination of activities related to the extension of the safe operation of the coating includes the design phase of the fifth.

[9] Moskal G., Swadźba L., Hetmańczyk M. et al.: op.cit., p. 2025-2034.

5. Conclusion

To sum up, the quality of the coating produced using hybrid method depends on: proper selection of coatings for working conditions, the quality of coating materials, methods (proper correlation process HVOF and micro-jet cooling), accuracy and compliance with technological regimes, taking into account the human factor in the performance of coatings and management procedure works repair.

The most important link affecting the quality of the final product remains the man. It depends on it to take the appropriate decision on the selection of materials, equipment and methods of execution, supervision of works and so on. It is also important to exchange experiences and knowledge between colleagues, mutual support during the work.

Hybrid method allows to obtain coatings having high performance of properties. The design, the structure and properties and received resistance to corrosion and erosion under conditions in the conducted tests confirmed high-quality of coatings obtained by using the innovative method. The quality of the process influences on the quality of the final product.

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