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The wear resistance of thermal spray the tungsten and chromium carbides coatings

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Properties

ABSTRACT

Purpose: The objective of the work concerns of wear-resistance of different kinds of thermal spray coatings covering industrial fun blades. The coatings were sprayed onto the fun blades by Plasma Spraying and High Velocity Oxygen Fuel Spraying (HVOF) methods. The Cr_3C_2, WC and also its compositions were sprayed into the fun blades. The coatings were tested in industry conditions and the effect of influence of centrifugation industry emissions on the stage of the wearing after the exploitation was compared for deposited coatings.
Design/methodology/approach: The investigations of coating microstructures by optical microscopy (MO) and transmission electron microscopy (TEM) were performed. The examination of fun blades after the exploitation and the analysis of the obtained results was correlated with the performed microstructure observations and microhardness data of coatings.
Findings: The microstructures of Cr and W carbides coatings were observed and analyzed. The microhardness of the sprayed coatings was compared. The coatings were evaluated from the point of view resistance against the wear.
Practical implications: The performed investigations provide information, which kind of carbide coatings characterize the most wear resistance in the industrial conditions.
Originality/value: It was assumed that HFOV coats have more uniform microstructure, higher microhardness, which could suggests better resistance against the wear and grindability.
Keywords: Plasma sprayed; High velocity oxy-fuel technique; Wear resistant coats; Cr_3C_2 and WC carbide coatings

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1. Introduction

The different coating technologies nowadays are more often applied to the surface covering of intermediate products and industrial goods [1, 2]. The wear resistant coats can be deposited by the physical vapour deposition technologies (PVD) [3-6]. This method is especially used for tools coating. The titanium aluminium nitride, chromium carbides coatings are by this technique easily deposited on different substrates. The main limitation of PVD is the size of a vacuum chamber, which restricted the size of coating elements. Therefore the techniques commonly used in the industry conditions are the plasma sprayed methods [1, 7, 8].

Thermal spraying methods are a well-established processes and preferred technique for deposition of corrosion, wear protection, and thermal barrier coatings [9]. Using the High Velocity Oxy-Fuel (HVOF) method the coatings with low porosity, high hardness and microstructure with small or nanograins is possible to obtained.

The coatings have very high bond strengths, fine as-sprayed surface finishes and low oxide levels [1]. Coatings from chromium and tungsten carbides are very often used in the industry conditions for protection against the wear and erosion [10]. Opposite to HVOF, plasma sprayed coats showed larger porosity, the existence of more not molten droplets and oxides [8]. Coatings consist of lamellas elongated in the direction parallel to the coating surface. Plasma spraying and HVOF method have been successfully used to produce different kinds of coatings on the alumina substrates [9].

The resistance against wear and erosion depends on the thickness of the coatings [10] and also on its hardness [11]. The presented in the work [12] results proof that the spray powder size distribution can strongly influence on the erosion-corrosion properties. It was also found that the diminishing of spraying powder size leads to the diminishing of grain size and contributes to the increase of wear resistance. The similar results was presented in the work [13]. The results of the work [14] show higher friction coefficient of about 20-30% and higher hardness of about 20% for nanocrystalline coats in comparison to Cr_3C_2 (25Ni20Cr) coats with the conventional size of grains. The obtained results suggest that refinement of coats microstructure favour higher resistance against wear. The nanometric coats contained less porosity but more oxidation, which are connected with the larger amount of grain boundaries. Larger amount of high energy grain boundary area of nano-powders tend to melt more easily and it causes a decreasing roughness of coated surface. Sidhu at al. [14]. The increase of hardness and smoothness of the coatings the better resistance against the wear and abrasion could be expected.

In the presented work the chromium and tungsten carbide coatings deposited onto the fun blades by Plasma Spraying and HVOF methods were investigated. The microstructure and hardness of coatings were examined before the exploitation in the industrial conditions. The defects of the fun blades, covered by the deposited coatings, appearing as the result of the wear abrasion during the rotor work in the industry conditions were investigated.

2. Experimental basis

The High Velocity Oxy-Fuel spraying (HVOF) and Plasma Sprayed techniques were used for coats spraying. The HVOF deposition parameters are presented in the Table 1. The Plasma Spraying parameters are presented in Table 2. The thickness of HVOF coatings was found of about 300 + 80 µm. In the case of the Plasma Spraying samples the thickness of coating was found of about 300+/- 20 µm.

Table 1.
HVOF spraying deposition parameters

	O_2 l/min	Kerosene l/h	N_2 l/min	Distance mm	Powder g/min
HVOF	944	25.5	9.5	370	92

The Table 3 contained chemical composition of seven investigated in the work coatings. The composition of coatings consisting from NiCrBSi, chromium and tungsten carbide and its mixtures or with the carbides with the addition of CrC, Ni, Co and Cr powders. The coatings were sprayed on the AlSi substrate.

Table 2.
Plasma Spraying deposition parameters

	Ar l/h	Voltage V	Current A	Distance mm
Plasma Spraying	3000	52	500	90

Table 3.
The chemical composition of deposited coatings

No	Chemical composition of coating	Deposition method
1	WC-Co-Cr	HVOF
2	WC-Co	HVOF
3	WC-Co+15% NiCrBSi	Plasma Spraying
4	WC-Co-CrC-Ni	HVOF
5	Cr_3C_2-NiCr	Plasma Spraying
6	NiCrBSi	HVOF
7	Cr_3C_2-NiCr	HVOF

The WC-Co-Cr coating (sample No 1), WC-Co (No 2), WC-Co-CrC-Ni (No 4) composite coating NiCrBSi (No 6) and Cr_3C_2 coating with the intermediate layers of NiAl (sample No 7) are sprayed by using High Velocity Oxy-Fuel method The spraying distance of 370 mm and gun speed 35 m/min were used. The special vibratory disc feeder CPF-2 Thermico firm, allowing feeding of powders with very low granulation 10-2 µm with the precision. ±2%, was used.

The sample No 3, consisting from the mixture of WC-Co + NiCrBSi and sample No 5 – Cr_3C_2-NiCr are deposited by the Plasma Spraying method. The plasma sprayed 80% Cr_3C_2 – 20% NiCr (wt%) coats were prepared by MIM40 device. The argon 3000 l/h and hydrogen 873 l/min were used for melting powders particles before their impact onto the substrate. The spraying distance of 90 mm and gun speed 25 m/min were used. The deposition of coatings was performed in enterprise Plasma System S.A., Siemianowice Śląskie, Poland.

The following powders were using for HVOF and Plasma Spraying deposition:

- 95% (WC-Co 88-12 -30+5 µm; WC 1 – 0.5 µm, agglomerating and sintering) +5% (Ni17Cr4Fe4Si3.5B1C Speroidal, Gas atomized, nanopowder);
- 73%(WC) + 20(CrC) + 7%Ni -45+15 agglomerating and sintering; WC – 1 µm ; .CrC 1 µm +5%(Ni17Cr4Fe4Si3.5B1C Speroidal, Gas atomized, nanopowder);
- 3%(WC) + 20(Cr_3C_2) + 7%Ni -45+15 agglomerating and sintering, WC – 1 µm; Ni17Cr4Fe3,5B4Si1C, grain size: -20+2 µm;
- 86%WC-10%Co-4%Cr, grain size:10+2 µm ; WC, grain size: 0.5-0.2 µm.

The microstructure of all coatings was studied by Olympus GX50 optical microscopy. Thin foils prepared from samples by the cross section technique were observed by JEOL 2010 ARB transmission electron microscopy with the Energy Disperse Spectrometer (EDS) for identification of chemical composition in microareas of layers. The microhardness of coats was measured by using PMT3 microhardness tester at load 200 G.

The samples to light microscopy observations were polished mechanically applied Struers equipment and technique. They were grinded, than polished in diamond pastes and in the suspension OPS. Thin foils, for TEM investigations, were prepared from cross sections by cutting grinding and ion sputtering, using Struers and Gatan instruments.

3. Investigation results

The microstructures of deposited coatings, observed by application of optical microscopy are presented in Figures 1-7. The characteristic feature of the observed coatings is strong refinement of their microstructures. The coatings contained different phases, which can be distinguished by the diversification of the microstructure contrast. The good adherence of coatings were found. There are any discontinuities between the substrate and coatings. The roughness of substrate contributes to the better adhesion of deposited coatings and is necessary in the thermal coatings technologies. It was found that in some places the silicon particles appeared in the contact places between the substrate and coatings.

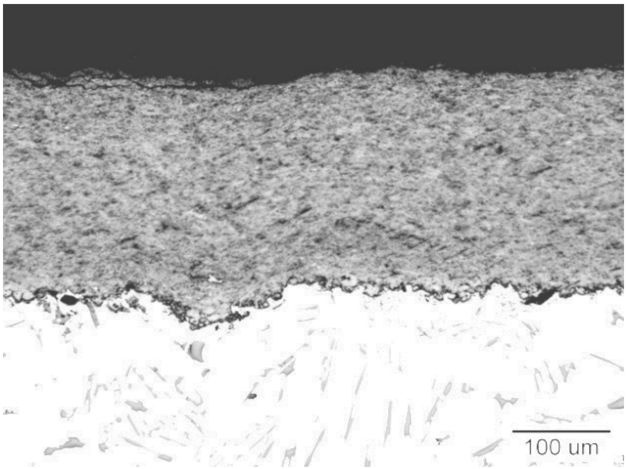

Fig. 1. WC-Co-Cr, HVOF deposition, optical microscopy observation

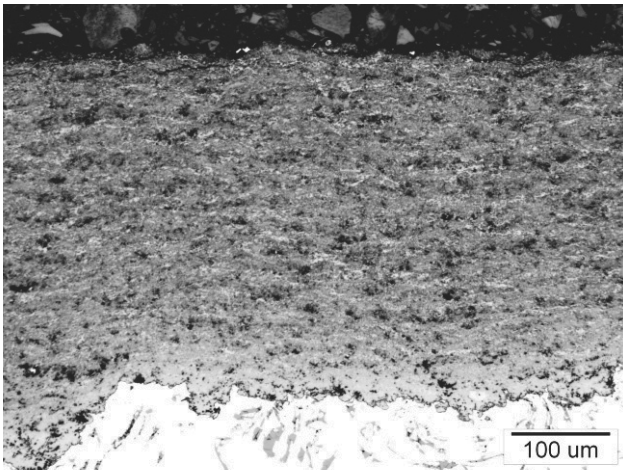

Fig. 2. WC-Co, sample No 2, HVOF deposition, optical microscopy observation

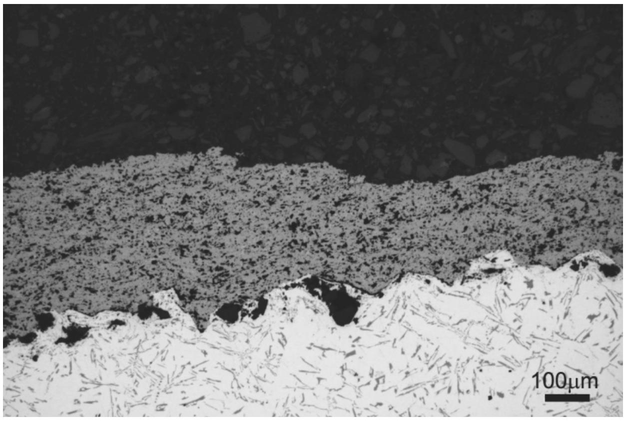

Fig. 3. WC-Co + 5% NiCrBSi, sample No 3, Plasma Spraying, optical microscopy observation

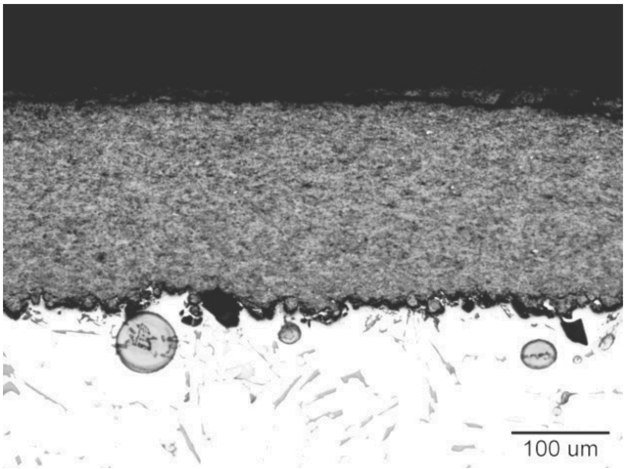

Fig. 4. WC-Co-CrC-Ni, sample No 4, HVOF deposition, optical microscopy observation

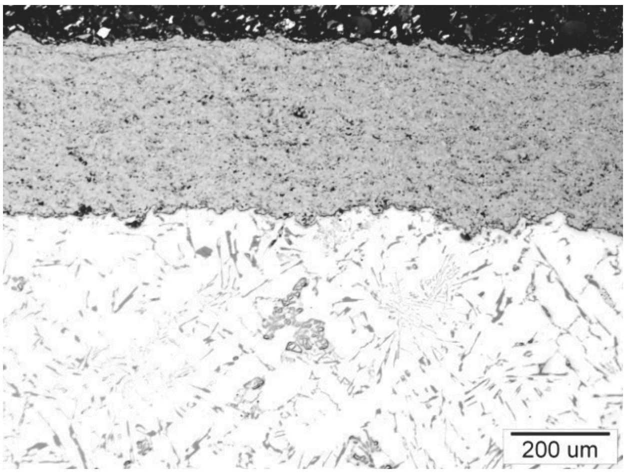

Fig. 5. Cr_3C_2-NiCr, sample No 5, Plasma Spraying, optical microscopy observation

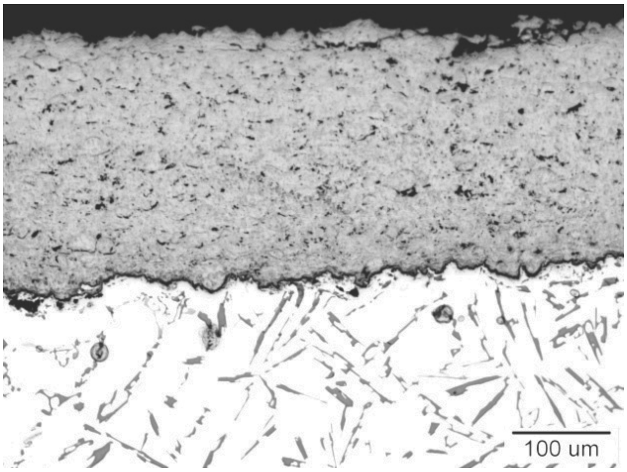

Fig. 6. NiCrBSi composite, sample No 6, HVOF deposition, optical microscopy observation

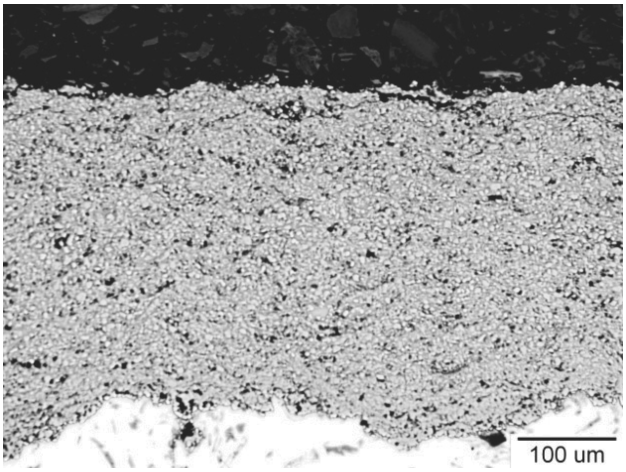

Fig. 7. Cr3C2 – NiCr, sample No 7, HVOF deposition, optical microscopy

Transmission electron microscopy investigations of deposited coatings are presented in Fig. 8 to Fig. 14. Respectively the microstructures of: WC-Co-Cr (HVOF), Fig. 8; WC-Co (HVOF), Fig. 9; WC-Co + 5%NiCrSiB (Plasma Spraying), Fig. 10; WC-Co-CrC-Ni (HVOF), Fig. 11; Cr_3C_2-NiCr (Plasma Spraying), Fig. 12; NiCrBSi (HVOF), Fig. 13 and Cr_3C_2-NiCr (HVOF), Fig. 14 are shown.

The molecules of the impacted droplets were observed at very high magnifications. The dimension of the molecules differs and is smaller in HVOF coatings (Figs. 8, 11) in comparison to the Plasma Sprayed coatings (Fig. 12). In the HVOF deposited WC carbide microstructures, containing addition of the NiCrSiB phase column microstructure was observed (Fig. 10, Fig. 13). Columns progress is clearly visible independently to the molecules size. In the WC-Co +5%NiCrSiB coating (Fig. 10) molecules are much smaller than in the NiCrSiB composite (Fig. 13). The molecules are directly distributed along the direction of column progress. This phenomenon is especially clearly visible in the Plasma Spraying NiCrSiB coating (Fig. 10).

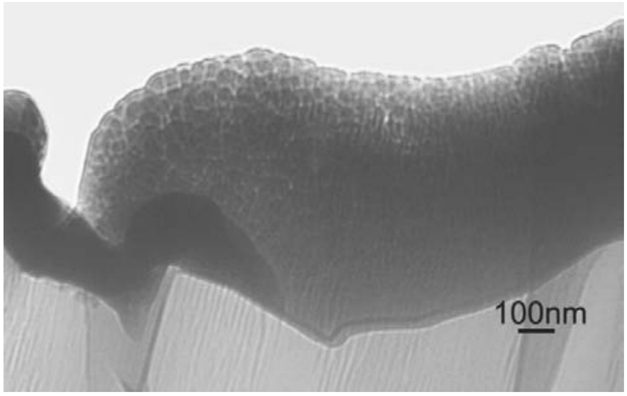

Fig. 8. WC-Co-Cr coating (TEM), sample No 1, HVOF

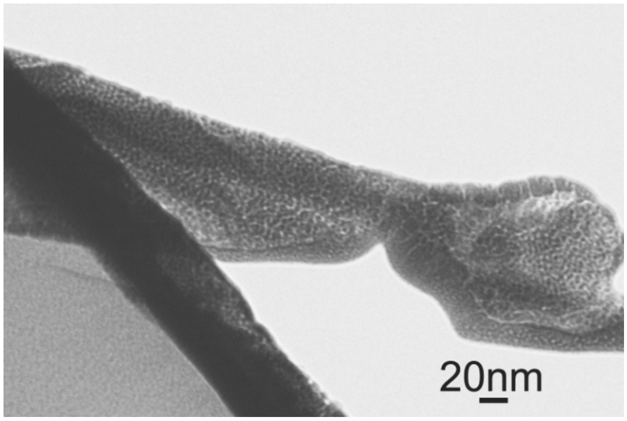

Fig. 9. WC-Co coating (TEM), sample No 2, HVOF

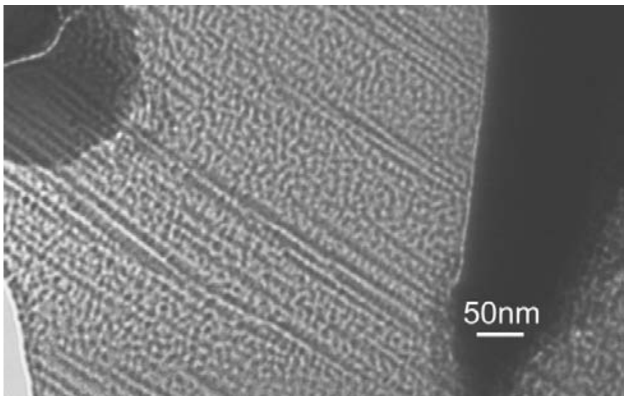

Fig. 10. WC-Co +5%NiCrSiB, TEM, sample No 3, Plasma Spraying

The microstructure of carbide coatings deposited by the HVOF technique has nanometric features. The WC-Co coating contained molecules below 20 nm (Fig. 9). The similar dimension of molecules, uniformly distributed inside the coating revealed WC-Co-CrC-Ni (Fig. 11). Larger molecules of about 50 nm are observed inside the WC-Co-Cr coating deposited by HVOF (Fig. 8).

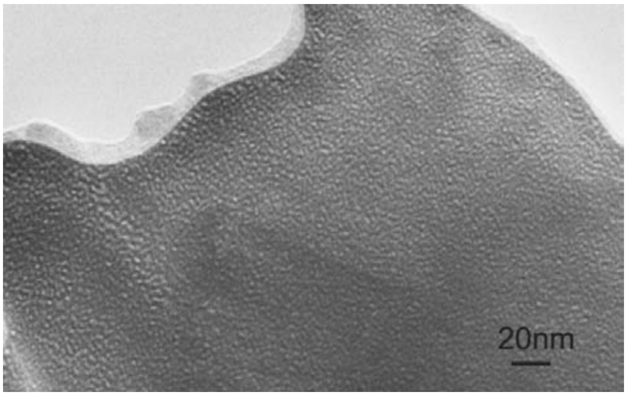

Fig. 11. WC-Co-CrC-Ni, TEM, sample No 4, HVOF

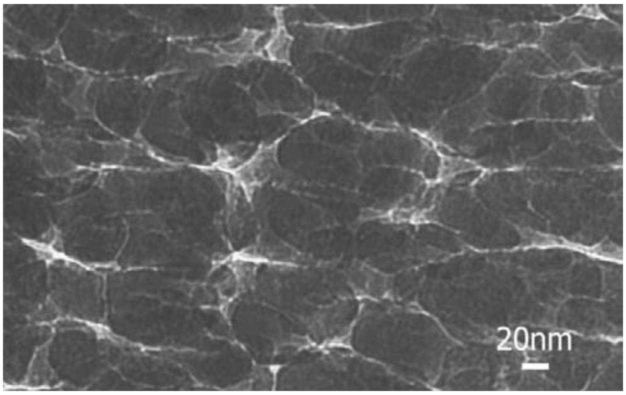

Fig. 12. Cr_3C_2-NiCr, TEM, sample No 5, Plasma Spraying

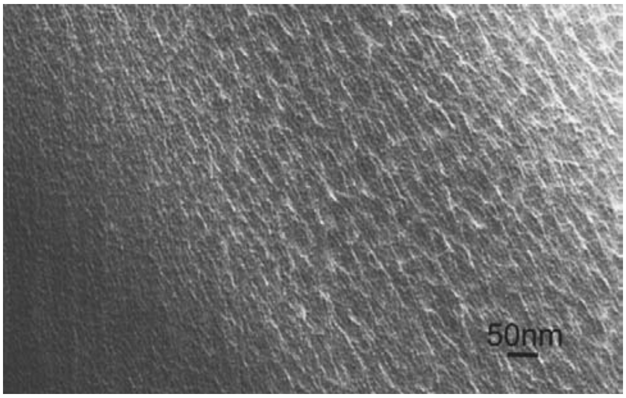

Fig. 13. NiCrBSi, TEM, Sample No 6, HVOF

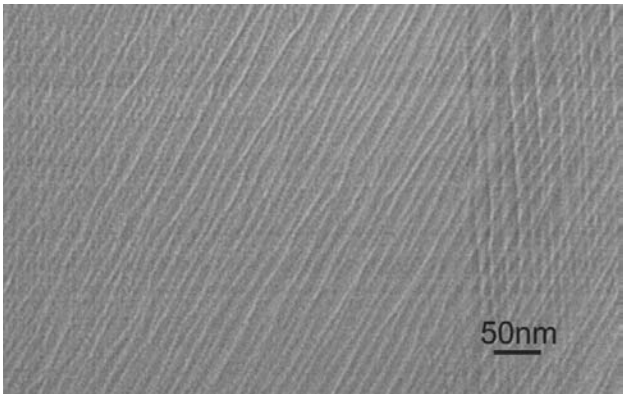

Fig. 14. Cr_3C_2-NiCr, TEM, Sample No 7, HVOF

The chromium carbide microstructure strongly depends on the thermal spraying technique. In the case of HVOF deposition the refinement of microstructure is such larger that it is impossible to distinguish the molecules (Fig. 14). The column microstructure was observed with the changeably direction of column propagation. Characteristic was the appearance of a few family of columns with the different propagation directions. The areas of mutually crossing columns were observed.

The Cr_3C_2 coating deposited by Plasma Spraying process revealed loose connected molecules, with microvoids between the grains of about 50 nm in dimension (Fig. 12).

The microhardness of deposited coatings is presented in Fig. 15. The highest level of microhardness characterize WC-Co-Cr coating. The lowest one Cr_3C_2-NiCr. Both coatings were deposited by HVOF technique. The coatings differ chemical composition and it is the main reason of the finding microhardness differences.

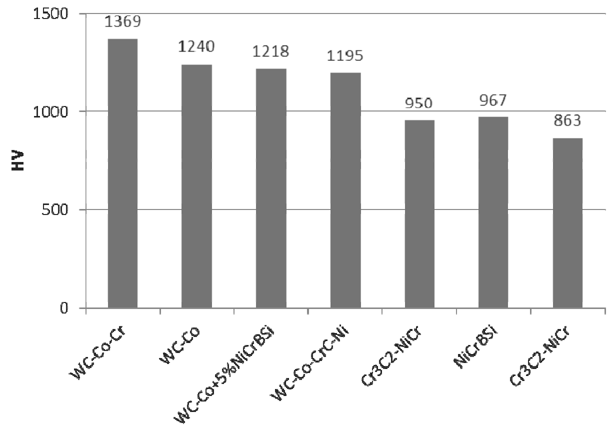

Fig. 15. Microhardness of sprayed coatings

The influence of molecules size on the microhardness level is no crucial, which could be evaluate by the comparison of molecules observed in Fig. 12 – Cr_3C_2-NiCr, TEM, sample No 5, μHV = 950, Plasma Spraying and molecules visible in Fig. 14 – Cr_3C_2-NiCr, TEM, sample No 7, HVOF – μHV = 863. The size of molecules in Fig. 12 is higher that observed in Fig. 14.

The coatings presented in Table 3 were sprayed on the fun blades of rotor working in the furniture industry. The dust damages the fun blades consists from the filings MDF, wool and MDF dust, iron filings of tools. There are hard conditions for fun working. The seven blades were covered by seven chosen coatings compositions. The every blade works in the same conditions.

After the industry testing every rotor fun blade was detail observed and the changes and damages of coating were evaluate and documented.

The observations show deep furrows at the bottom of every blade in contact surface with the base (Fig. 16). The damages of the active surface of blades have form of cuts, furrows or grinders. The whole surface of some coatings was damage, as it is presented especially in Fig. 17, Fig. 19, Fig. 21 and Fig. 22. The defects characterize dark contrast clearly visible in Figures 17-23. Every blades show failure of the frontal part, besides the blade No 4, which exhibit the least failure in this place (Fig. 20).

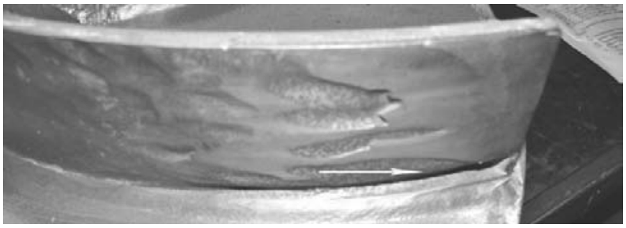

Fig. 16. Deep furrow at the bottom of the blade indicated by arrow

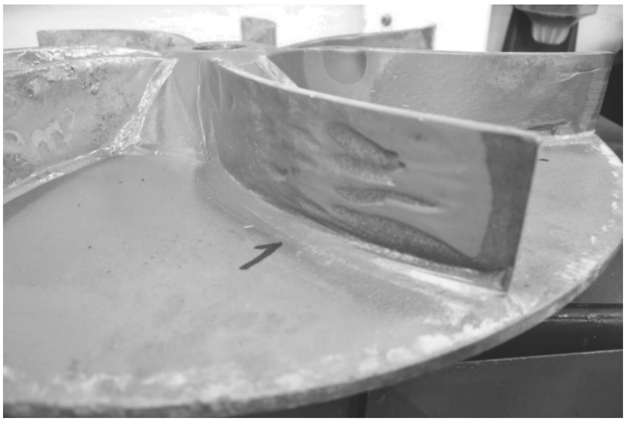

Fig. 17. Wear erosion of fun blade covered by the coating WC-Co-Cr (HVOF), μHV = 1369

During the evaluation of the quality of fun blades coatings after their exploitation it was established that least damage blades pass the test successfully. The analysis of fun blades surfaces after the exploitation allows to determine the best coatings (No 2, No 4 and No 7). They have respectively the following chemical composition and microhardness: No 2 – WC-Co (HVOF), μHV = 1240; No 4 – WC-Co-CrC-Ni (HVOF), μHV = 1195 and No 7 – Cr_3C_2-NiCr (HVOF), μHV = 863. The coating No 4 exhibited the best surface between the blades classified as the best, and shows the least failures.

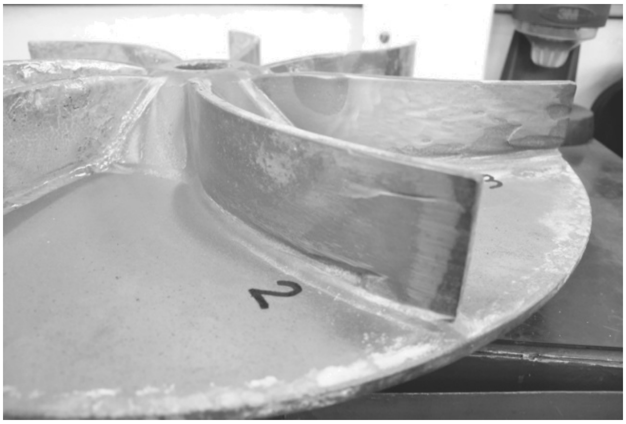

Fig. 18. Wear erosion of fun blade covered by the coating WC-Co (HVOF), μHV = 1240

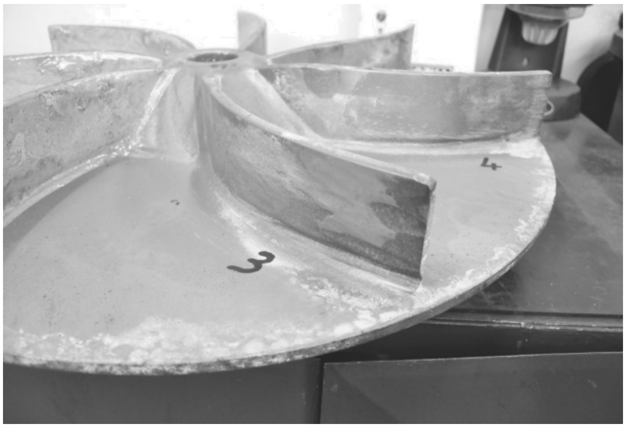

Fig. 19. Wear erosion of fun blade covered by the coating WC-Co +5%NiCrSiB (Plasma Spraying), μHV = 1218

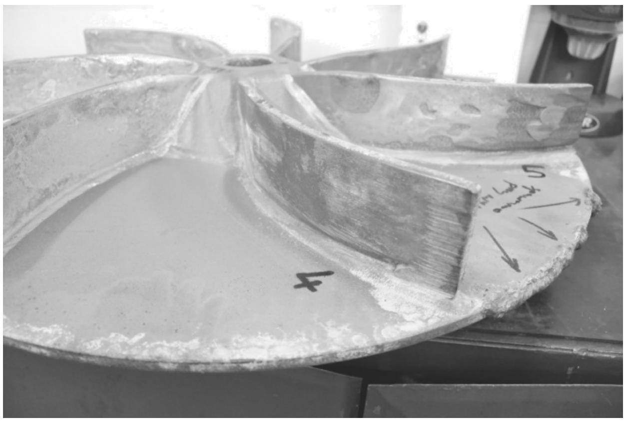

Fig. 20. Wear erosion of fun blade covered by the coating WC-Co-CrC-Ni (HVOF), μHV = 1195

Fig. 21. Wear erosion of fun blade covered by the coating Cr_3C_2-NiCr (Plasma Spraying), μHV = 950

Fig. 22. Wear erosion of fun blade covered by the coating NiCrBSi (HVOF), μHV = 967

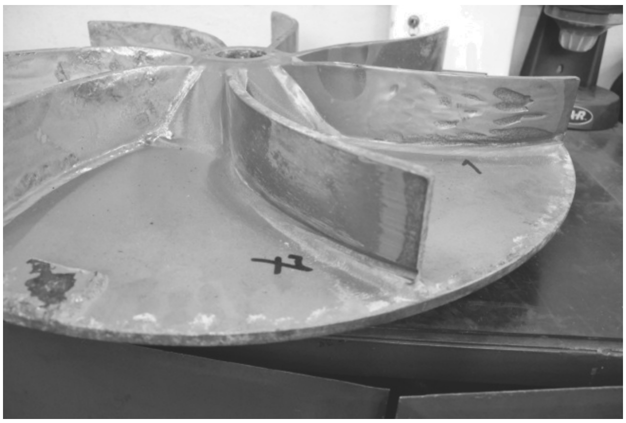

Fig. 23. Wear erosion of fun blade covered by the coating Cr_3C_2-NiCr (HVOF), μHV = 863

The best coatings deposited on the blades No 2, No 4 and No 7 characterize the large refinement of microstructure, about which proofs examples presented in Fig. 9, Fig. 11 and Fig. 14. The size of molecules observed by TEM technique is below 20 nm. This result indicated that the deposited coatings have nanometric microstructure. Nanometric coatings were deposited by HVOF method of thermal spraying, which confirm possibility of nanostructure coating by this technique [15].

Industrial testing of rotor gives very interesting result, which proofs that the refinement of microstructure coatings to the nanometric dimensions determinately influence on the wear resistance. The influence of the microhardness level on the wear resistance was no such important as the influence of microstructure refinement. The wear resistance strongly depends on the smoothness of the coating surface [16, 17], which becomes better if the size of grains/molecules becomes lesser. From this point of view the refinement of coating microstructure strongly influence on their wear properties of thermal spraying fun blades.

4. Summary

The presented investigations concerns industrial testing of the thermal sprayed coatings covering the fun blades working in the furniture industry. The air contained sharp and hard laminate wood filings, wood filings, dust, cuttings of furniture's and others was centrifugation. The rotor of fun working with speed of about 3000 revolutions per minute (r.p.m.). The fun worked during two and half of month. After this time the coatings were evaluate by visual inspection. The defects and incisions were examined. The performed investigations allowed to choose the coatings exhibited the best surface after the exploitation. It was: No 2 – WC-Co (HVOF), μHV = 1240; No 4 – WC-Co-CrC-Ni (HVOF), μHV = 1195 and No 7 – Cr_3C_2-NiCr (HVOF), μHV = 863. The highest rating obtained the coating No 4 – WC-Co-CrC-Ni (HVOF), μHV = 1195, sprayed by the HVOF technology, which showed the least defects.

The coating No 4 (Fig. 15). belongs to the group of WC-Co coatings exhibited microhardness higher than Cr_3C_2 coating group. The level of the coating No 4 microhardness is not the highest from the obtained results. However the analysis of microstructure of coating No 4 indicated the largest refinement of molecules, which dimension is below 20 nm (Fig. 11). Additionally the microstructure of coating No 4 is very uniform results from the existence of the random molecules distribution. It should advantageously influence on the surface smoothness.

In comparison to this, the columns microstructure, which size of molecules is comparable or even lower than in coating No 4, observed in coatings No 3 and No 7, creates the directional distribution of molecules, which can unfavourably influence on the surface smoothness.

The week dependence of wear resistant on the microhardness level implicates for searching the other reasons of resistance against the wear of the deposited coatings. Some data suggests that the wear mechanisms depending on the roughness of the coating face [16, 17].

The obtained results indirectly confirm this suggestion and indicate that the wear resistance is complicated mechanism and depends not only from the hardness but also from the state of the coating surface and its internal microstructure. Especially it was found that the refinement of microstructure to the nanometric dimensions favourably influence on the wear resistance.

5. Conclusions

The High Velocity Oxy-Fuel sprayed coats show more uniform and fine grained microstructure than plasma sprayed coats.

The microhardness of WC-Co carbide coats placed above 1000 μHV, and chromium carbide coats below 1000 μHV.

The wear resistant strongly depends on the internal microstructure of coatings. The nanometric features contributes to the increase of surface smoothness of coatings and increase the resistance against the wear.

Acknowledgements

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