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Influence of WC/Co Concentration on Structure and Mechanical Properties of the Thermally Sprayed WC/Co-NiCrBSi Coatings

Eitvydas GRUZDYS[1,2*], Šarunas MEŠKINIS[1], Algis JURAITIS[1]

[1]*Institute of Physical Electronics of Kaunas University of Technology, Savanorių 271, LT-50131 Kaunas, Lithuania*
[2]*JSC „Technologija", Breslaujos 3B, LT-44403 Kaunas, Lithuania*

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In this study the influence of WC/Co concentration in thermally sprayed WC/Co-NiCrBSi coating on its properties was evaluated using different analytical methods. A number of coatings were deposited on steel substrates by flame spraying using powder with different WC/Co concentrations (0 %, 15 %, 20 %, 25 %, 30 %, 45 %). Those coatings were subsequently remelted at high temperature using flame torch. Microstructure of as-sprayed and remelted coatings was evaluated using optical microscope. XRD analysis as well as hardness testing and wear testing, were performed on the samples. Wear tracks were also analyzed to estimate the nature of the wear of the different coatings. Experimental results were compared to determine which coating shows the best quality in terms of the wear resistance.
Keywords: flame spraying, wear resistance, NiCrBSi.

1. INTRODUCTION

Wear resistant hard coatings deposited by different powder spraying and melting techniques are applicable in many areas of industry. These coatings prolong the life of machinery parts because of its exclusive properties. There is a wide range of the powders available to use for synthesis of these coating. These powders differ in their chemical composition, grain size, production method and, because of those differences, in the field of application [1]. By applying coatings on a surface one can reach different goals: to increase hardness, wear resistance, fracture toughness, corrosion resistance. Depending on the possible goals mentioned above, the proper powder material should be chosen for the coating synthesis. One of the widely used materials is tungsten carbide – cobalt (WC/Co). The WC-Co is notable for its high hardness and toughness. WC-Co powder particle consists of the hard tungsten carbide grain imbedded in tough cobalt matrix. Another material used to produce these coating properties is a self-fluxing alloy NiCrBSiFeC. Actual composition of this material may vary due to the field of application, but the properties are mainly influenced by hard boride, carbide and silicide phases [2, 3]. By adding WC/Co powder to NiCrBSi onwe can change properties of the produced coating. Physical and mechanical properties in such a case depend on the proportions of those materials in the coating [4, 5].

In present study, the flame spraying technique was used for the formation of the coating where flame is created by combustion of fuel gas and oxygen mixture in the gas chamber of the thermal spraying gun. Powder is injected into the flame using inert compressed gas. It melts in the flame and is transferred in this state to the substrate where it cools down. In the case of self-fluxing alloys, post treatment is required to achieve good metallurgical bond between the coating and substrate. This treatment is called remelting and is performed using flame torch or high temperature furnace [5, 6].

The goal of this study was to evaluate the influence of WC/Co concentration in NiCrBSi-WC/Co powder on coatings physical and mechanical properties after it is sprayed and remelted. Concentration varied from 0 % of WC/Co in the mixture to 45 % WC/Co.

2. EXPERIMENTAL

2.1. Formation of Coatings Using Flame Spraying

WC/Co and NiCrBSi powders were used for the flame spraying. Chemical composition of these powders is shown in Table 1 and Table 2. Here and further in the paper, composition of the materials is expressed in mass concentration percentage.

Table 1. Chemical composition of WC/Co powder used for spraying

C, %	Co, %	Fe, %	Ni, %	W, %
5.13	12.1	~0.1	~0.4	82.27

Table 2. Chemical composition of NiCrBSi powder used for spraying

Cr, %	Mo, %	Si, %	C, %	B, %	Cu, %	Fe, %	Co, %	Ni, %
14	2.,3	4.1	0.6	2.9	2.5	4.4	0.03	~70

SEM pictures of the powders applied can be seen in Fig. 1. Particle size distribution of the NiCrBSi powder calculated from the Fig. 1 is presented in Fig. 2. It can be seen, that size of the almost half of all the particles fits into the 74 μm – 100 μm range and only several percents of the particles are smaller than 44 μm. For WC-12 %Co powder particle size distribution was: 95 % 22 μm – 45 μm and about 5 % >45 μm.

*Corresponding author. Tel.: +370-37-327605, fax.: +370-37-314423.
E-mail address: *eitvas@gmail.com* (E. Gruzdys)

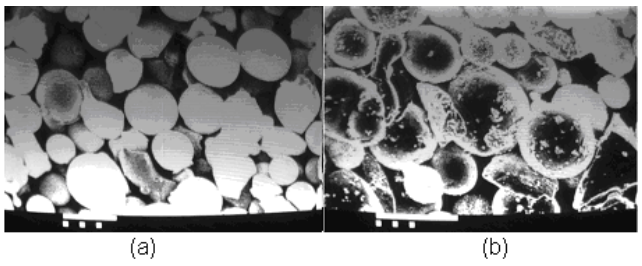

Fig. 1. SEM pictures of powders used to form coatings: NiCrBSi (a), NiCrBSi-30 %WC/Co (b). Mark size 100 μm

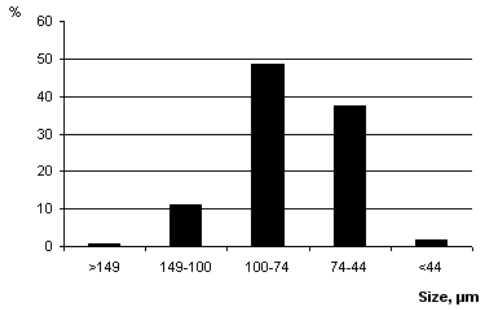

Fig. 2. Particle size distribution of NiCrBSi powder

The flame spraying equipment consisted of flame spraying gun, powder feeder and gas supply system. Compressed nitrogen was used as carrier gas for powder transportation from feeder to gun and acetylene with oxygen were used to form flame. Specimens were mounted on a cylinder shaped holder and rotated around axis at about 200 rpm. Coatings were deposited on (8×8×100) mm size steel substrates. Coating thickness was 1 mm. All coatings were remelted using acetylene-oxygen flame torch. Fusing and cooling was performed in air.

2.2 Methodology of Sample Analysis

Prepared specimens were cut to several pieces perpendicular to the coating using SiC saw. Microstructure analysis, hardness tests, phase composition evaluation was performed.

For the microstructure analysis, samples were mounted and polished according to the metallographic procedures. Etching was performed in 15 ml water, 30 ml HCl, 15 ml HNO_3 and 15 ml acetic acid. The samples were analyzed using optical microscope and SEM. Porosity was determined from the micrographs using image analysis programs.

Phase composition of the coatings was evaluated using X-ray diffractometer DRON-3. X-ray lamp 2.0BSV-24Cu with a copper anode (characteristic wave length $\lambda = 0.154178$ nm) has been used as a radiation source. Phase composition of the coatings was evaluated using Fullprof program comparing distance between the planes d and reflecting angle from crystallographic plane with data from JCPDS database. By comparing intensities of the different X-ray pattern peaks, we determined relative concentration of different crystal phases in coatings. Surface morphology and structure were investigated using scanning electron microscope JEOL JSM-IC25S and optical microscope with a digital camera attached.

Rockwell C hardness was measured on the polished surface of coatings using Rockwell cone indenter. Every sample was measured five times and the average value was defined. Indentations were done in the different regions of the sample surface. Surface was grounded before measurements to avoid roughness influence on the results.

2.3 Wear Testing

Two-body abrasive wear test was performed for each of the coatings. The principal scheme of the custom made machine used is shown in Fig. 3. SiC grinding paper of grit size 120 μm was used as counter abrasive. Disk was rotating at 1350 rpm. The applied load was 0.8 kg. Mass loss was measured and paper was changed every 2700 revolutions. Maximum of 13500 revolutions was made on every sample, which corresponds to sliding distance of 4.24 km. To avoid surface roughness influence on the results, the samples were grounded before wear test. Mass loss was evaluated using a weighing machine VLR-200. Accuracy of the machine was 0.05 mg.

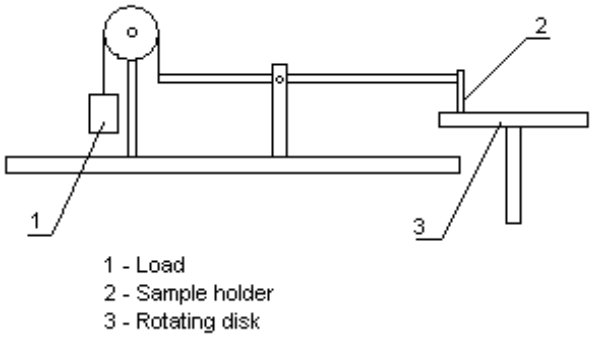

Fig. 3. Scheme of Pin-On-Disk wear test machine

3 EXPERIMENTAL RESULTS

3.1 Results of Powder and Sample Analysis

X-ray diffractograms are shown in Fig. 4, Fig. 5 and Fig. 6. In Fig. 4 three spectra of NiCrBSi can be seen. Top one shows the powder diffraction peaks, middle – as sprayed and the bottom one shows XRD spectra of remelted coating. As it can be expected in all three cases the Ni peaks are the strongest. According to Table 2 there is 14 % of chromium in powder. We can see a small Cr peak at 49° and at about 45° chromium peak overlaps with the strong Ni peak. There are some minor peaks in all three spectra. These belong to borides, carbides and silicides. It can be observed that no significant changes occur in diffractograms after the coating is sprayed on and remelted. Ni peaks are still the most intensive and there is just small increase in their widths. It indicates slight amorphisation during deposition and remelting processes. Smaller peaks of CrC, NiB and CrB can be hardly detected in the diffractograms of the sprayed and remelted coating. It is possible that decomposition of some of those compounds took place during the heat treatment.

In Fig. 5 XRD spectra of NiCrBSi-25 %WC/Co powder and coating can bee seen. As in previous spectra the Ni peaks stay strongest. It can be seen, that the addition of WC-12 %Co results in appearance of the tungsten carbide related peaks. In powder diffractogram these peaks are relatively weak. It can be explained by the different

particle size and different mass of the powders mixed. Gradual separation of the NiCrBSi and WC/Co particles can be possible reason that we can't see stronger WC peaks in the powder diffractogram. The peaks become much stronger in XRD spectra of sprayed coating. Here one can detect new peaks of W_2C and metallic W. They appear on the expense of WC. After remelting of the coating W_2C peaks become stronger and WC peaks are not so intense. We can assume that phase transformation between these compounds takes place. Smaller peaks of CrC, NiB and CrB appear in all of diffractograms and no major changes occur here after spraying or remelting of the coating.

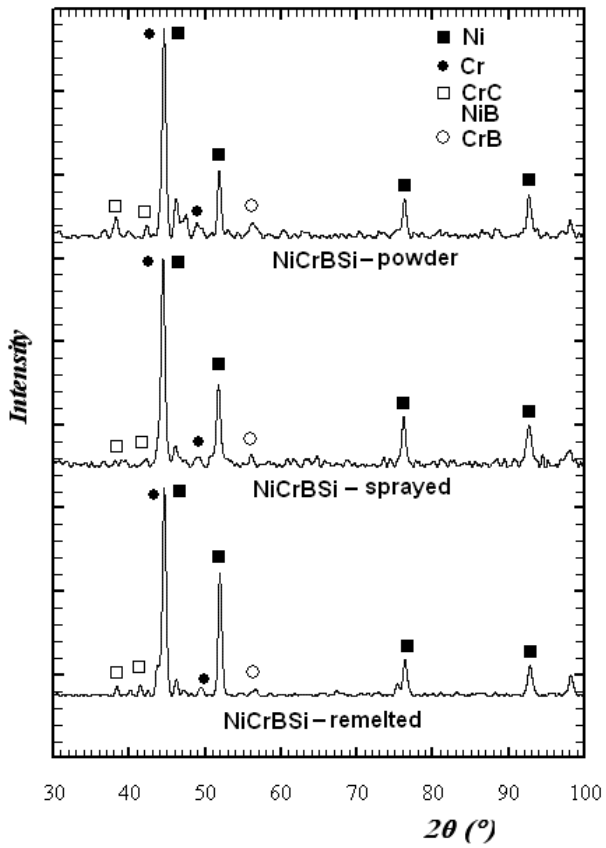

Fig. 4. X-ray diffractograms of the NiCrBSi powder and coating

In Fig. 6 XRD diffractograms of NiCrBSi-45 %WC/Co can be seen. As in the case of the NiCrBSi-25 %WC/Co mixture, Ni peaks are still the strongest. WC peaks of the NiCrBSi-45 %WC/Co powder are more intensive in comparison with the NiCrBSi-25 %WC/Co powder. However, intensity of the WC related XRD peaks increases as a result of the spray deposition as well (Fig. 6). It can be seen in Fig. 6, that in the case, of the coating deposited from NiCrBSi-45 %WC/Co powder mixture, intensity of the WC peaks is almost the same as intensity of the Ni peaks. Cobalt is not seen in these diffractograms. It can be related to possible overlapping of the Co and Ni related peaks at about 44°, 75° and 90°.

WC/Co-NiCrBSi coatings were analyzed with optical microscope before and after remelting process to evaluate its structural and morphological changes. In Fig. 7 pictures of as-sprayed (a) and remelted (b) coating of 20 %WC/Co-NiCrBSi can be seen. If we look closely at the left

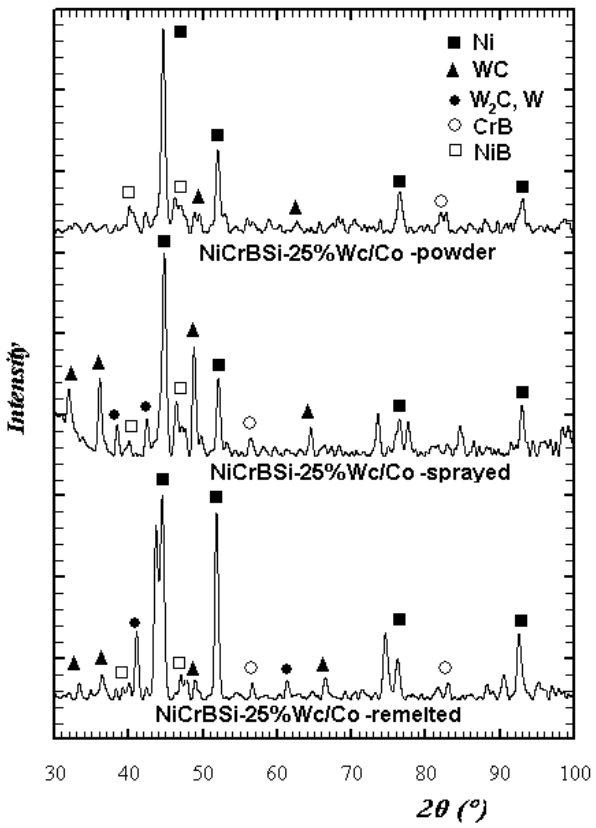

Fig. 5. X-ray diffractograms of the NiCrBSi-25 %Wc/Co powder and coating

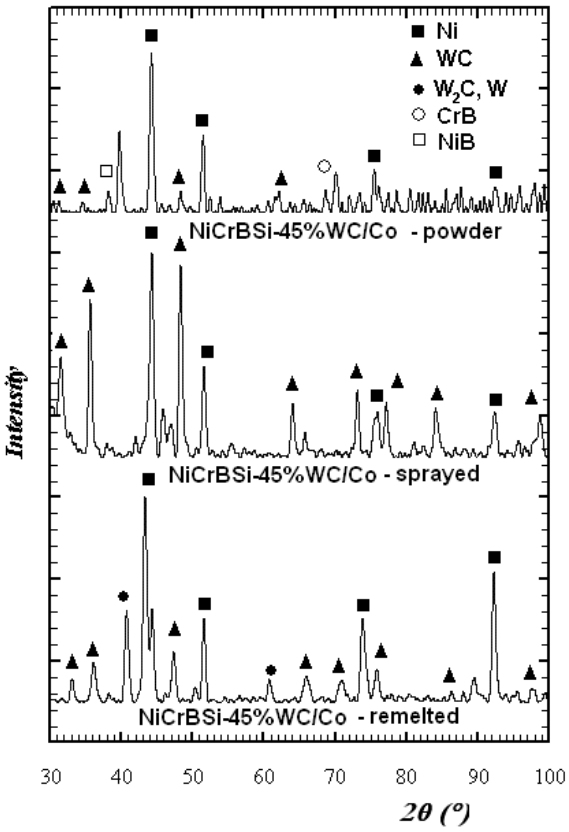

Fig. 6. X-ray diffractograms of the NiCrBSi-45 %WC/Co powder and coating

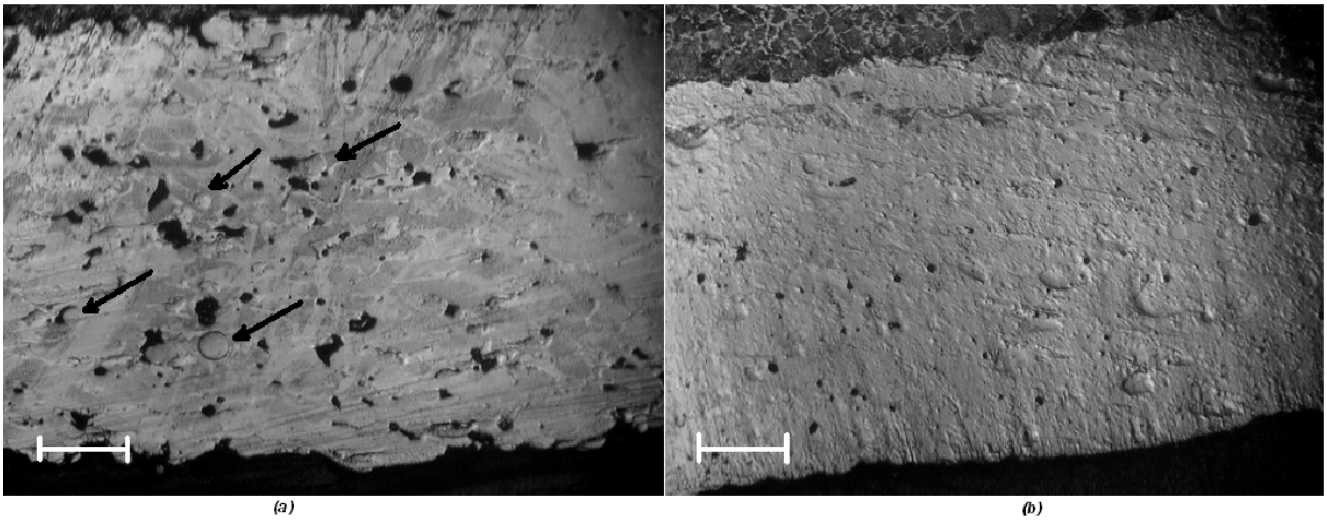

Fig. 7. Pictures of 20 %WC/Co-NiCrBSi coating before (a) and after remelting (b). Mark size 200 μm

picture we can see big round shaped holes of around 30 μm – 60 μm diameters. These are probably the result of WC particles removal during grinding process. Diameter of the holes approximately matches the size of WC particles. Another important thing to notice is a black random shaped spot scattered across the surface of the cross-section. Those are pores formed during the spraying process. If we now look at remelted coating we can see that presence of the pores is not so noticeable. In the process of remelting coating is heated to a temperature of about 1000 °C. At this temperature porosity decreases and thus, density of the coating increases.

3.2 Hardness and wear resistance

Rockwell C hardness measurements were performed to estimate macrohardness of the coatings. The results are shown in Table 3. As is can be seen, addition of WC powder to NiCrBSi has almost no effect on macrohardness of coatings. Reports of the other authors confirm these results [7].

Table 3. Macrohardness of NiCrBSi – X%WC/Co coatings (in HRC)

0 % WC	15 % WC	20 % WC	25 % WC	30 % WC	45 % WC
53.4	53.6	48.8	50.1	49.5	47.2

Abrasive wear measurements of the coatings under examination showed expected results. In the case of NiCrBSi coating with no WC/Co present, weight loss was high, 15 % and 45 % WC/Co similar and so was 20 %, 25 % and 30 %. As it can be seen from Fig. 8 last group has relatively highest wear resistance. Measurement of 15 % WC/Co shows similar results as 45 %. It is due to the fact that in the case of 45 % WC/Co carbide particles are ripped out from the surface. NiCrBSi serves as a binder. Therefore, cohesion between the WC/Co particles and the coating decreases with decrease of the amount of the NiCrBSi. Optical examination of of the wear tracks presented in Fig. 9 support such results assumption. The effect of the WC/Co particle removal can be clearly seen in Fig. 9, c. Coatings, showed the best results in the wear test, were with WC/Co percentage at around 25 %. In this case hard carbide particles have enough strong binding with the coating and its concentration is high enough to prevent forming of deep wear tracks. Similar results have been reported by other authors as well [9].

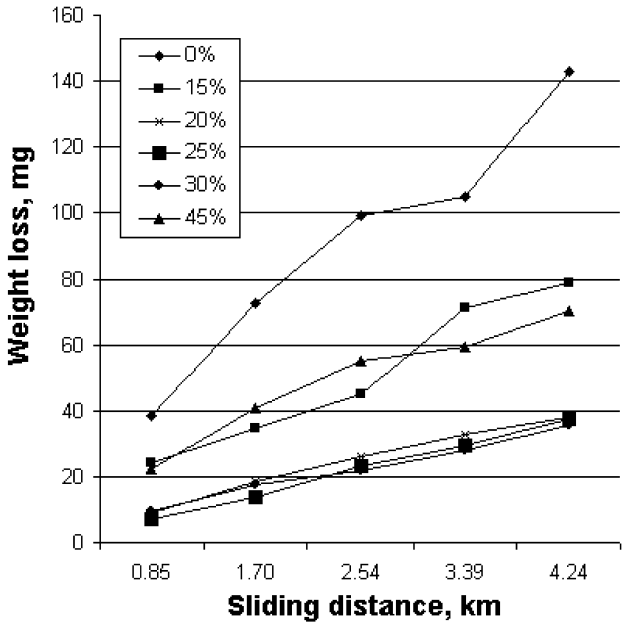

Fig. 8. Results of wear resistance measurements

Not only WC is responsible for the lower wear. As we could see in diffractograms (Fig. 4, Fig. 5, Fig. 6) phases of the hard borides, silicides and carbides are formed during deposition and remelting processes. Wear tracks left on the coatings can be seen in Fig. 9. At the picture 9, a, wear tracks of the coating with no carbides are seen. Whole surface is affected gradually and it is relatively smooth. Picture 9, b, shows wear tracks of 20 %WC/Co. Surface is much rougher due to carbides standing out. And in a last picture (Fig. 9, c) one can see tracks obtained from the 45 %WC/Co coating. Large pores are observed here. Those gaps are left after carbide particles or even small regions of the coating are ripped from the surface as it was mentioned above.

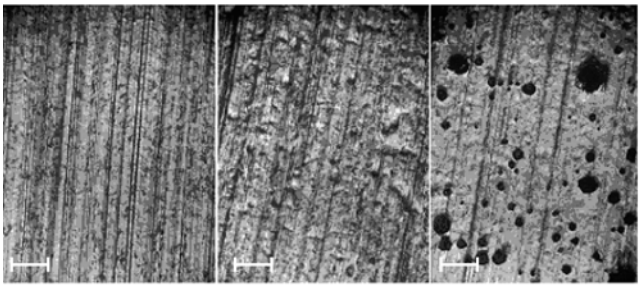

Fig. 9. Wear track of: (a) 0 % WC/Co-NiCrBSi, (b) 20 %WC/Co-NiCrBSi, (c) 45 %WC/Co-NiCrBSi. Mark size 200 μm

CONCLUSIONS

Coatings formed by flame spraying using NiCrBSi and WC/Co powders are suitable for surface protection because of their exclusive properties. These properties can be altered according to specific situation of application. The results show that though there are no significant changes in macrohardness, and the best wear resistance is demonstrated by coatings which contains about 25 %WC/Co. Further increase in WC/Co percentage increases risk of carbide particles being removed form the surface due to the decreased cohesion.

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