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PROPERTIES OF WC–Co–Cr COATINGS, DEPOSITED BY MULTICHAMBER DETONATION DEVICE AND THEIR APPLICATION

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ABSTRACT

Coatings from WC–Co–Cr AMPERIT®554.074 powder were deposited using a multichamber detonation device. Investigations of coating microstructure and phase composition were conducted, using scanning electron microscopy and X-ray structural analysis. Dense coatings form at spraying by this method, which consist of inclusions of tungsten carbide phases, uniformly distributed in Co–Cr matrix. Coating porosity is equal to ~0.2 %, microhardness is 10.4 ± 1.2 GPa. Experience of application of multichamber detonation device for deposition of wear-resistant coatings from WC–Co–Cr powder is shown, both at the stage of part reconditioning and at design of components of various mechanisms.

KEYWORDS: thermal spraying, detonation device, hard alloy, coating, microstructure, wear, porosity, hardness, industrial application

INTRODUCTION

Metal-ceramic coatings, spray-deposited by thermal methods, are an efficient solution of a wide range of problems as regards extension of the service life of parts of machines and various devices [1, 2]. Coatings based on tungsten carbide and chromium carbide are often used to improve the wear resistance in friction pairs, abrasive, corrosion and erosion wear in pumping and compressor and turbine equipment, pipeline and stop valves, parts for pulp and paper, textile and aviation industries, etc. Moreover, spraying of hard alloy coatings is believed to be an alternative to galvanic chrome plating, because of strict environmental standards and problems with consumption during the process of galvanic coating deposition [3]. Metal-ceramic coatings are applied predominantly by high-velocity oxyfuel (HVOF) method and detonation spraying (DS) [4–6], due to lower temperature of powder particles in the combustion product flow and shorter flight time, compared to plasma methods. It allows avoiding a considerable content of brittle phases, as well as lowering of the degree of carbide decomposition during spraying, while preventing a decrease of hardness and wear resistance. In addition, higher particle velocities in high-velocity processes ensure better quality coating with higher cohesion, adhesion, and low porosity. At present, in view of ever growing requirements to the quality of metal-ceramic coatings, work is in progress both on development of the new, and optimization of the current technologies of thermal spraying. Alongside HVOF and DS, such technologies as cold gas-dynamic spraying (CS) and method of high-velocity air-fuel spraying (HVAF) are ever wider used for metal-ceramics deposition [7, 8]. The direction of detonation spraying of metal-ceramic coatings is also developing [9]. As one of the numerous variants of the design of detonation guns for thermal spraying PWI developed a multichamber valveless detonation device (MCDD). The objective of this work is investigation of the microstructure and properties of coatings of WC–Co–Cr system, produced by MCDD, as well as the possibility of its application for coating deposition on products for various industries.

EQUIPMENT, MATERIALS AND PROCEDURES FOR INVESTIGATIONS

WC–Co–Cr powder (86 %–10 %–4 %) (H.C.Stark) with 15–45 μm particles size (AMPERIT®554.074 grade) was used for coating deposition on the surface of 12Kh18N10T steel samples. Investigations of powder microstructure, elemental composition and morphology (Figure 1, Table 1) were conducted in scanning electron microscope QUANTA 200 3D. Energy dispersive X-ray analyzer of EDAX Company, built into the scanning electron microscope, was used to obtain the spectra of the characteristic X-ray radiation of the powder sample surface.

Coatings were sprayed with multichamber detonation device (MCDD) [10]. This device realizes the mode of detonation combustion of a gas mixture in specially profiled chambers. The device is schematically shown in Figure 2.

Accumulation of combustion energy from the two chambers (cylindrical and circular) in the barrel ensures formation of a high-velocity jet of the combustion products, which accelerates and heats the powder

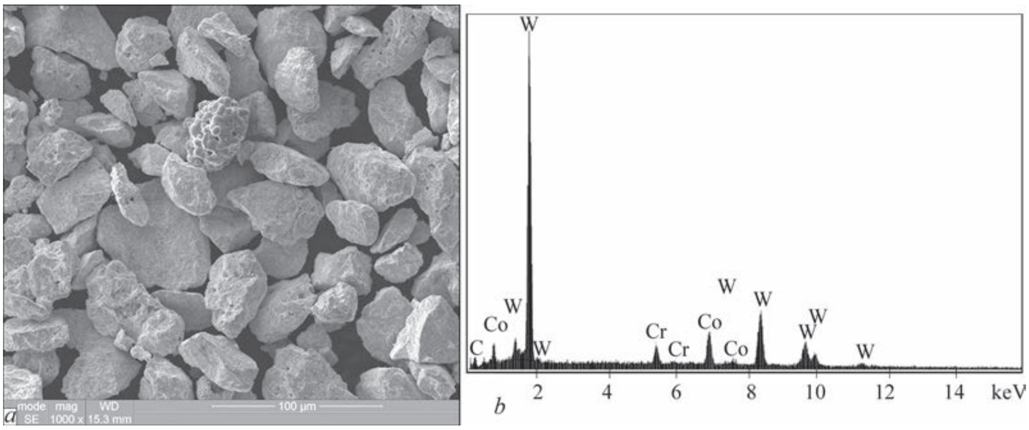

Figure 1. Powder of AMPERIT®554.074 grade: *a* — surface morphology of WC–Co–Cr powder; *b* — spectrum of characteristic X-ray radiation of the powder surface

Table 1. Elemental composition of WC–Co–Cr powder

Powder	Elements, wt.%/at.%			
	C	Cr	Co	W
WC–Co–Cr	4.77/36.94	3.57/6.39	9.60/15.16	82.05/41.51
Note. wt.% is the element weight fraction; at.% is the element atomic fraction.				

being sprayed [11]. In the device a continuous feeding of the combustible gas mixture and powder is realized, which allows initiation of the detonation combustion process at a high frequency of 20 Hz and higher. Figure 3 shows MCDD for spraying of coatings, located in a soundproof box, fitted with equipment for controlling the technological process. The equipment consists of a sprayer, standard powder feeder with feeding of up to 3 kg/h of powder, standard low pressure gas panel (max. 0.3 MPa) for feeding oxygen, propane-butane, air and automated control system.

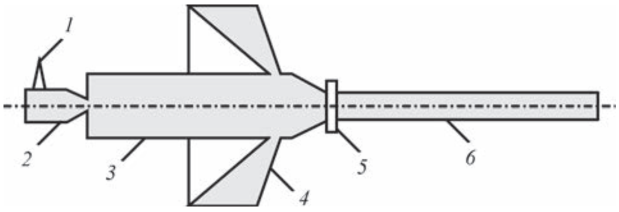

Figure 2. Schematic of a multichamber detonation device; *1* — spark plug; *2* — prechamber; *3* — cylindrical combustion chamber*;* *4* — circular combustion chamber; *5* — powder feed; *6* — barrel

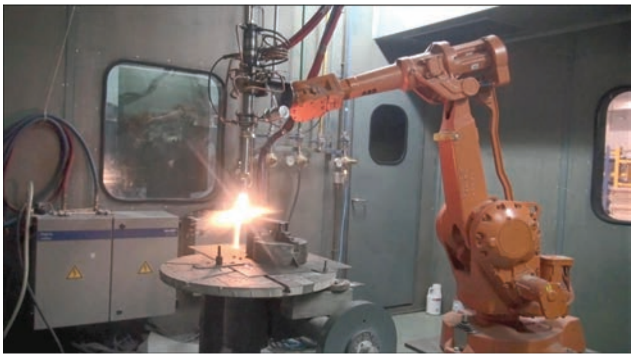

Figure 3. Device for coating deposition using MCDD

During spraying the speed of movement of the sprayed sample relative to the detonation device barrel was equal to 2000 mm/min, distance to the sample was 50 mm, powder consumption was 1/5 kg/h, transport gas flow rate (nitrogen) was 1 m^3/h, detonation frequency was 20 Hz. Table 2 gives the data on consumption of the combustible gas mixture components.

Structural-phase analysis of samples of the powder and sprayed coating from WC–Co–Cr was conducted by X-ray diffraction method in the range of 2θ angles from 20 up to 100° with step-by-step scanning $\Delta(2\theta) = 0.05°$ and 7 s exposure time in the point, using DRON-UM1 diffractometer (in monochromatic CuK_α-radiation, $\lambda = 0.154059$ nm), which provides integral information about a layer of the thickness of several microns. Graphite single crystal was used as a monochromator.

Transverse microsections were prepared to study the powder coatings on samples. Coating microstructure was examined using scanning electron microscope Quanta 200 3D. Porosity was determined by

Table 2. Flow rates of combustible mixture components

Flow rate of combustible mixture components, m^3/h		
Oxygen	Propane (70 %) + butane (30 %)	Air
2.7*/2.6**	0.66*/0.62**	1.7*/1.6**
*Cylindrical combustion chamber. **Circular combustion chamber.		

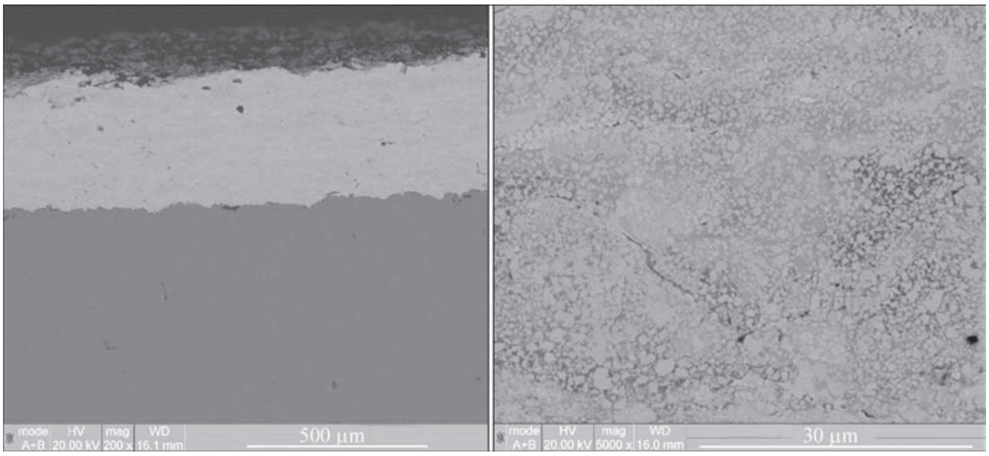

Figure 4. Image (SEM) of transverse microsection of WC–Co–Cr coating

the metallographic method with elements of qualitative and quantitative analysis of pore geometry, using optical inverted microscope Olympus GX51. Volume fraction of pores and structural components was determined using ATLAS software in several fields of vision. Microhardness is determined in keeping with DSTU ISO 6507-1:2007 in M-400 microhardness meter of LECO Company by Vickers test at 300 g load on the indenter.

Wear resistance of WC–Co–Cr coating was studied by tribometry methods using computer-controlled automated friction machine (Tribometer, CSM Instruments) by a standard ball-on-disc testing scheme to ASTM G-99 standard. The sample was mounted in a holder, and a rod was fastened normal to the sample plane, its end carrying a 6 mm dia ball from aluminium oxide. Testing was conducted in air (ambient air temperature of 30 °C, humidity of 23.8 %) at 10 N load and 10 cm/s linear speed, friction path was 1000 m.

INVESTIGATION RESULTS AND DISCUSSION

Figure 4 shows a scanning electron microscopy image at different magnification of surface microstructure of a transverse microsection of a sample with WC–Co–Cr coating.

Thickness of the deposited coatings on the examined samples was equal to approximately 370 ± 10 µm. No cracks or delamination areas were observed on the transverse section images.

Structural studies showed that the coatings consist of uniformly distributed carbide particles of 0.5 to 2 µm diameter and Co-Cr matrix interlayers of up to 1 µm thickness. In the coating micrographs the carbide particles are presented in the form of light-coloured areas with angled edges, unmelted during spraying, accordingly; the gray zone corresponds to the matrix, rich in Co and containing Cr, W and C. Black areas are pores. The histogram of pore size distribution in the coating is given in Figure 5. Porosity of WC–Co–Cr coating is equal to ~0.2 %.

X-ray structural analysis was conducted for a more detailed identification of phases, both in the initial powder and in the coating. X-ray structural analysis of the initial powders revealed that in the initial WC–Co–Cr powder (AMPERIT®554.074 grade, particle size composition of 45 + 15 µm) the main phase is WC (~80 %). Up to 12–14 % of Co_3W_3C phase was also found, its presence being probably related to processes occurring in powder manufacturing (bulk material sintering and sintered sponge grinding). The balance are Co_6W_6C and Co-Cr metal matrix (Figure 6, *a*). Analysis of coating roentgenographs (Figure 6, *b*) deposited using MCDD, showed that structure formation in this case is similar to phase formation processes, occurring when other methods of high-velocity thermal spraying are used [12]. New W_2C (~18 %) and W (~6 %) phases appear in the coating simultaneously with the main WC phase (~60 %). Their presence leads to the conclusion that the processes of WC grain dissolution and decarbonisation take place. During spraying the high-temperature products of detonation combustion heat the powder. Here, the decarbonisa-

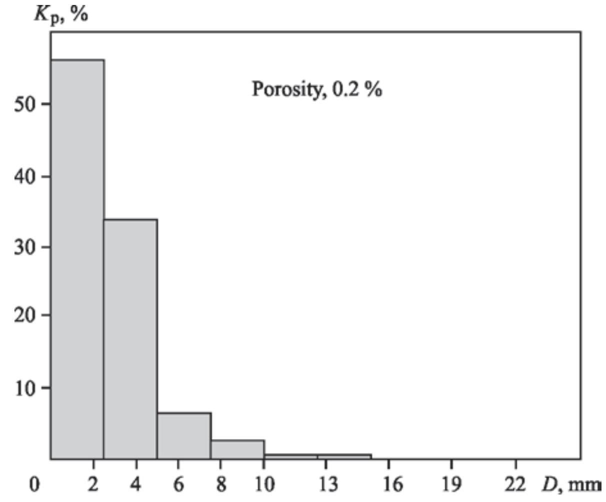

Figure 5. Pore size distribution

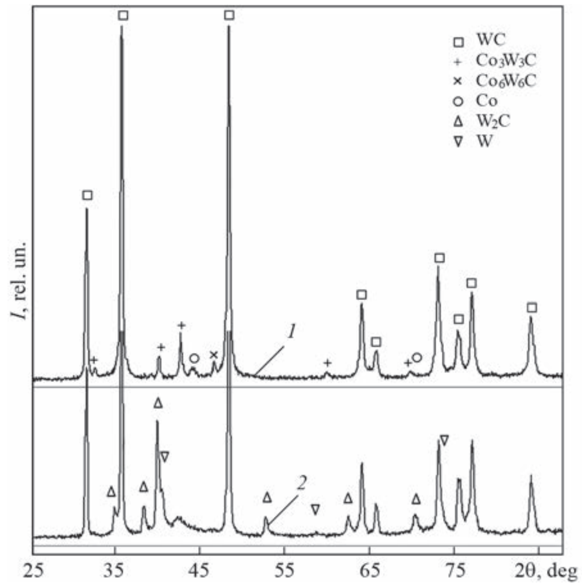

Figure 6. Analysis of coating roentgenograph: *a* — roentgenograph of initial WC–Co–Cr powder; *b* — coating roentgenograph

tion mechanism begins developing from melting of Co–Cr metal binder, as it has a lower melting temperature than that of WC carbides. Here, the boundaries of WC grains begin dissolving in the molten metal. As a result, carbon interacts with oxygen in the combustion products. At the moment of collision with the sample surface, the particles quickly cool down. W_2C layers form in the matrix from the oversaturated solid solution around the existing WC carbide particles. No Co peak (as in the powder) is found in the matrix. Despite the fact that W_2C hardness is higher than that of WC, presence of a more brittle W_2C phase, surrounding the WC particles, leads to lowering of wear resistance [6]. Moreover, enrichment of Co–Cr binding phase by tungsten and carbon increases its hardness and leads to strength decrease. In the roentgenograph a halo is present between angles $2\theta = 37–45°$, which is indicative of the fact that Co–Cr matrix can be in an amorphous-nanocrystalline state, which is determined by high cooling rates, inherent to the spraying process with application MCDD application.

Microhardness measurements were conducted over the entire coating cross-section. Obtained $HV_{0.3} = 10.4 \pm 1.2$ GPa value corresponds to hardness level in the coatings produced by various high-velocity spraying processes [4].

Intensity of wearing of the sample and the counterbody as a result of the conducted friction tests (Figure 7) was evaluated by the following formula:

$$W = V/(Pl),$$

where W is the wear intensity, $mm^3 \cdot n^{-1} \cdot m^{-1}$; V is the removed material volume, mm^3; P is the load, n; l — is the friction path, m.

Testing showed that the friction coefficient is equal to 0.527 ± 0.029 on average. Coating wear rate is $1.125 \cdot 10^{-5}$ $mm^3 \cdot n^{-1} \cdot m^{-1}$, and that of the counterbody is $4.603 \cdot 10^{-6}$ $mm^3 \cdot n^{-1} \cdot m^{-1}$.

EXAMPLES OF INDUSTRIAL APPLICATION OF THE COATING

High physical-mechanical and service properties of coatings from WC–Co–Cr powder, applied by MCDD, were confirmed in practice. For instance, it is rational to apply such coatings for reconditioning of stop valve components: gate valves, ball valves, wedge plugs, etc. (Figure 8, *a*). Metal-ceramic coatings have proven themselves well at reconditioning of parts for pulp and paper industry and polygraphy: scrapers, rollers, traction and support plates, valves and paper drawing shafts (Figure 8, *b*).

Application of metal-ceramic coatings is not limited only to part reconditioning sector. The produced coatings also allow development of fundamentally new engineering solutions for machine parts already at their design stage. As an example, Figure 9 shows parts from light alloys with a wear-resistant coating, spray-deposited by MCDD. WC–Co–Cr coating on

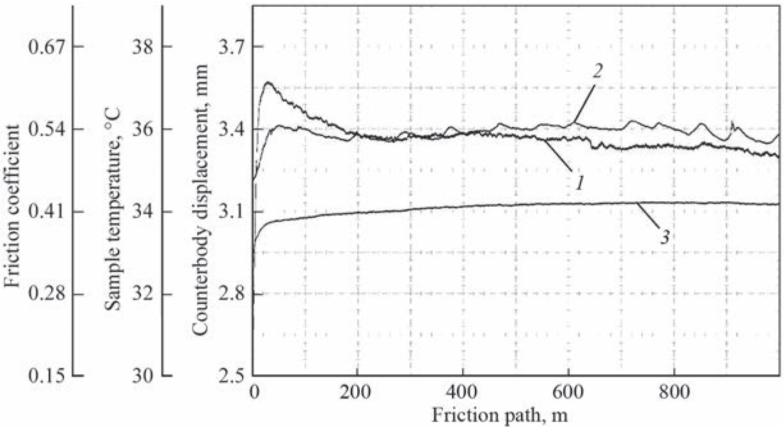

Figure 7. Friction parameters: *1* — friction coefficient; *2* — sample temperature; *3* — counterbody movement in the direction normal to the tested sample surface

Figure 8. Parts with coating from WC–Co–Cr powder: *a* — stop valve parts; *b* — parts for pulp and paper industry and polygraphy

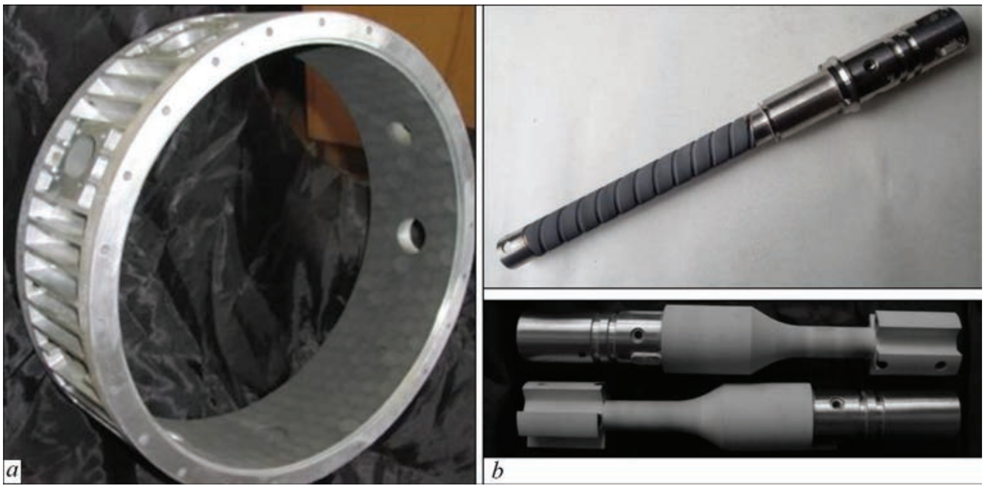

Figure 9. Light alloy parts: *a* — rotary piston engine housing; *b* — drill telemetry parts

the inner surface of rotary piston engine housing from an aluminium alloy allowed a considerable extension of its service life at weight reduction. Fulfilment of this condition is one of the most important elements during design of light flying vehicles. Application of a hard-alloy coating on titanium parts for drilling telemetry is geodesy enabled protecting them for intensive hydroabrasive wear and thus increasing the period between rather costly repair-adjustment operations.

Several examples of application of hard alloy coatings are considered. Now the range of problems solved is rather large and it is constantly expanded. Detonation spraying methods are also improved, and new samples of equipment are developed, which opens up new prospects and technology application spheres.

CONCLUSIONS

A multichamber detonation device was used to realize high-velocity thermal deposition of coatings from WC–Co–Cr powders.

X-ray diffraction analysis showed that coating formation with MCDD application is accompanied by the processes of partial decarbonisation of the carbides and formation of hard, but brittle phases, which is also characteristic for other HVOF and detonation methods of coating deposition, which are widely accepted.

Hardness of the produced coatings of $HV_{0.3} = 10.4 \pm 1.2$ GPa and low porosity of ~0.2 % allow their application for prevention of abrasive, corrosion and erosion wear of the surfaces of various parts of machines and plants.

The effectiveness of WC–Co–Cr coatings deposited with MCDD application on the parts of various industrial devices has been confirmed by their practical application.

REFERENCES

1. Ang, A.S.M., Howse, H., Wade, S.A. et. al. (2016) Development of processing windows for HVOF carbide-based coatings. *J. of Thermal Spray Technol.*, **25**, 28–35. DOI: https://doi.org/10.1007/s11666-015-0318-z
2. Berger, L.M. (2015) Application of hardmetals as thermal spray coatings. *Int. J. of Refractory Metals and Hard Materials*, **49**, 350–364. DOI: https://doi.org/10.1016/j.ijrmhm.2014.09.029
3. Sun, B., Fukanuma, H., Ohno, N. (2013) Investigation and characterization of HVAF WC–Co–Cr coatings and comparison to galvanic hard chrome coatings. In: *Proc. of the Inter. Thermal Spray Conf. 2013 (May 13–15, 2013, Busan, Republic of Korea)*, 389–394.
4. Borisov, Yu.S., Astakhov, E.A., Murashov, A.P. et al. (2015) Investigation of structure and properties of thermal coatings of WC–Co–Cr system produced by high-velocity methods of spraying. *The Paton Welding J.*, **10**, 25–28. DOI: https://doi.org/10.15407/tpwj2015.10.04
5. Singh, L., Chawla, V., Grewal, J.S. (2012) A review on detonation gun sprayed coatings. *J. of Minerals and Materials Characterization and Engineering*, 11(**03**), 243. DOI: http://dx.doi.org/10.4236/jmmce.2012.113019
6. Picas, J.A., Punset, M., Baile, M.T. et. al. (2009) Properties of WC–Co–Cr based coatings deposited by different HVOF thermal spray processes. *Plasma Processes and Polymers*, **6**, 948–953. DOI: https://doi.org/10.1002/ppap.200932402
7. Torkashvand, K., Gupta, M., Björklund, S. et. al. (2021) Influence of nozzle configuration and particle size on characteristics and sliding wear behavior of HVAF-sprayed WC–Co–Cr coatings. *Surf. and Coat. Technol.*, **423**, 127585. DOI: https://doi.org/10.1016/j.surfcoat.2021.127585
8. Granata, M., Gautier di Confiengo, G., Bellucci, F. (2022) High-pressure cold spray coatings for aircraft brakes application. *Metals*, 12(**10**), 1558. DOI: https://doi.org/10.3390/met12101558
9. Bamola, R., Ewell, T., Robinson, P. et. al. (2016) Coatings deposited using a valve-less detonation system. In: *Proc. of the Int. Thermal Spray Conf. 2016 (May 10–12, 2016, Shanghai, P.R. China)*, 127–131. DOI: https://doi.org/10.31399/asm.cp.itsc2016p0127
10. Tyurin, Yu.M., Kolisnichenko, O.V. (2008) *Method of detonation spraying of coatings and device for its realization*. Pat. 8383, Ukraine.
11. 11.Kolisnichenko, O.V., Tyurin, Yu.N., Tovbin, R. (2017) Efficiency of process of coating spraying using multichamber detonation unit. *The Paton Welding J.*, **10**, 18–23. DOI: https://doi.org/10.15407/tpwj2017.10.03
12. Garfias Bulnes, A., Albaladejo Fuentes, V., Garcia Cano, I. et. al. (2020) Understanding the influence of high velocity thermal spray techniques on the properties of different anti-wear WC-based coatings. *Coatings*, 10(**12**), 1157. DOI: https://doi.org/10.3390/coatings10121157

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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