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DETONATION-SPRAYED WC-12%Co AND WC-17%Co DIAMOND-IMPREGNATED SEGMENTS

NATRYSKIWANIE DETONACYJNE POWŁOK WC-12%Co i WC-17%Co NA SPIEKI METALICZNO-DIAMENTOWE

This paper presents results of investigations of WC-12%Co and WC-17%Co coatings detonation sprayed on a sintered cobalt substrate.

The main objective of the present work was to establish a new production route of sandwich type diamond-impregnated segments for circular sawing of stone and other construction materials.

Unalloyed cobalt was chosen as the substrate material. Prior to coating the specimens were made by means of hot pressing of Extrafine cobalt powder in a graphite mould.

The segments were then coated with WC-Co. The effects of the coating process on the thickness, microhardness, microstructure and wear resistance of the deposits were investigated.

The properties of the coatings were established by performing the following tests: a microstructure analysis, a point analysis of chemical composition and a linear analysis, a phase composition, a microhardness tests and abrasion resistance.

Keywords: cobalt, sinter, hot pressing, diamond impregnated tools

W pracy przedstawiono wyniki badań detonacyjnego nanoszenia powłok WC-12%Co WC-17%Co na spieki kobaltu.

Badania prowadzono w celu opracowania nowej technologii wytwarzania trójwarstwowych segmentów metaliczno-diamentowych typu sandwich przeznaczonych do produkcji tarczowych pił diamentowych i innych materiałów budowlanych.

Próbki do badań otrzymano z proszków kobaltu gatunku Extrafine techniką prasowania na gorąco w grafitowej matrycy, a następnie na ich powierzchnię natryskano powłoki WC-Co.

Badano wpływ parametrów procesu natryskiwania na grubość, mikrotwardość, mikrostrukturę i odporność na zużycie ścierne uzyskanych powłok.

Przeprowadzono następujące badania uzyskanych powłok: obserwację mikrostruktury, analizę punktową i liniową składu chemicznego, analizę składu fazowego, pomiar mikrotwardości oraz badanie odporności powłok na zużycie ścierne.

1. Introduction

Detonation spraying is a thermal spray process whereby high density, hard and high adhesion coatings can be deposited on a substrate material in order to increase its resistance to wear [1-2]. The process consists in using repeated gas explosions to heat and accelerate particles of a suitable powder material through a detonation gun barrel and to throw them at a high velocity onto the substrate located adjacent to the outlet of the barrel [3]. By careful pre-treatment of the substrate surface and control of the spraying regimes it is possible to deposit metallic coatings of a predetermined thickness and microstructure [4].

The main objective of the present work is to implement the detonation spraying technology to reinforce the sides of uniform diamond-impregnated segments located on the circumference of circular saw blades used for cutting natural stone, concrete, brickwork and other ceramic materials.

The diamond-impregnated segments are exclusively produced by powder metallurgy in a variety of shapes and internal structures that may greatly affect the tool life and its cutting behaviour [5,6]. Although uniform and simple-shaped segments are cheaper to manufacture, the application requirements often justify selection of complex designs. A three-layer (*sandwich* type) structure of segments has been found the best choice for most of the circular sawing applications. As the outer layers differ from the inner one in their susceptibility to wear a desirable saddle-like wear profile is being developed at work on the working face of each segment (see Fig. 1) which imparts a self-guiding characteristic to the saw blade and prevents it from deviating in the cut.

The sandwich structure of the segment is produced by cold pressing the three layers of suitably prepared diamond grit-matrix powder mixtures. The green segments are subsequently hot pressed to near-full density in graphite moulds [7,8,9].

As the production of thin sandwich segments for small saw blades is arduous and expensive the application of detonation spraying to reinforce the sides of uniform segments by deposition of wear resistant WC-Co coatings has been proposed as an alternative technology.

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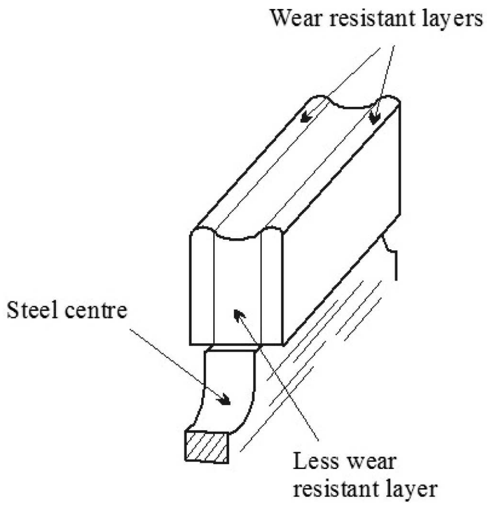


Fig. 1. Structure of a *sandwich*-type segment and saddle-shaped wear of the working surface

2. Experiment

A commercial *Extrafine* cobalt powder (Umicore, Belgium), having Fisher sub-sieve size of around 1.5 μm, was used to manufacture the target material for the detonation spraying experiments. The powder is shown in Fig. 2.

The substrate specimens were prepared by means of hot pressing the cobalt powder in a graphite mould at 850°C for 2 minutes under a pressure of 35 MPa.

All sintered specimens were tested for density and hardness. The density was determined by weighing them first in air and then in water. Their hardness was established at a load of 10kG using the Vicker's hardness test method. Then the specimens were analyzed using a Leica DM4000 light microscope in order to determine their microstructure, respectively.

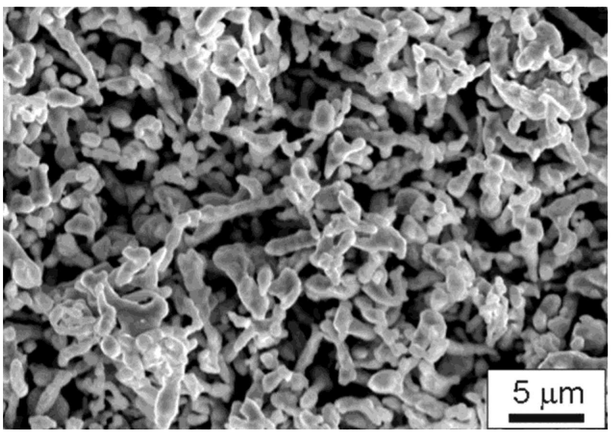


Fig. 2. Extrafine cobalt powder

The coatings were produced using a Perun-S valveless dispenser at the Surface Advanced Technology Inc. in Warsaw. To used the follows powders: AMI 5109.1 (WC-12%Co) of the company Amil Werkstofftechnologie GmbH and Diamalloy 04152 (WC-17%Co) of the company Sulzer Metco.

Prior to coating, the surfaces were degreased with acetone and grit-blasted with electrocorundum *EB 14*.

Portions of WC-12wt% Co and WC-17wt%Co powder, having a narrow range of particle sizes between 22-45 μm, were repeatedly ejected at 4Hz for 6 minutes from a 580 mm barrel at a velocity of around 1000 m/s to be deposited on the cobalt target positioned 300 mm head of the barrel outlet.

The properties of the coatings were established by performing the following tests: a microstructure analysis, a point analysis and a linear elements distribution analysis using a Jeol JSM 5400 scanning microscope equipped with an ISIS 300 energy dispersive X-ray spectrometer (EDS), a phase composition analysis using a Bruker D-8 Advance X-ray diffractometer, a microhardness test, and abrasion resistance test using a T-07 tester.

3. Results

The analysis results showed that the sinters had a density of 8.73 ±0.01 g/cm^3, which was close to the theoretical density, a high hardness of 271 ±4 HV10 (the scatter bands were estimated at 95% confidence level) and a fine-grained microstructure, as shown in Fig. 3. It has been concluded that further research is required.

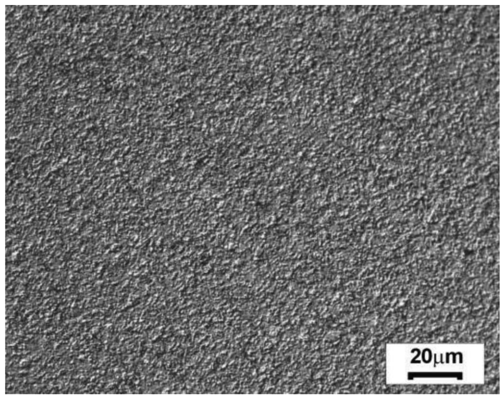


Fig. 3. Microstructure of the sinters Co (EF), the Nomarski contrast

The microstructure of the coatings obtained by detonation spraying are shown in Fig. 4.

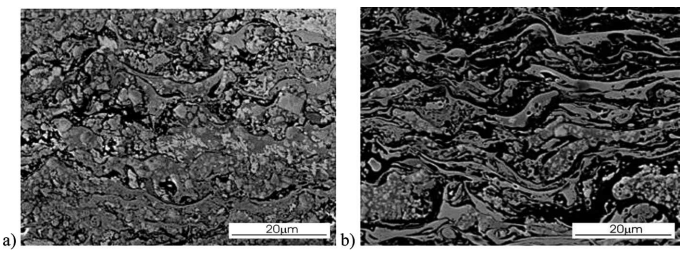
a)  b)

Fig. 4. Microstructure of the coatings: (a) WC-12%Co, (b) WC-17%Co

The multi-layer microstructure of the coatings results from the strong deformation of the powder particles, which occurs during the deposition process. The layers vary considerably in the oxygen content, as shown by the point and linear chemical content analyses (Fig. 5, 6, 7).

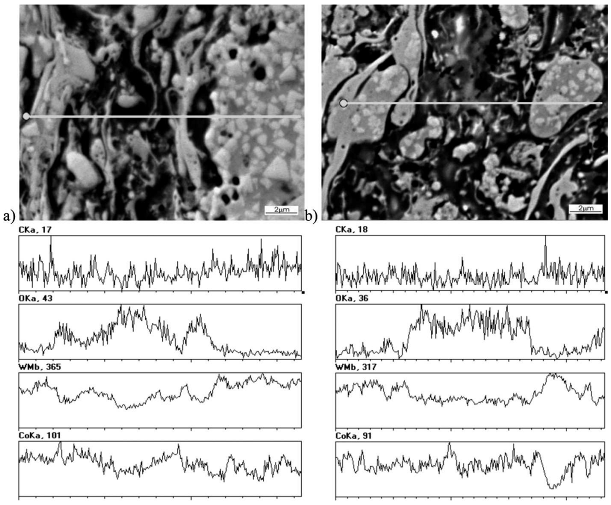


Fig. 5. EDS analysis of the coatings: (a) WC-12%Co, (b) WC-17%Co

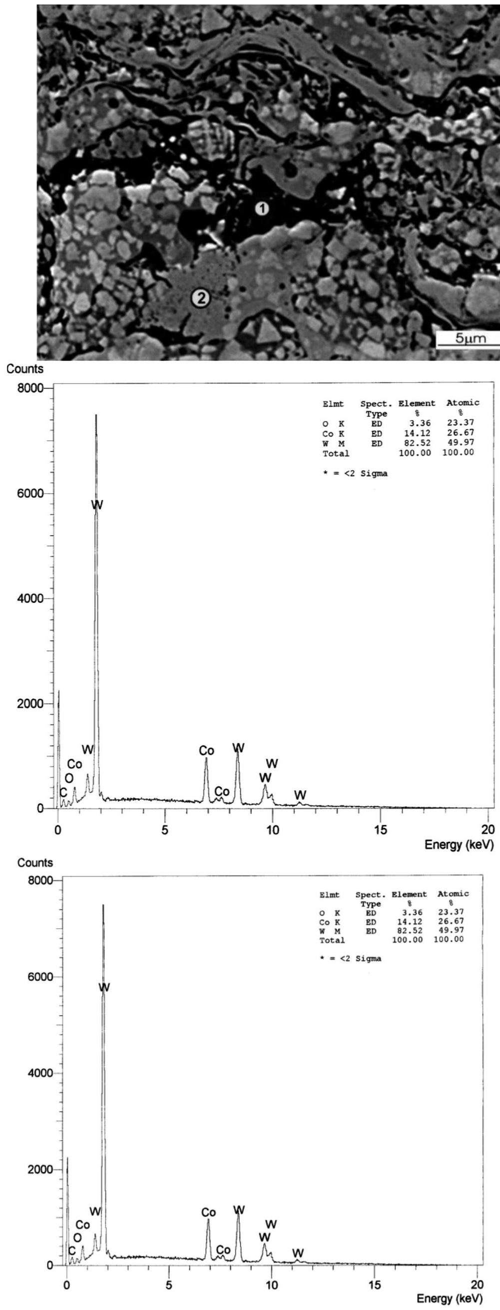


Fig. 6. Point analysis by EDS of the WC-12%Co coating: the dark-coloured component (1), the light-coloured component (2)

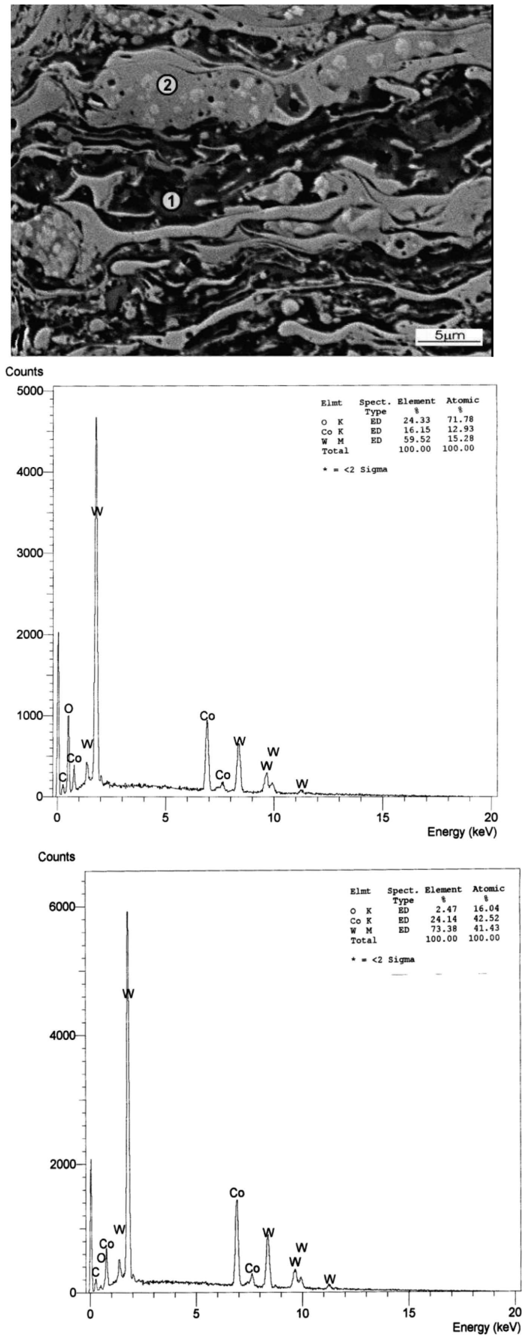


Fig. 7. Point analysis by EDS of the WC-17%Co coating: dark-coloured component (1), light-coloured component (2)

Phase identification using the X-ray diffraction technique revealed considerable differences in the composition of the carbide phase in the coatings. The WC-12%Co coating contained WC and a small amount of W_2C (Fig. 8).

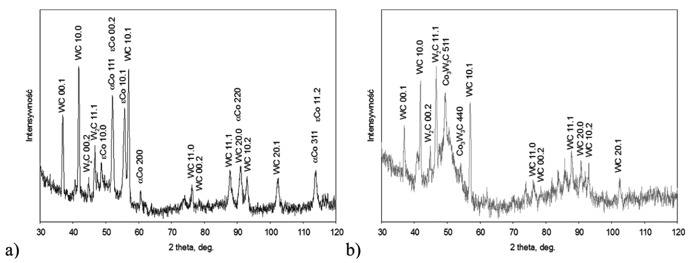


Fig. 8. Diffractograms of the coatings (a) WC-12%Co and (b) WC-17%Co

The content of WC and W_2C carbides in the WC-17%Co coating increased significantly. The analysis revealed also the presence of another carbide - $(W,Co)_6C$.

A change in the composition of the carbide phase was probably due to the partial combustion of carbon during the detonation spraying of the coating. The porous structure of the *Diamalloy 04152* powder particles was also of significance; it allowed diffusion of the oxidizing gases.

The formation of complex M_6C-type carbides is regarded to be an unfavourable phenomenon. A decrease in the content of the binding cobalt phase may lead to a considerable decrease in the strength and plastic properties of the coating material.

The hardness of the WC-12%Co coating was much higher than that of the WC-17%Co coating (Fig. 9). After a Vicker's hardness test, there were no cracks around the indentation corners, which indicates that the coatings have appropriate plastic properties. No cracking or delamination around the indentations at the interface between the coating and the substrate confirms good adherence of the coating to the substrate. The strength of the substrate surface layer was improved by cold working, which involves collisions of the WC-Co powder particles with the sinter surface.

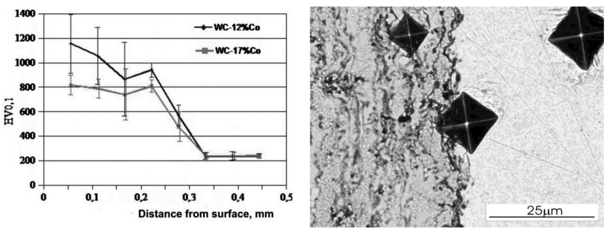


Fig. 9. Relationship between the microhardness and the distance from the surface

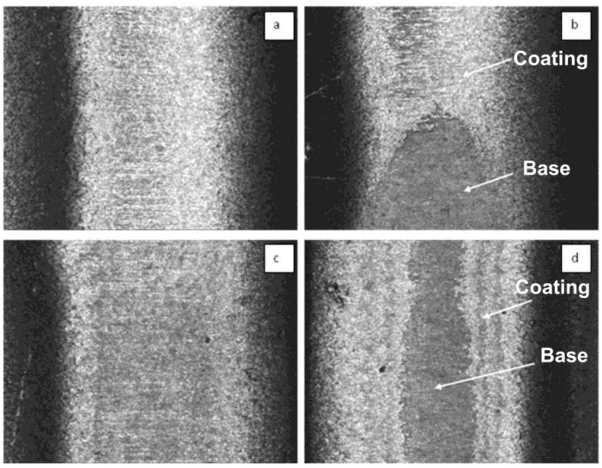


Fig. 10. Traces of wear after abrasion resistance tests: WC-12%Co coating (a), WC-12%Co coating (measurement results not taken into account) (b), WC-17%Co coating (c), WC-17%Co coating (test results not taken into consideration) (d)

The abrasion resistance of the coatings was measured using a T-07 tester. The tests reveal that the wear resistance of the WC-12%Co coating is high, higher than that of the WC-17%Co coating (Fig. 10). It is supposed that the high rate of wear of the WC-17%Co coating, which is twice as high as that of the WC-12%Co coating, is attributable to a decrease in the content of WC at the expense of W_2C and $(W,Co)_6C$.

4. Conclusion

The experimental results confirm that the gas detonation method is well-suited for depositing WC-Co coatings with high hardness and different chemical and phase composition. The coatings produced from WC-12%Co powder possessed higher hardness and nearly twice as high abrasion resistance as the WC-17%Co coatings. Both coatings were well adhered to the cobalt substrate. As a result, the strength of the substrate surface layer, several dozen micrometers in thickness, was improved significantly by cold working.

During coating deposition, the temperature of the substrate material did not exceed 150°C; it had virtually no effect on the properties of the diamond crystals. It can be concluded that the method is suitable for increasing the abrasion resistance of the segment side surfaces. Thin WC-Co coatings applied to the side surfaces of the homogeneous metallic-diamond segments ensure uniform lateral wear of the saw. This can be an alternative to *sandwich*-type segments. The analysis described in this paper was qualitative in nature. No tests were conducted to estimate the efficiency of the tool.

Reliable tests to assess the durability of metallic-diamond tools are static in nature, time-consuming and very costly. This paper deals with qualitative analysis only; the wear rate was typical of saws used for cutting sandstone slabs.

REFERENCES

[1] J. Konstanty, Powder Metallurgy Diamond Tools, Elsevier, Oxford 2005.
[2] J. Konstanty, Powder metallurgy diamond tools – a review of manufacturing routes. Materials Science Forum **534-536**, 1121-1124 (2007).
[3] J. Borowiecka-Jamrozek, Engineering structure and properties of materials used as a matrix in diamond impregnated tools, Archives of metallurgy and materials **58**, 1, 5-8 2013.
[4] A. Romański, J. Konstanty, Ball milled Fe-Ni and Fe-Mn matrix powders for sinterted diamond tools, Archives of Metallurgy and Materials **59**, 1, 189-193 (2014).
[5] A. Romański, Factors affecting diamond retention in powder metallurgy diamond tools, Archives of Metallurgy and Materials **55**, 1073-1081 (2010).
[6] J. Konstanty, T.-W. Kim, S.-B. Kim, Resistance to abrasive wear of materials used as metallic matrices in diamond impregnated tools. Materials Science Forum **534-536**, 1125-1128 (2007).
[7] D. Hao, H. Weigang, and all; Influence of process variable on the qualities of detonation gun sprayed WC-Co coatings. Materials Science and Engineering A **408**, 202-210 (2005).
[8] J. Sobiecki, J. Ewertowski, and all; Influence of Surface Preparation on the Properties of Tungsten Carbide Coatings Produced by Gas-Detonation Method. Materials Science Forum **426-432**, 2587-2592 (2003).
[9] R. Poorman, US Patent 2964420, (1960).

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