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COMBINED STUDY OF WEAR PHENOMENA USING STEEL WHEEL ABRASION TEST

KOMPLEKSOWE STUDIUM ZJAWISK ZUŻYCIA Z ZASTOSOWANIEM TESTU ŚCIERALNOŚCI

Key words:

abrasive wear, three-body abrasion, HVOF, flame spraying, surface flame melting

Słowa kluczowe:

zużycie ścierne, ścieranie z trzecim ciałem, HVOF, metalizacja natryskowa, płomieniowe nadtapianie powierzchni

Summary

In the present work, thermally sprayed tungsten carbide-based coatings deposited by methods of high velocity oxy-fuel (HVOF) and also flame

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spraying (FS) combined with surface flame melting (SFM) were studied. Different powders and spraying systems were used to evaluate abrasive wear resistance of thermally sprayed coatings. Steel Wheel Abrasion Test (SWAT) has been applied to test setup for three-body abrasion. The wear rates were sensitive to the microstructure of the coatings. Studied coatings show wear behavior depending on the bond strength of carbide particles to the binder and also the size of carbides and type of binder. Relatively uncomplicated application and good abrasive resistance of deposited coatings are the main factors that contribute to implementation of SFM method into practice.

INTRODUCTION

Tribological properties of machine components surfaces, namely their wear resistance and friction properties, are in many cases the determining factors for their proper function. In order to improve the surface properties, it is possible to create hard, wear resistant coatings by thermal spraying technologies. Thermally sprayed cermet coatings have emerged as a viable solution for a wide range of wear resistance applications to improve the service life of machine components. Many methods may be selected in the area of thermally sprayed surface treatments which involve flame spraying, flame spraying plus melting, HVOF plus melting, plasma spraying. The applied remelting treatment after spraying plays important role in reducing wear [**L. 1**].

Tungsten carbide and chromium carbide-based coatings are frequently used for many applications in gas turbines, steam turbines and aero-engines to improve the resistance to sliding, abrasive and erosive wear.

WC with different metallic binders like Co, Ni and Fe have been studied using different amounts of binder contents [**L. 2, 3, 4**].

It has been reported that the abrasive wear rate for the cermet coatings is controlled by several factors like the morphology of powder, the size and distribution of the carbide particles, hardness of the carbide particles relative to the abrasive, properties of the matrix and its volume fraction and the coating process, which determines the coating characteristics like the phases, density, macrohardness and the residual stresses [**L. 3, 4, 5**].

This investigation focuses on three-body abrasion of hard coatings with abrasive media to better understand their tribological behaviour, especially the wear mechanisms in operation.

The WC-17Co coatings work particularly well in abrasive conditions both in two-body abrasive wear where wear is caused by hard protuberances of the counterface and three-body abrasive wear where wear is caused by the hard particles that are free to roll and slide between two surfaces. Very different abrasive wear rate are obtained from these coatings depending on the thermal spraying methods and experimental test parameters used [**L. 6, 7**].

In the present study, the three-body abrasion resistance behaviour of WC–17Co applied by HVOF method and NP60WC50 coating deposited by flame spraying (FS) combined with surface flame melting (SFM) have been compared. Wear rates were determined and mechanisms of surface degradation were observed and compared. The relationship between microstructure and wear rate was found to be dependent on the type of binder material and the size of the carbides.

EXPERIMENTAL STUDY

The coating WC-17Co examined in this study was sprayed onto flat grit blasted surfaces of samples using the JP 5000 HVOF spraying system. Coating material is commercially available as FST K- 674.23 (WC-17Co). The size range of hard phases differs for each coating. The spray powder with particle size range 45/15 μm for WC-17Co was used [**L. 8, 9, 10**]. The coating NP60WC50 was applied by flame spraying (FS) combined with surface flame melting (SFM) by Super EutaloyJet spraying system in VUZ PI-Welding Research Institute – Industrial Institute of SR, Bratislava.

The powder particles size range for NP60WC50 coating was 100/45μm**.** The chemical composition of powders (**Fig. 1** and **2**) is given in **Table 1**.

Table 1. Chemical composition of powders
Tabela 1. Skład chemiczny proszków

Coatings	**C**	**Si**	**B**	**Fe**	**Cr**	**W**	**Co**	**Ni**
NP60WC50* 32529	max. 0,6	max. 5,0	max. 3,9	max. 5,0	max. 20,0	*	-	rest
WC-17Co 1343MV	5,5	-	-	0,036	-	78,4	16,2	-

* mixture contains 50% of carbides [VUZ PI, Bratislava].

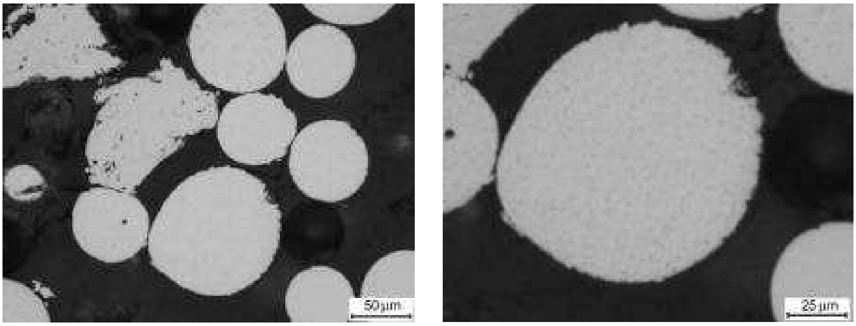


Fig. 1. Powder NP60WC50
Rys. 1. Proszek NP60WC50

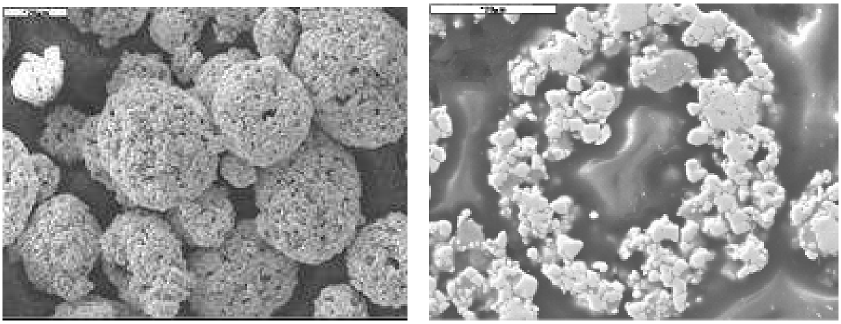


Fig. 2. Powder WC-Co 1343 VM
Rys. 2. Proszek WC-Co 1343 VM

The coatings were deposited on mild steel substrate (S355J2G3- 1.0570) of dimensions 70 mm x 22 mm x 8 mm grit blasted using Al_2O_3 grits of grain size 0,8 - 1,0 mm under pressure 0,55 MPa.

All coatings were created using previously optimized parameters. The thickness of coatings was in the range from 300 μm to 500 μm [**L. 8, 9, 10**].

Procedure Steel Wheel Abrasion Test (SWAT) according to standards ASTM G65 and ASTM-B611 was chosen. SWAT is a variation of the Rubber Wheel Abrasion Test (RWAT), the most commonly employed test setup for three-body abrasion. The tribotester applied in all of these studies is shown in **Fig. 3**. The test sample was fixed to a holder. The wheel contacted the test specimen with the force 35 N under test conditions given as given in **Table 2.** Force was recorded by MATLAB & Simulink software. The dry garnet was pressed against a rotating wheel, 229 mm in diameter, on metallic plane specimen. Abrasive particles were delivered into the gap between the specimen and wheel and dragged through the contact zone **(Fig. 4)**. In the three-body

Fig. 3. Photo of tribotester setup for three-body abrasion
Rys. 3. Fotografia tribotesteru do badania zużycia ściernego z trzecim ciałem

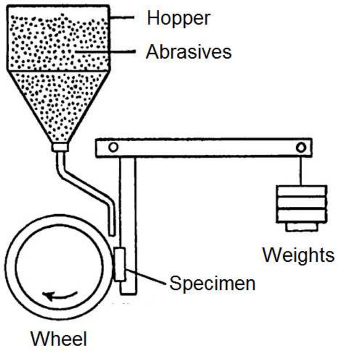


Fig. 4. Scheme of dry sand rubber wheel abrasion test apparatus [L. 13]
Rys. 4. Schemat testera do badania ścieralności z ogumioną rolką

Table 2. Test parameters
Tabela 2. Warunki testowania

Wheel diameter	[mm]	229
Wheel speed	[RPM]	287
Specimens sizes	[mm]	70 x 22 x 8
Load	[N]	35
Sliding distance	[m]	1031
Particle size	[mm]	0,80

abrasion process particles are loose and free to roll. Garnet abrasive (GARNET #80, Standard 11126, Mohs hardness at 20°C: 8 to 9, category: neosilicates, crystallography: cubic and facet angles) with typical chemistry given in **Table 3** was used for these tests.

Table 3. Chemical composition of the Garnet abrasive
Tabela 3. Skład chemiczny materiału ściernego Garnet

Garnet $Fe_3Al_2(SiO_4)_3$	SiO_2 [%]	FeO [%]	Fe_2O_3 [%]	Al_2O_3 [%]	CaO [%]	MgO [%]	MnO [%]
	41.34	9.72	12.55	20.36	2.97	12.35	0.85

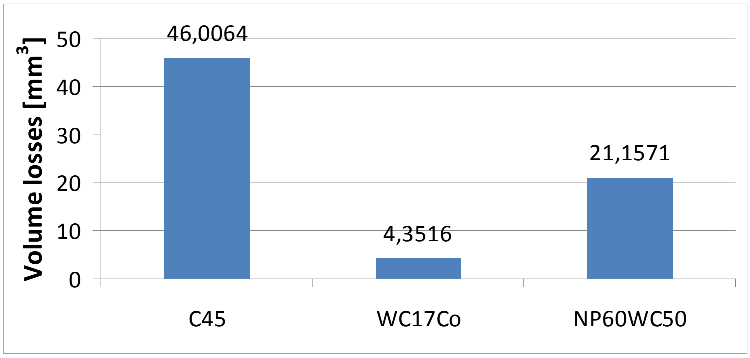
Microhardness measurements were carried out on sectioned and polished surfaces of studied coatings. Obtained microhardness for WC-17Co and NP60WC50 coatings was respectively HV0.1= 1218 (HRC 64) and HV0.1 = = 937 (HRC 75-85). As standard material C45-1.1191 steel with pearlitic-ferritic structure (HB 225/HV166) was applied.

THE RESULTS AND DISCUSION

Analyses of abrasive wear behaviour as a function of sliding distance under constant load were carried out by three body abrasion test. The results revealed the abrasive wear losses (volume losses) lower in the case of WC-17Co (HVOF) coating compared to NP60WC50 deposited by flame spraying combined with surface flame melting (SFM). The wear volumes of tested materials under three-body conditions applying abrasive are shown in **Fig. 5**. The wear rates were calculated as an average value using three tested samples.

The tested specimens were weighed before and after the test with accuracy ± 0.0001 [g] as required according to ASTM G65 Standard. Mass losses were recorded directly.

The wear tracks of the damaged coatings were studied by optical and scanning electron microscopy.



* Volume losses [mm^3] = Mass losses [g] / (Density [g/cm^3]*1000)

Fig. 5. Volume losses for tested materials under three body abrasion test
Rys. 5. Zużycie objętościowe testowanych materiałów dla ścierania z udziałem trzeciego ciała

Fig. 6 and **Fig. 7** show the cross-sectional profile after abrasive wear for both WC-17Co and NP60WC50 coatings indicating the different morphology of wear.

WC-17Co transverse section shows the homogenous structure. This region shows minimized effect of wear scars (**Fig. 6**).

The polished cross-section of the NP60WC50 coating indicates the different morphology and also carbides size in coating compare to WC-17Co. In the case of NP60WC50 coating, as can be seen in **Fig. 7**, the larger size of carbides in a nickel matrix was observed. Coating structures show a very low oxide content and a very good contact with the substrate, indicating a good bonding to the substrate.

The SEM micrographs of the worn surface for WC-17Co coating are shown in **Fig. 8**. In the case of WC-17Co **)** polishing and microabrasion are prevailing mechanism of wear **(Fig. 8a).** The wear tracks involve an initial removal of the binder phase mainly produced by three-body abrasive wear and followed by pull out of the carbides.

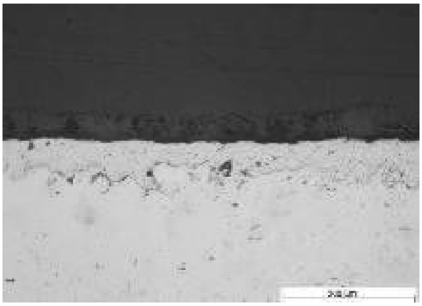


Fig. 6. Cross-section of WC-17Co
Rys. 6. Przekrój materiału WC-17Co

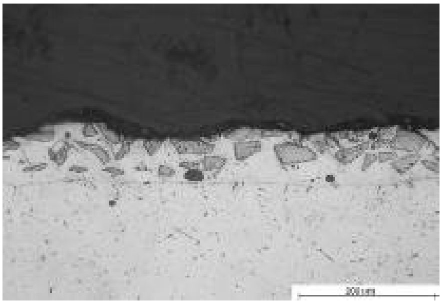


Fig. 7. Cross-section of NP60WC50
Rys. 7. Przekrój materiału **NP60WC50**

The surface of the WC–17Co coating has a very small size of WC, the worn surface indicates where Co matrix has been removed. Cobalt as a binder has good wetting and adhesion characteristics (**Fig. 8b).**

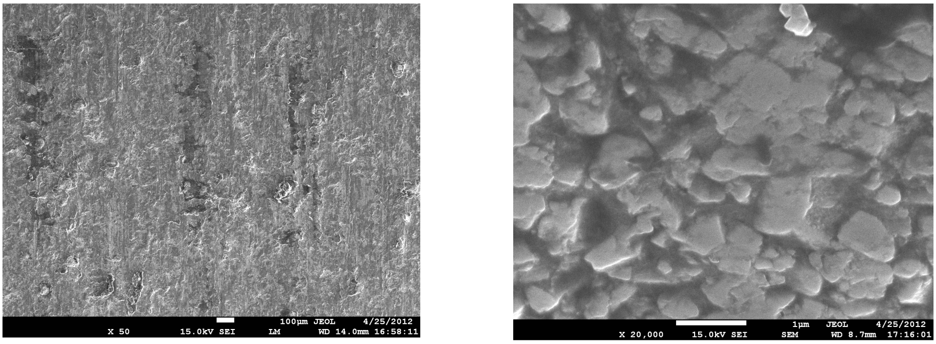


Fig. 8. Morphology of WC17Co after test: a) polishing and microabrasion, b) detail of small carbides embedded in cobalt matrix

Rys. 8. Mortologia materiału WC17Co: a) polerowanie i mikrościeranie, b) powiększenie małych cząstek węglika w matrycy kobaltowej

The main wear mechanism for WC–Co coating is polishing and microabrasion. Morphology under three body abrasion tests indicates the different surfaces changes of both WC-17Co and NP60WC50 coatings. The worn surface of NP60WC50 coating (**Fig. 9a**) shows carbide grains fracture and their protruding from the binder phase. Wear of NP60WC coating involves damage of the hard phase mainly by microcrackings (**Fig. 9b**). Carbides are well embedded in Ni matrix with good adhesion. Carbide microcrackings occur in contact with tips of hard abrasives.

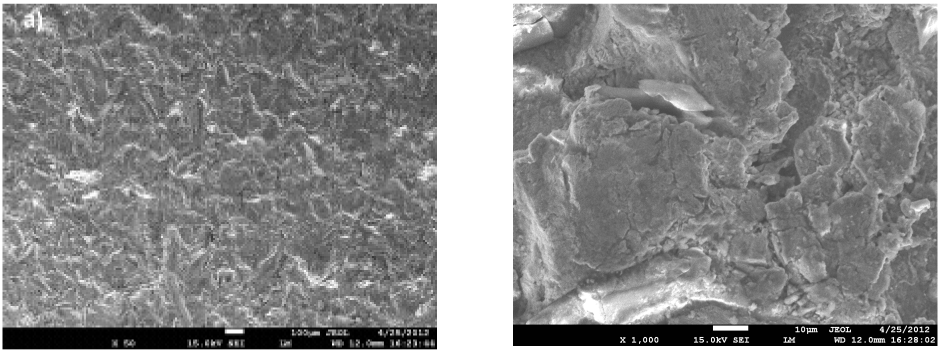


Fig. 9. SEM of worn surface of NP60WC50: a) microcutting b) microcracking

Rys. 9. Obraz SEM zużytej powierzchni NP60WC50: a) mikroskrawanie, b) mikropękanie

Thermally sprayed tungsten carbide-based WC-17Co coating deposited by method HVOF and flame sprayed coating NP60WC50 combined with surface flame melting (SFM) are associated with the amount, type of binder material and the size of the carbides. The abrasive wear resistance is connected with microstructural parameters such as the hardness, volume fraction indicating the different morphology and wear rates [**L. 10, 11**].

CONCLUSIONS

Wear tests showed that under three-body abrasive conditions the microstructural differences influence the wear behaviour of both coatings. The abrasive wear resistance of such composites depends on different microstructural parameters such as hardness, shape, size, volume fraction and distribution of the embedded phases, the properties of the matrix and the interfacial bonding between the second phase and the matrix [**L. 14, 15**]. It can be concluded:

- The higher abrasive wear resistance was recorded for the WC-17Co coating what can be explained with the smaller size of carbide particles compare to the NP60WC50 coating.
- Dominant wear mechanism contributing towards three-body abrasive wear in NP60WC50 coating is microcracking of hard phases.
- It was observed that the wear rate increased with increasing shape, size, with volume fraction and distribution of the embedded phases.

The results of experimental procedure confirm the possibility of application of the HVOF and RFS methods for creating sliding surfaces on sheet reeling machines.

Acknowledgements

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Streszczenie

W prezentowanej pracy wykonano badania powłok na bazie węglika wolframu nanoszonych metodami termicznymi za pomocą szybkościowego napawania tlenowo-gazowego (HVOF) i metalizacji natryskowej (FS) połączonych z płomieniowym nadtapianiem powierzchni (SFM). Dla oceny odporności na zużycie ścierne powłok nanoszonych metodami termicznymi zostały użyte różne proszki i różne systemy metalizacji. Zastosowano test zużycia ściernego ze stalową rolką (SWAT) do badań ścieralności z trzecim ciałem. Wartość intensywności zużywania były zależne od mikrostruktury powłok. Na zachowania zużyciowe testowanych powłok wpływa wytrzymałość wiązań cząstek węglików z żywicą, a także rozmiar cząstek i rodzaj żywicy. Stosunkowo prosta aplikacja i dobra odporność na ścieranie są czynnikami, które przyczyniają się do praktycznego zastosowania metody SFM.