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B. SZCZUCKA-LASOTA*

INNOVATION IN THE PROCESS OF THERMAL SPRAYING COATINGS

In this paper, the hybrid method connects the ultrasonic spraying method with a injector of complex cooling micro-jet system is presented. The use of properly constructed injector allows for local and selective cooling of the coating structure immediately after spraying process. The construction of injector is the subject of patent in Polen. The presented new technology gives practical possibility of control of coatings structure. This is the kind of positive feedback between the technology process and obtained product (the quality of the process increases the quality of the final product). The initial experimental investigations, presented in this paper, show, that the obtained coatings structure is: fine-dispersion of the grain, with a lower porosity, good compactness and adhesion to the substrate.

Keywords: control structure of the coating, local and selective cooling, hybrid method

1. Introduction

The study noted the lack of a holistic view and incompleteness of publications on the possibility of structure control by the using coatings technology. Based on published results, it can be concluded, that the obtained coatings have got different properties, despite the similar chemical composition . The decisive role played [1-8]:

1. the phase composition of coatings and compared the percentage of individual phases
2. the obtained structure of coatings materials.

At first, the energy (supplied during the spraying process) forms a kind of phases in the coating material. The technology of spraying has got significant role in the forming process.

Secondly, the registered differences in the properties of the materials with the same phase composition are the results of the construction structure (porosity, compactness, density, uniformity). The structure is shaped during the manufacturing and determined directly by the spraying technology. It can be conclude, that the coating technology influences the properties of coatings primarily by shaping its structure. Based on the presented results, it can be say, that: *controlled regulation of structure through the technology can improve the utility properties of coating*, for example a resistance of the coating on the type of wear.

The coatings technology's for applications in complex corrosion and erosive conditions include: supersonic, ARC and plasma spraying methods. Supersonic processes — especially HVOF (High velocity oxy-fuel) spraying and they modifications — are the preferred methods for producing coating with low porosity and high density and good adhesion.

The main modifications of the process are: [5-14]:

- reduce the diameter of guns, that accelerate the movement of particles of spraying materials.
- spraying at high speed in gases to obtaining layers of lower porosity, like HVAF- High Velocity Air Fuel method, etc. (The differences between modifications of HVOF systems are presented in Table 1.)
- the use of additional equipment in order to turn the process of cooling the surface, e.g. using the new instrumentation of cooling system, like micro-jet injector [11-14]. It is the most promising new modification of spraying coatings technology. The type of injector is mounted as a part of equipment of new hybrid spraying method. The design of micro-jet injector is patented in Polen.

TABLE 1

HVOF systems - the differences between gun generations [5-6]

Type of gun design:	**Gas velocity related to the sonic speed**	**Power level (kW) of total heat Output**	**Chamber pressure (bar)**	**Ability to spray Kg/h**
Straight (1st generation)	maximum of 1 Mach	80	3 - 5	2 - 6
de Laval (2nd generation)	over 1 Mach	80-120	5 - 10	2 - 10
de Laval (3rd generation)	over 1 Mach	100-300	8 - 25	10 - 12

* UNIVERSITY OF OCCUPATIONAL SAFETY MANAGEMENT ,8 BANKOWA STR., 40-007 KATOWICE, POLAND

Corresponding author: bszczucka-losota@wszop.edu.pl

Until now, the system was used only for welding technologies [15-21]. The latest national and international research publications contained findings and information, that indicate, that the cooling system of micro-jet gives the ability to control the structure and can be successfully used in automated thermal spray technologies of coatings [1-6].

The new thermally spraying method allows to modification of the classical technology of thermal spraying coatings, such as HVOF, HVAF, ARC. The jets injector allows to obtain coatings in a shorter time than in conventional spray methods. These coatings have a dense structure, low porosity and good adhesion to the substrate, and comparable or better properties, such as corrosion, corrosion - erosion and abrasive resistance at the high or elevated temperature [1-12]. The structure is a result of high speed of particle spraying and the micro-jet cooling system. The system provides accurate, local, selective cooling (Fig.1.).

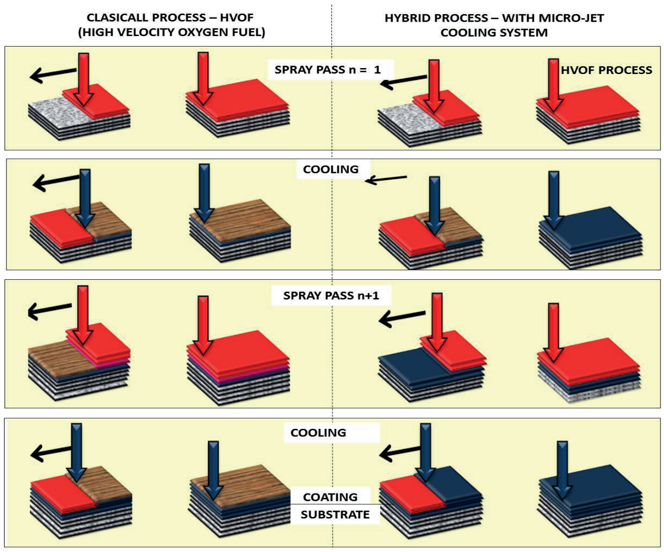


Fig. 1. Scheme of cooling process in: classical HVOF and hybrid method

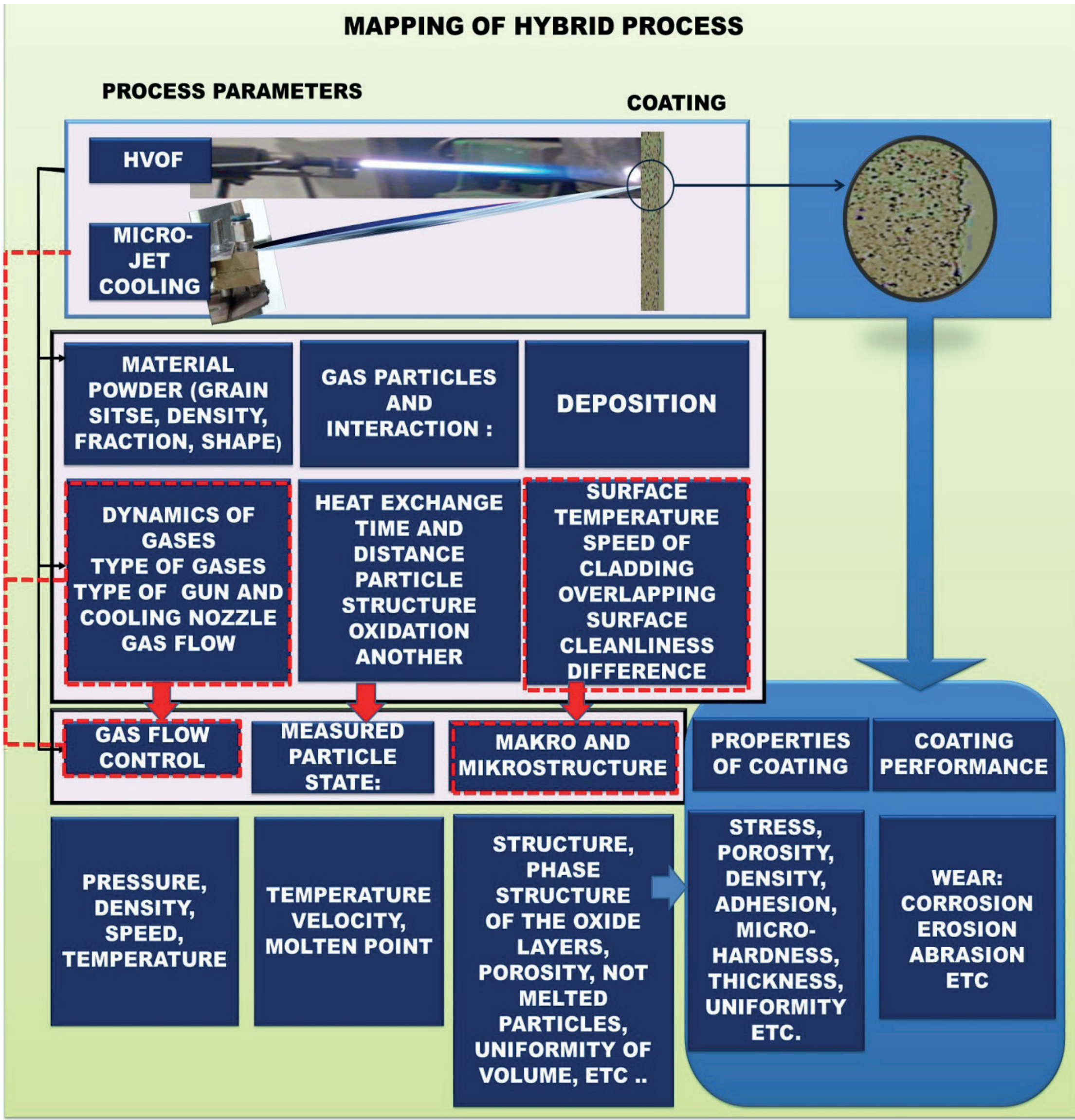


Fig. 2. Mapping of hybrid process to obtaining wear resistance coating - scheme bases on [2]

The aim of the study is to update knowledge on the use of modern spraying methods to achieve structure with high corrosion resistance properties (Fig.1). It was assumed, that such possibility gives innovative hybrid method with cooling micro-jet system [6-10].

The author wants to present the possibility of using the micro-jets system as the modification of HVOF coating spraying technology.

2. Research materials and methods

The material to research were thermally sprayed coating by the innovative process. In the work, the HVOF process was selected as the most prospective method for the obtaining protective coating protecting large areas of power construction (Fig.3.)

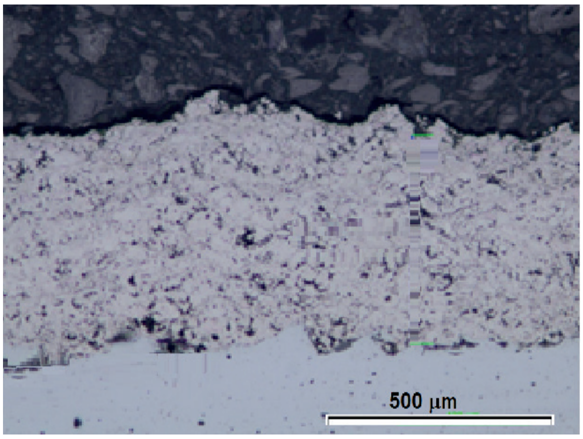
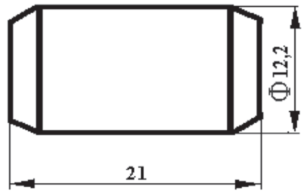


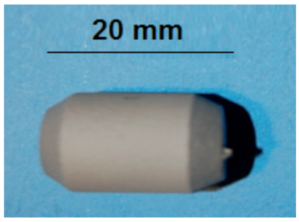
Fig. 3. HVOF spraying system and structure of coating [12]

The method was modified using micro-jet system. It was assumed, that the regulation of the properties of the obtained materials is available only using specialized installation of hybrid spray nozzle and the unique construction of the micro-jets. The selection of cooling parameters require unconventional methods of measuring able to determine precisely the intensity of heat exchange between the substrate and the cooling micro-jet. For the cooling process were chosen nozzle: type A 40. The nozzle had god the diameter of 40 mm. The another type of nozzle is not recommended for this process, what was confirmed in the reconnaissance investigation, presented in [12]. Too intense cooling during the process caused exfoliation or cracks in the coating, the result was presented in [12]. The used gas was nitrogen, it was selected based on literature data, presented in [11,13-14].

The powders materials were sprayed on the corrosion resistance steel rollers (Fig.4). In a single pass was obtained the layer with a thickness of 1 mm . The speed of the gun with micro-jet nozzle regard to the sample was about of 0.5 [m/s]. The distance between the gun and the surface of metal was about of 25 [cm].



a)



b)

Fig. 4. Example of the samples to research a) dimensions of samples b) view on the surface of coating obtained by hybrid system

The gun with cooling injector was located at a distance of 0.3 ± 0.03 [m] from the sample surface. The parameters of base - HVOF process were consistent with the manufacturer's instructions for the powder materials. According to the procedure, the speed of gases was above of 2000 [m/s]. Current parameters of thermally sprayed process were: voltage in the range of 25÷30 [V] and the intensity of 150÷250 [A]. The obtained structure (presented in Fig 4 - Chapter 4) was investigated. The plan of investigation included:

- define the macro and microstructure of the obtained coatings by the LM (light microscopy) and SEM (scanning electron microscope) method
- determine the chemical composition of the coating by the SEM with the detection of X-ray analysis.
- measurement of micro-hardness (TH170 micro-hardness tester)
- measurement of thickness (thickness gage)
- determine selected tribological properties of the obtaining coatings (abrasion test on T07 stand; two erosion tests under load 200 g in ambient and elevated temperature)
- oxidation test at elevated temperature. The kinetics test of the coatings' mass change was carried out by periodic oxidation method. The exposure time of test was 500 hours. The materials was heating to the 6500 C, annealing in the temperature during 24, 48, 72… hours and cooling after the test time.

3. Results and discussion

The results indicate that the technology allows to obtain the correct micro-structures using micro-jet cooling system in the shorter time, than in the HVOF process. The cooling reduced the time between spraying operation of about 50 %. Result can be explained by the facts that:

- The surface – layer is precisely and selectively cooling immediately after spraying process (Scheme - Fig.1, Chapter 1)
- The new hybrid spraying method with micro-jet cooling shows to reduce thermal fluctuations during spray operations (Fig.5)

The pores in the structure, registered by program Hitachi (EDX), are of about 1.04 % (TABLE 2). The compactness and uniformity structure is confirmed that the hybrid method enables the preparation of coatings with the desired density structure. The structure is finely dispersed and it is comparable to the microstructure obtained by HVAF system, presented in the publication [7]. The structure is slightly better than the HVOF coating structure showed in Fig. 3. The selected properties of obtained coatings are presented in (Fig.6-7 and Table 2).

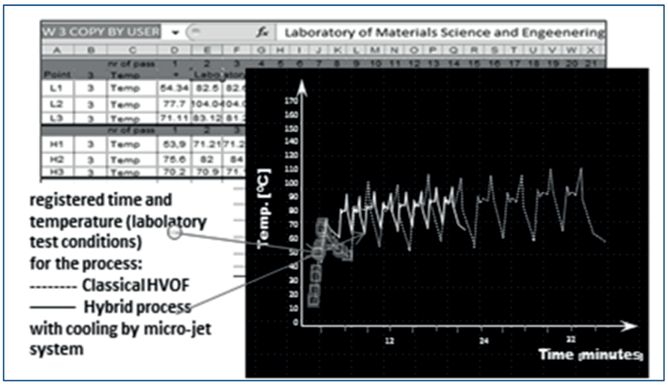


Fig. 5. The reduce thermal fluctuations during spray operations in laboratory test

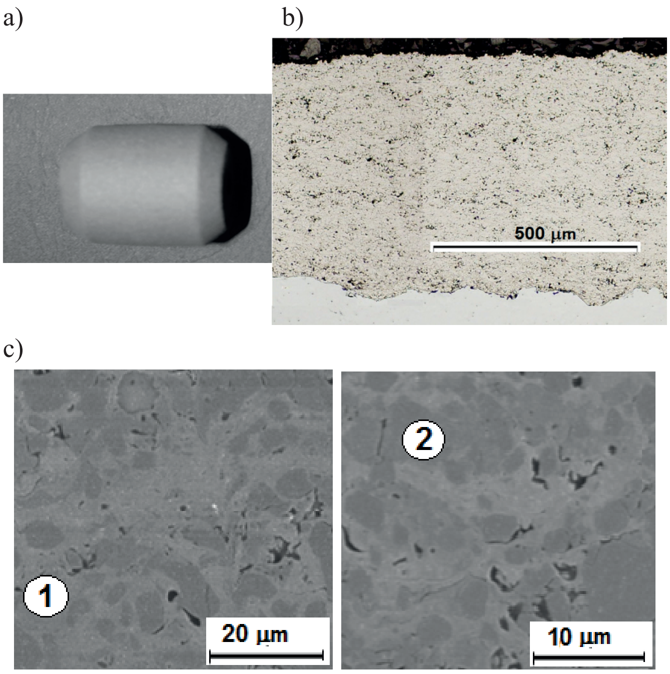


Fig. 6. a) View on the surface and b) microstructure c) morfology of coating sprayed by hybrid system with injector type A40 – Sample B

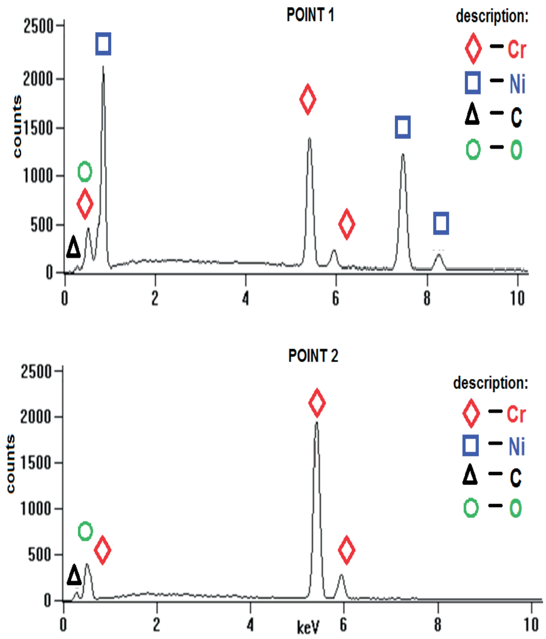


Fig. 7. X-ray spectrum from an energy dispersive (EDS) for the coating presented in Fig.6c

TABLE 2

Selected properties of coatings

Materials signify	Microhardness [μHV100]	Thickness [mm]	Porosity [%]
Sample 1	979 ± 56	545 ± 23	1,04 ± 0,1
Sample 2	982 ± 43	547 ± 18	1,02 ± 01

TABLE 3

Abrasion resistance of coatings

Sample:	Abrasion resistance [g]: m_1 (mass of sample bevor test) m_2 (mass of sample after test)		
	m_1 [g]	m_2[g]	δ m= m_1-m_2 [g]
Sample 1	28.19586	28.15023	0.04563
Sample 2	34.44527	34.39854	0.04673

TABLE 4

Erosion resistance of coatings at ambient temperature - 20° C

Sample	Erosion resistance [g] at ambient temperature					
	m_1 [g] (mass of sample bevor test)	m_2[g] (mass of sample after 1 test)	δmI (m_2-m_1) [g]	m_3[g] (mass of sample after 2 tests)	δm_{II}[g] (m_3-m_2)	Δm[g] (δm_I+ δm_{II})
Sample 1	28.2061	28.2122	0.0061	28.2718	0.05963	0.0611
Sample 2	34.5201	34.5263	0.0062	34.5934	0.06710	0.0609

TABLE 5
Erosion resistance of coatings at elevated temperature - 650° C

Sample	Erosion resistance [g] at elevated temperature (650° C)		
	m_1[g] mass of sample bevor test	m_2[g] mass of sample after test	Δm[g] (m_2-m_1)
Sample 1	49,9426	49,9888	0,0464
Sample 2	49.8824	49,9289	0,0465

The tribological properties of the coatings, presented in Table 3-5, indicate good resistance to abrasive and erosive wear of materials obtained by hybrid method. In this case, the micro-jet is suitably designed injector for spraying the coating process.

TABLE 5
Erosion resistance of coatings at elevated temperature - 650° C

Sample	Erosion resistance [g] at elevated temperature (650° C)		
	m_1[g] mass of sample bevor test	m_2[g] mass of sample after test	Δm[g] (m_2-m_1)
Sample 1	49,9426	49,9888	0,0464
Sample 2	49.8824	49,9289	0,0465

The oxidation resistance of obtained coating is good. The mass changes as a function of the heating time are presented in Fig.8. The mass change of the all studied composite coatings obtained by hybrid method is comparable and the oxidation process of these materials obeys parabolic rate law . The cracks on the surface after the corrosion process are not observed (Fig.8 a).

b)

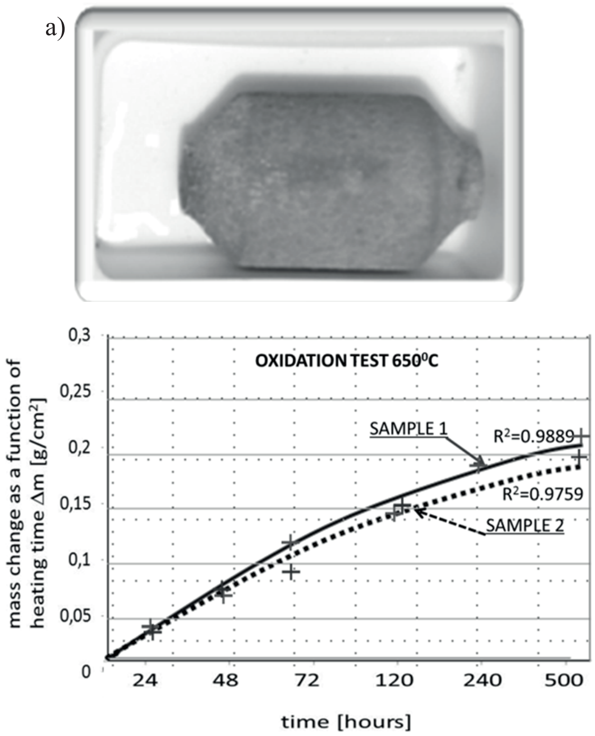


Fig. 8. a) View on the surface after oxidation test b) the mass change as a result of heating time in 650° C

Good properties of materials are the result from the construction of the coating structure (good density and low porosity). The obtained structure was determined by the hybrid technology.

The new technology combines the speed of spraying with cooling precision. The precision of cooling provides for obtaining compact and fine-grained structure thereby it influences the resistance properties of materials.

4. Conclusion

It can be concluded, that the micro-jet cooling was a very good modyfication of HVOF process to obtained high protective coatings. The presented and analyzed result showed that the coating obtained by hybrid spraying method had got the correct structure with a thickness of about 550 mm. Testing of micro-jet-cooled coatings, presented in this paper and in [2-5] showed substraty hardness and microporosity improvement over HVOF sprayed coatings samples, while bond strength, coating microhardness, and abrasion resistance of the hybrid-sprayed coatings were essentially unchanged.

As a result of the hybrid process, the coating structure was a finely dispersed with very low porosity. The result translated into high corrosion resistance properties of investigated materials. Comparison of the results with literature data indicates, that the structure of coating was proper and comparable to the structures of coatings obtained by HVAF (high velocity air fuel) method, but the obtained structure was better, than the HVOF structure of coatings. The microstructure, wear resistance and mechanical properties of micro-jet cooled coatings were tested and proved to be as good as or better than those of sprayed by classically HVOF method. The properties of coatings sprayed by hybrid method were comparable with HVAF sprayed coatings.

Hybrid method, combining thermal spraying and micro-jets cooling represents the modern coating technology, characterized by exceptional precision.

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REFERENCES

[1] B. Wielage, H. Pokhmurska, M. Student, V. Gvozdeckii, T. Stupnyckyj, V. Pokhmurskii, Surf. Coat. Tech. **220**, 27-35 (2013).
[2] M. Oksa, E. Turunen , T. Suhonen, T. Varis, S. P. Hannula, Coats, **1**, 17-52 (2011).
[3] Y. Song, L. Z. Lv, Y. Liu, X. Zhuan, T. J. Wang, Appl. Surf.

Sci., **324**,1,627–633(2015).
[4] I.A. Gorlach, R&D J. S Afr.Inst. Mech. Eng., **24** (3), (2008).
[5] P. Fauchais, A. Vardelle, Thermal Sprayed Coatings Used Against Corrosion and Corrosive Wear, Advanced Plasma Spray Applications, in: H. Jazi (Ed.), InTech, 2012.
[6] http://www.intechopen.com/books/advanced-plasma-spray-applications/thermal-sprayed-coatings-usedagainst-corrosion-and-corrosive-wear
[7] K. Szymański, A. Hernas, G. Moskal, H. Myalska, Surf. Coat. Tech. (2014) DOI:10.1016/j.surfcoat.2014.10.046 (in press).
[8] L. Chang–Jiiu, Y. Guan–Jun, Int. J. Refract. Met. Hard. Mater. **39**, 2-7 (2013).
[9] H. Myalska, G. Moskal, K. Szymański, Surf. Coat. Tech. **260**, 303-309 (2014).
[10] A. Hernas (Ed.), The processes of destruction and protective coatings used in power industry, 2015 Racibórz, Polska.
[11] B. Szczucka–Lasota, W. Majewski, AMR, **1036**, 152-157(2014).
[12] B. Szczucka–Lasota, K. Szymański, Solid State Phenom., **226**,193-198 (2015).
[13] R. Ghosh, Spraytime,**14** (4),2-4(2007).
[14] Z. Zurecki, R. Ghosh, T. Mebrahtu, M.J. Thayer, S.R. Stringer, in: E. Lugscheider (Ed.), Air Products & Chemicals, 2008 Maastricht, Netherlands.
[15] L. Thakur, N. Arora, R. Jayaganthan, R. Sood, Appl. Surf. Sci. **258**, 1225–1234, (2011).
[16] T. Węgrzyn, J. Piwnik, J. Wieszała, D. Hadryś, Arch. Metall. Mater, **57**, 3679-685 (2012).
[17] W. Tarasiuk, B. Szczucka–Lasota, J. Piwnik, W. Majewski, AMR, **1036**, 452-457(2014).
[18] T. Węgrzyn, T. Piwnik, J. Wieszała, D. Hadryś , Arch. Metall. Mater, **57**, 3, (2012) 679-685
[19] T. Węgrzyn, J. Piwnik, J. Łazarz, D. Hadryś, Arch. Metall. Mater, **58** (2) 551-553 (2013).
[20] T. Węgrzyn, J. Piwnik, D. Hadryś, Arch. Metall. Mater, **58** (4),1067-1070 (2013).
[21] A. P. Wang, Z.M. Wang, J. Zhang, J.Q. Wang, J. Alloys Compd. **440**, 225–228 (2007).