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Investigation of wear resistance of high velocity oxy-fuel sprayed WC-Co and Cr_3C_2-NiCr coatings

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1. Introduction

High velocity oxy-fuel (HVOF) flame spraying is used for producing high quality carbide coatings. This method represents a major development in thermal-spray technology [1, 2]. HVOF sprayed metallic coatings often have properties superior to those of plasma-sprayed ones and equal to or superior to the coatings produced using the detonation method. It is also a competing technology to several other surface modification technologies, e.g. the replacement of hard chromium coatings. The HVOF sprayed coatings are still under intensive discussion.

The cermet powders compounded from carbides and metallic binder are highly suitable for HVOF spraying [3, 4]. The most often applied materials for thermal sprayed layers are the materials with WC or Cr_3C_2 and different metal matrix (Co, CoCr, NiCr). WC-Co layers show high wear resistance. The hard WC particles in the coatings lead to high coating hardness and high wear resistance, while the metal binder (Co, Ni, or CoCr) supplies the necessary coating toughness [5, 6].

Tungsten carbide-cobalt based spray coatings are widely used in industry for the applications requiring abrasion, sliding, fretting and erosion resistance [7, 8]. High wear resistance and also the resistance to corrosion and high temperatures show the Cr_3C_2-NiCr coatings [3].

Coating properties are influenced not only by the properties of the used powders but also significantly by the used spray process and spray parameters [4, 8, 9]. The technology of thermal spraying determines the microstructure of coating. Corrosion-erosion resistance of WC-Co and Cr_3C_2-NiCr coatings in relation with their morphology were performed in [6, 7], mechanical properties of WC-Co coatings, processed with different thermal spray guns, was investigated in [8, 9], but tribological studies linked with the microstructure are undervalued.

Wear resistance of cermet coatings is connected with single lamellae and strength of single carbides [5, 10, 11]. Wear resistance of cermet coatings is influenced by optimal dimension of carbides or hard phases in matrix, better distribution of carbides and by suitable micro and macro structures. Discontinuities, such as pores, thermal-stress induced cracks, oxide lamellas or incompletely molten spray particles, can be considered as initial micro cracks, usually associated with brittle damage of chromium carbides [11, 12].

The comparative investigations of wear mechanisms and interrelationship to wear particles formation were carried out for WC-Co and Cr_3C_2-NiCr coatings. These materials generally show high wear resistance, in the case of WC-Co coating the resistance is established up to the temperature of approximately 500°C and Cr_3C_2-NiCr wear resistance sustains up to the temperature approximately of 850°C. Triboparticles of wear formed under friction process could be the source of valuable information on wear mechanism. Rubbing, cutting, and severe sliding wear are the few examples of wear particles formation.

The goal of this study was to compare two different thermal spray coatings deposited by HVOF method on wear resistance during dry sliding. The method of formation of thermally sprayed coatings has great influence on their microstructure and therefore, the applied methods of thermally spraying have to be in synergy with the wear mechanisms of coatings. Consequently the influence of microstructure on the wear resistance of HVOF coatings and also the relationship of the microstructure and the wear debris formation was analysed.

2. Testing procedures

For the experimental tests thermally sprayed coatings (cermet coating WC-Co and Cr_3C_2-NiCr) were selected. The coatings were deposited by HVOF method from commercially available WC-17%Co -HC Starc FST K-674.23 and Cr_3C_2-25%NiCr-1375 VM [13] powders on commercially available mild steel St 37 (Fig. 1).

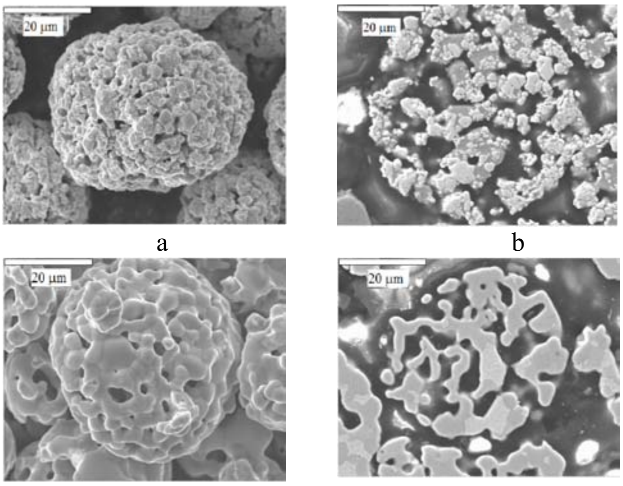
For the deposition of both types of coatings (WC-Co and Cr_3C_2–NiCr) the equipment TAFA JP 5000 was used for HP/HVOF [14]. Argon was used as a powder driving gas of high velocity oxygen-fuel process. The spraying parameters are shown in Table. Prior to the spraying, the substrate surface was grid blasted.

Table

Parameters of HVOF thermal spraying

Parameters of spraying	WC-Co	Cr_3C_2-NiCr
Started powder	WC-17%Co	Cr_3C_2-25%NiCr
Barrel length, mm	150	150
Bearing gas of powder	Argon	Argon
Flow of bear gas, sl/h	8	8
Revolutions of screw of feeder, rev/min	330	200
Deposition distance, mm	380	360
Equivalent ratio Φ*	0.8	0.8

*Equivalent ratio for stoichiometry of the fuel is defined as the actual air fuel ratio/the air fuel ratio for complete combustion. Particle size of powder was in the range of 15-63 μm. The size and shape of powder grains are shown in Fig. 1, a and c. Well seen porosity of grains is a result of applied method of powder production. The both powders are trade materials designated for thermal spraying. Cross-sections of the grain of powders are shown in Fig. 1, b and d.



a b

c d

Fig. 1 General SEM pictures of powder used to for coatings: WC-17%Co (a, b) and Cr_3C_2-25%NiCr (c, d). b and d – cross-sectional views

The hardness of sprayed coatings was 62 HRC for WC-Co, 59 HRC for Cr_3C_2-NiCr, and microhardness HV01 for WC-Co was 1218 and for Cr_3C_2-NiCr was 945. Metallographical investigation was carried out using optical microscopy and scanning electron microscopy (SEM) JOEL JSM-5400. The element distribution was analysed with a microprobe ISIS 300 Oxford Instrument.

Evaluation of tribological parameters was carried out by tribotester Falex (T-09 ITE Radom). Tribotester (principle of the test is shown in Fig. 2, a) enables the research of sliding properties and realization of the tests according to standards ASTM D 2625, ASTM D 2670, ASTM D 3233. For the tribological examination, the coatings were deposited on the samples (V-blocks) with the dimensions: diameter D = 12.7 ±0.05 mm, length L = = 10.0±0.05 mm with the groove on the face surface. The sample holder (Fig. 2, b) was used for the fixation of the samples during the deposition of the coatings by HVOF method.

a b

Fig. 2 Principle of the wear test (a) and sample holder for deposition of HVOF coatings (b) [15]

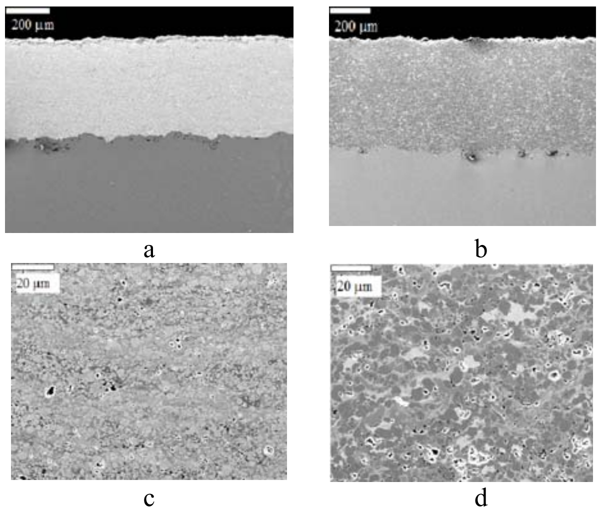
During the test pressure force P is produced by holder on samples with a groove on the sample face. Samples are pinned on a rotating pin (journal) between their faces. Maximum holding force value P is up to 20 kN. Rotating pin between the tested samples was pinned by a uniformly increased force up to galling occurred. The speed of the pin rotating between prismatic faces was constant during the tests v = 200 rev/min. The tests were carried out under dry conditions. The material of the pin was St 45 steel with chemical composition: C – 0.42-0.50%, Mn – 0.50-0.80%, Si – 0.37%, Cr – 0.30%, Ni – 0.30%, Cu – 0.30%, its hardness after heat treatment was 50 - 55 HRC [16].

The wear debris after scuffing were studied by AFM.

3. Results and discussion

Fig. 3 shows the structure of HVOF coatings. WC-Co and Cr_3C_2-NiCr form dense-compact carbidic cermet HVOF coatings with good adhesion to substrate. Structure and a connection between the single deposited layers are good. Interface coating-substrate does not show any changes of adhesion (Fig. 3).

Cross-sectional analysis shows that coatings sprayed at the optimum parameters of thermal spraying with equipment TAFA, especially at high impact velocity of the particles, have good cohesion and adhesion to the substrate. The layers of the coatings are formed by the impingement and solidification of ceramic particles as they are deposited in successive layers. Each layer consists of several lamella (thin layers) deposited on top of each other which created homogeneous, compact layers. The solidification of these lamellae depends on the particle size, velocity, temperature, substrate surface conditions and physical properties of the impinging ceramic material. Fig. 3, c and d show the microstructure of HVOF sprayed carbide coatings. Microstructure of WC-Co is fine grained, grains are smaller than in the case of coating Cr_3C_2-NiCr.

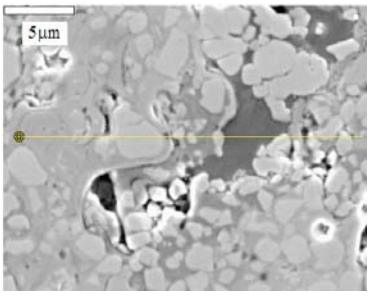


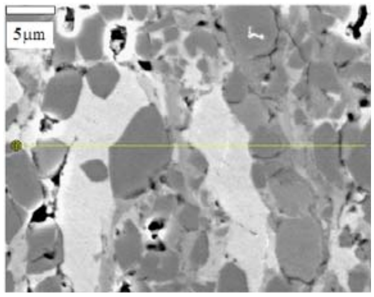
a b

c d

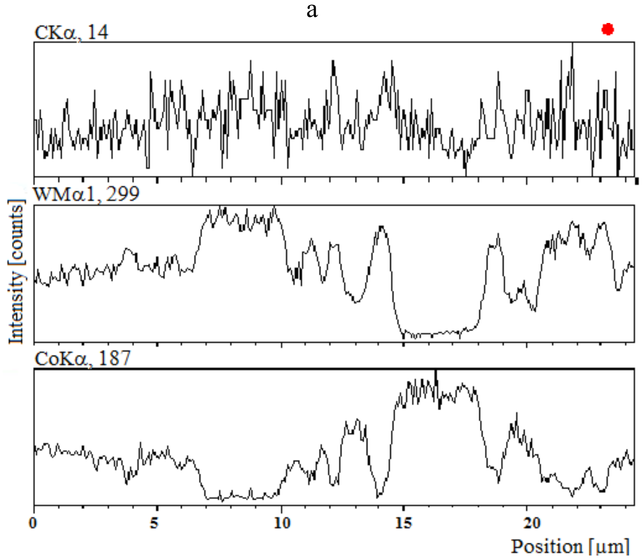
Fig. 3 Cross-sectional view (a, b) and microstructure (c, d) of coatings WC-Co (a, c) and Cr_3C_2-NiCr (b, d)

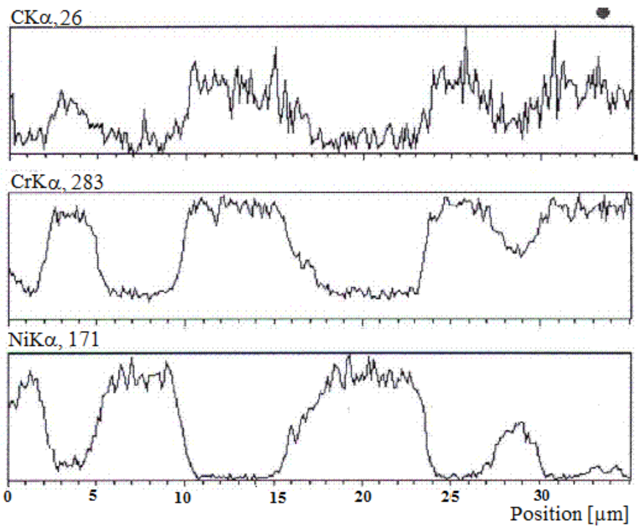
Cross-section of WC-Co coating (Fig. 4, a) reveals nondeformed grains of WC in the cobalt matrix. In a tungsten carbide coating, the white grains testify the presence of tungsten and the dark matrix appears to be rich in cobalt and contain little amount of tungsten. Data of linear spectra of the elemental distribution derived from X-ray energy dispersion microprobe analysis (Fig. 4, c) proved a composition of the coating in particular zones in a tungsten carbide coating.





a b

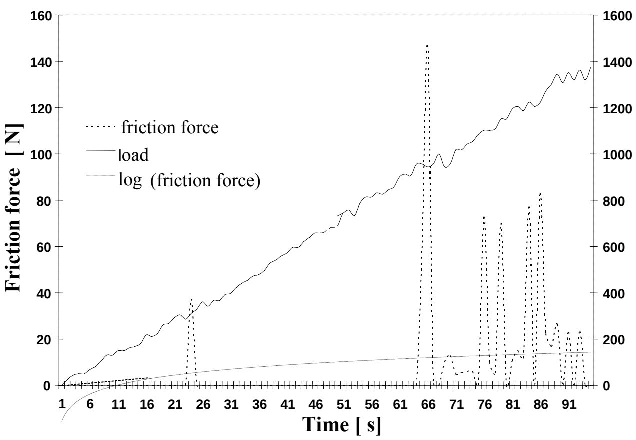


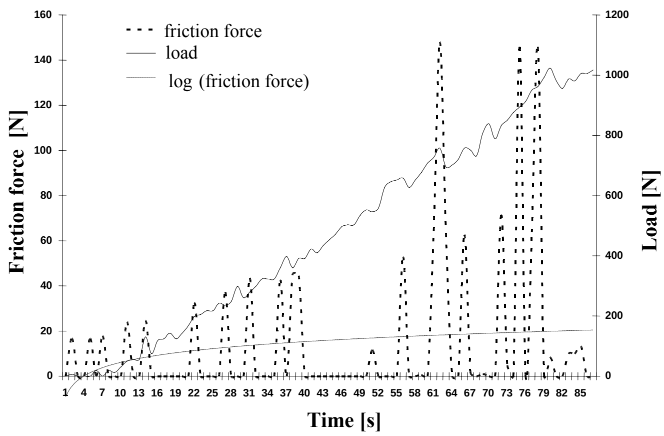


c d

Fig. 4 Microstructure and linear EDX spectra of WC-Co (a, c) and Cr_3C_2-NiCr (b, d)

Characteristic spectral lines and their wavelengths (Å) are shown in Fig. 4, c and d. In the case of the cross-section of Cr_3C_2-NiCr coating bigger nondeformed dark grains are embedded in light matrix (Fig. 4, b). Elemental line profile analysis (Fig. 4, d) shows that dark grains are a phase with high content of chromium, whereas light matrix is an area with high content of nickel. In both sprayed coat-ings the presence of small pores is visible as the darkest spots [17].The typical friction force vs. time course and maximum force where scuffing occurred are presented in Fig. 5, a and b.





a b

Fig. 5 F_{max} of scuffing resistance for WC-Co (a) and Cr_3C_2-NiCr (b)

Force where the scuffing occurred was deter-mined from three measurements for each coating. As it is indicated in the two diagrams, a steady course of the load force and friction force occur with a growth tendency. The course of WC-Co load force is stabilized during the tests with increasing the load force. Wear resistance was deter-mined as maximum force where the galling occurred and the test was stopped. The mean value of F_{max} for WC-Co was 1205 N. The course of Cr_3C_2-NiCr load force is with increased tendency with oscillations. Mean value of the maximum load force was F_{max} = 1099 N for the Cr_3C_2-NiCr coating with higher oscillations during of the test [10]. Analysis of the loading force sequence of the Cr_3C_2-NiCr coating shows that mating with pin (St 45 steel) after heat treatment under dry friction conditions leads to the scuffing during test.

Under dry friction conditions, WC-Co coating shows much higher resistance against scuffing than Cr_3C_2-NiCr coating (Fig. 5). Measurement of scuffing resistance of WC-Co coating showed the best scuffing resistance connected with the most homogeneous structure and low porosity (0.7%) than Cr_3C_2-NiCr coating with porosity 1.17%.

Atomic force microscopy (AFM) analysis was applied to study wear particles. Surface morphology of the tested samples is shown in Fig. 6. Higher resistance against scuffing of WC-Co coating corresponds with lower size of carbides and with the formation of small wear debris. A cluster of debris of rounded shapes for WC-Co coating is shown in Fig. 6, a and c. For coating Cr_3C_2-NiCr the solitary triboparticles were recorded, rugged and with shaped geometry (Fig. 6, b and d).

Wear resistance of cermet coatings is connected with single lamellae and strength of single carbides [5, 8]. Wear resistance of cermet coatings is influenced by optimal dimension of carbides or hard phases in matrix, better distribution of carbides and by suitable micro and macro structures.

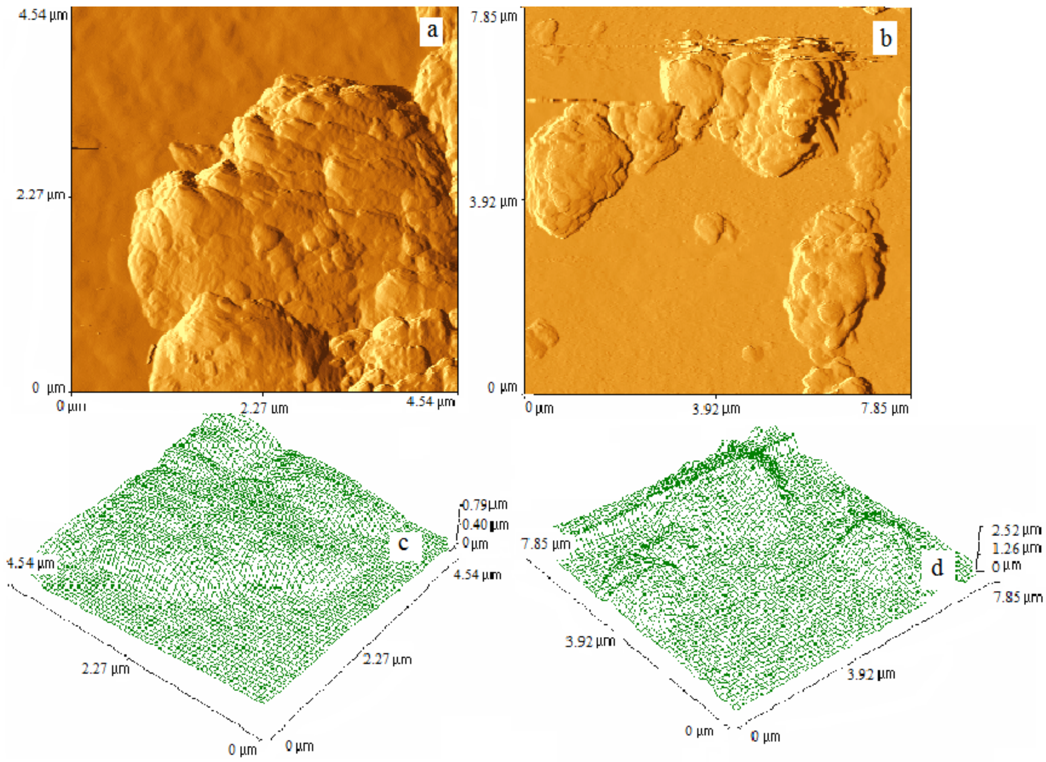


Fig. 6 Surface morphology of debris for WC-Co (a, c) and Cr_3C_2-NiCr (b, d)

4. Conclusions

1. HVOF sprayed Cr_3C_2-NiCr coatings showed less scuffing resistance than WC-Co ones. In the structure of Cr_3C_2-NiCr coating the inhomogeneity and local differences were observed.

2. Wear resistance of coatings is connected with the microstructure, specifically with the behavior of the individual hard phases and their association with matrix.

3. High tribological characteristics of the coating WC-Co were also determined by good adhesion of fine carbides WC in cobalt matrix. The optimised spraying conditions contribute a significant input in the higher scuffing resistance of WC-Co coating.

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GREITUOJU LIEPSNINIU PURŠKIMU SUFORMUOTŲ WC-Co IR Cr_3C_2-NiCr DANGŲ ATSPARUMO DILIMUI TYRIMAS

Reziumė

Straipsnyje aprašomi didelio greičio liepsniniu purškimu suformuotų volframo karbido (WC-Co) ir chromo karbido (Cr_3C_2-NiCr) dangų atsparumo dilimui tyrimai. Dangų dilimo procesas nagrinėjamas susiejant jį su dilimo dalelių sandara. Dangų atsparumas dilimui buvo tiriamas FALEX T-09 įrenginiu. Dilimo dalelės buvo analizuojamos atominės mikroskopijos būdu (AFM). Dangų metalografiniai tyrimai atlikti optinės ir skenuojamosios elektronų mikroskopijos (SEM) būdais. Dangų sudėčiai nustatyti naudota dispersinė rentgeno spindulių mikroanalizė. Iš gautų rezultatų galima spręsti, kad WC-Co dangos pasižymi geresnėmis tribologinėmis charakteristikomis. Nustatyta, kad dangų atsparumą dilimui nulemia jų mikrostruktūra.

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INVESTIGATION OF WEAR RESISTANCE OF HIGH VELOCITY OXY-FUEL SPRAYED WC-Co AND Cr_3C_2-NiCr COATINGS

Summary

In the present work, the comparative investigation of wear resistance was carried out for two types of thermal spray coatings – tungsten carbide-based (WC-Co) and chromium carbide-based (Cr_3C_2-NiCr) coatings deposited by high velocity oxy-fuel (HVOF) spraying process. The wear mechanism was investigated in the interrelationship with wear particles formation. Wear resistance of coatings was evaluated by tribotester FALEX T-09. The wear debris after scuffing were studied by atomic force microscopy. Metallographical investigation was carried out using optical microscopy and scanning electron microscopy (SEM). X-ray energy dispersion microprobe analysis was used for the investigation of the composition of coatings. The obtained results show that WC-Co coatings are characterized by better tribological characteristics. Wear resistance of coatings was connected with the microstructure.

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ИССЛЕДОВАНИЕ ИЗНОСОСТОЙКОСТИ ПОКРЫТИЙ WC-Co И Cr_3C_2-NiCr, НАПЫЛЕННЫХ ВЫСОКОСКОРОСТНЫМ СПОСОБОМ ГАЗОПЛАМЕННОГО НАПЫЛЕНИЯ HVOF

Резюме

В настоящей работе приведено исследование износостойкости двух типов газопламенных покрытий на основе карбида вольфрама (WC-Co) и карбида хрома (Cr_3C_2-NiCr), напыленных высокоскоростным способом газопламенного напыления HVOF системы „кислород-топливо“. Процесс износа исследуется путём поиска связи с строением частиц продуктов износа. Исследование износостойкости покрытий проводилось на триботестере FALEX T-09. Атомный силовой микроскоп (AFM) использовался для анализа частиц износа. Для металлографических исследований покрытий использовали оптический и сканирующий электронные микроскопы, для анализа покрытий – дисперсионный анализ рентгеновских лучей (EDX). По полученным результатам, покрытия на основе WC-Co обладают лучшими трибологическими характеристиками. Установлено, что микроструктура покрытий обуславливает их износостойкость.

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