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Effect of WC concentration on structure and properties of the gradient tool materials

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Materials

ABSTRACT

Purpose: The goal of this work is to obtain the contemporary gradient materials based on the tungsten carbide reinforced high-speed steel using the conventional powder metallurgy method and increasing the high-steel hardness (80 HRA = 800HV) by introducing the tungsten carbide as the reinforcing phase, with hardness exceeding 2200HV.

Design/methodology/approach: The materials were fabricated with the conventional powder metallurgy method consisting in compacting the powder in the closed die and finally sintering it. Forming methods were developed for powders of the HS6-5-2 high-speed steel and WC, making it possible to obtain material with seven layers in the structure.

Findings: It was found out basing on the microhardness tests that hardness of test pieces grows along with the sintering temperature and with WC content in the interface layers and in the high-speed steel ones. It was also observed that porosity decreases along with the WC concentration increase in these layers. It was found out, basing on the comparison of structures and properties of the compacted and sintered test pieces, that in structures of all examined test pieces in the sintered state fine carbides occurred distributed homogeneously in the high-speed steel layer.

Research limitations/implications: It was noticed, that increase of the sintering temperature results in the uncontrolled growth and coagulation of the primary carbides and melting up to forming of eutectics in layers consisting of the high-speed steel.

Practical implications: Material presented in this paper has layers consisting on one side from the mix of the high-speed steel and WC, and on the other side the high-speed steel, characteristic of the high ductility. Such material is tested for milling cutters.

Originality/value: The layers were poured in such way that the surface layer consists of the mix of the high-speed steel and WC, and the middle one from the high-speed steel. The layers inside the material are mixes of the high-speed steel and WC in the relevant proportions.

Keywords: Tool materials; Powder metallurgy; High-speed steel; WC

1. Introduction

Gradient materials may be fabricated with, among others: powder metallurgy methods, connected with differentiation of chemical composition in particular layers, and hence structure change with the material, and also with the temperature gradient during sintering and with liquid phase. One can obtain them by sintering the prepregs formed by compacting, by filling the die with successive layers of powders with various compositions. Employment of the powder metallurgy method gives the possibility to retain the high abrasion wear resistance (characteristic of the sintered carbides or cermets) with ensuring the high ductility (corresponding to the high-speed steels and traditional cermets) with the simultaneous cutting of manufacturing costs [1-4]. The main advantage of such solutions is combining the very high abrasion wear resistance with the relatively high ductility of materials cores, which is especially important in materials for blanking tools and tools for plastic working, highly efficient tools for high-speed cutting, and for form tools. The goal of this project is development of the contemporary gradient materials using the powder metallurgy methods to ensure the required properties and structure of the designed material.

2. Materials for research

The investigations were made using the test pieces fabricated with the conventional powder metallurgy method consisting in compacting the powder in the closed die and finally sintering it. Specifications of powders used for fabricating the test pieces are listed in Table 1. Chemical compositions of the powders used are listed in Table 2.

Table 1.
Powders used for fabricating the materials

Powder	Grain size, μm	Additional information
HS6-5-2	>150	High-speed steel powder, atomised with water, made by HOEGANAES
WC	>0,86	Tungsten carbide powder made by reduction of tungsten oxides, made by Baildonit

The uniaxial compacting method was used for making the prepregs . The compacted and sintered test pieces were made from the HS6-5-2 and WC powders. Four single layer test pieces were made for the first test, with various concentrations of tungsten carbide. Each test piece is composed of the mix of the HS 6-5-2 and WC in relevant proportions (Fig.1).

The test pieces were mixed at ambient temperature for 30 min in the special agitator (WAB–TURBULA–typeT2F). Compacting was carried out in the uniaxial unilateral die, under the pressure of 500 MPa. Next, the test pieces were sintered in the vacuum furnace at the temperature of 1250°C for 60 minutes.

Table 2.
Chemical composition of HS 6-5-2 steel powder, Hoeganaes

Element	Mass concentration, [%]	
	HS 6-5-2	WC
C	0.75÷0.90	6.11
Mn	0.20÷0,45	-
Si	≤0.45	≤0.002
P	≤0.04	-
S	≤0.04	0.003
Cr	3.75÷4.5	-
Ni	0.2	-
Mo	4.5÷5.5	≤0.001
W	5.50÷6.75	balance
V	1.6÷2.2	0.19
Co	0.1	-
Cu	0.1	-
Fe	balance	0.003
Ca	-	0.003
Al	-	≤0.002
Mg	-	≤0,001
K	-	≤0.001
Na	-	≤0.001
C free	-	0.02

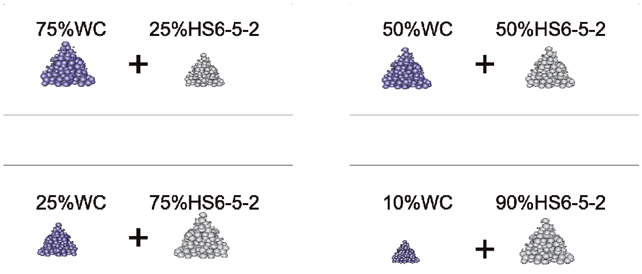

Fig. 1. Proportions for mixing the test pieces for selection of the appropriate chemical composition

It was found out, based on microstructure examinations that porosity grows along with the WC contents growth. The smallest porosity has the test piece with 10% content of WC. Therefore, it was assumed that 10% WC is the maximum WC percentage in the surface layer for the test pieces designed next. The WC percentages for the remaining layers were chosen experimentally. Proportions and layers pouring method in the seven-layers test pieces are presented in Fig.2.

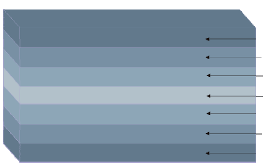

Fig. 2. Pouring proportions for layers of the compacted and sintered test pieces

Compacting was carried out in the uniaxial unilateral die, under the pressure of 500 MPa.

The compacted test pieces were sintered in the vacuum furnace at the temperatures of 1210÷1270°C every 20°C.

All test pieces in the sintered state were subjected to examination of density, porosity, and microhardness; observations were also made on the scanning electron microscope (SEM) equipped with the back-scatter electrons detector (BSE) and the dispersive energy analyser (EDAX D4). Archimedes method was used to measure the density, consisting in measurement of the apparent test piece mass when immersed in water. Hardness was tested with Rockwell and Vickers methods. In case of the Rockwell method the test was made on surface of the sinters at five randomly selected locations in scale A, using CENTAUR hardness tester. Average values from the readings feature the final test results. Vickers method was used to determine hardness values of the particular layers, at the indenter load value of 9.8 N on the HV-1000 (DIGITAL) hardness tester. About sixteen indents were made across the test piece beginning from 0.2 mm from the surface due to problems with identifying boundaries between layers and small widths of the particular layers. Porosity measurement was made using the optical microscope at 20x magnification. Each time five random points from each layer were selected for tests.

3. Description of achieved results of own research

Density of the compacted and sintered test pieces grows along with the sintering temperature increase (Fig. 3).

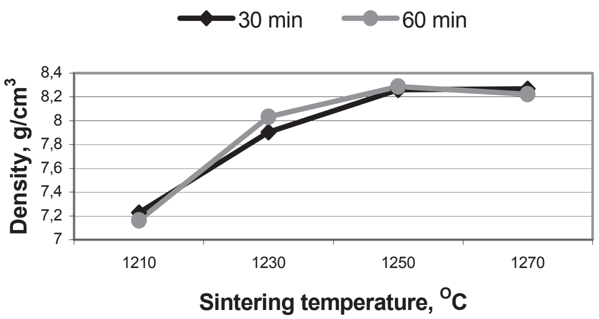

Fig. 3. The density/sintering temperature chart for PM speciments

Hardness of the compacted and sintered test pieces measured with Rockwell method grows along with the sintering temperature increase. It was noted that employing longer sintering time results in slight hardness lowering (Fig.4).

Hardness of the compacted and sintered test pieces measured with the Vickers method grows along with the WC concentration increase in the particular layers and with the sintering temperature increase. The layer from the high-speed steel demonstrates very low hardness compared to the intermediate layers and to the surface layer (Fig.5).

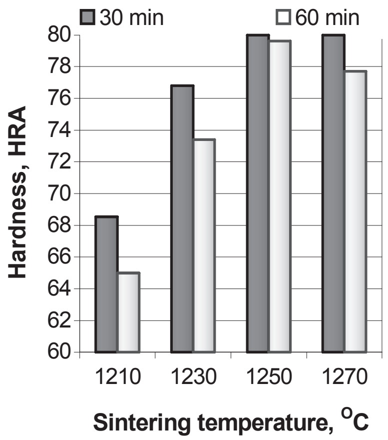

Fig. 4. Relationship of HRA hardness with the sintering temperature for test pieces with the surface layer: 10%vol.WC + 90%vol.HS6-5-2, sintered in vacuum

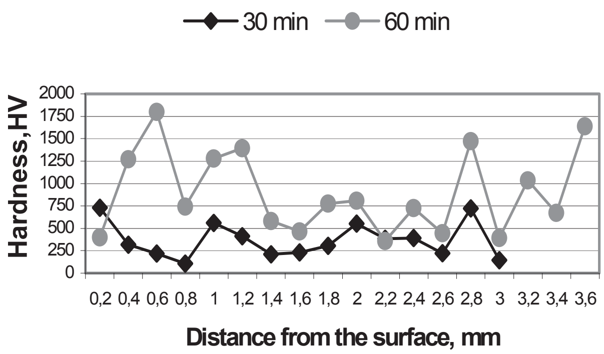

Fig. 5. Hardness of the test pieces with the surface layer with the composition: 10%vol.WC+90%vol.HS6-5-2, sintered in vacuum at temperature of 1210°C

Porosity grows along with the WC content growth in the particular layers. It was observed the sintering time has an effect on porosity growth. The longer is sintering time, the bigger is the porosity (Fig.6).

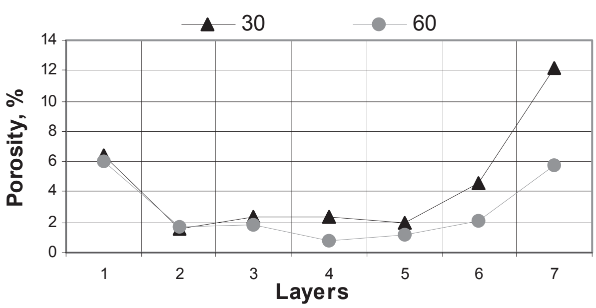

Fig. 6. Porosity of the test pieces with the surface layer with the composition: 10%vol.WC+90%vol.HS6-5-2, sintered in vacuum at temperature of 1210°C

Microstructure of the compacted and sintered test pieces is presented in Figure 7. The grey colour represents the matrix from the HS 6-5-2 high-speed steel, whereas the white colour corresponds to the tungsten carbides (WC) contained in the steel. The best results were obtained for the test piece sintered at the temperature of 1270°C for 30 minutes. One may notice that this test piece has the smallest porosity of its structure, demonstrating thus its higher density.

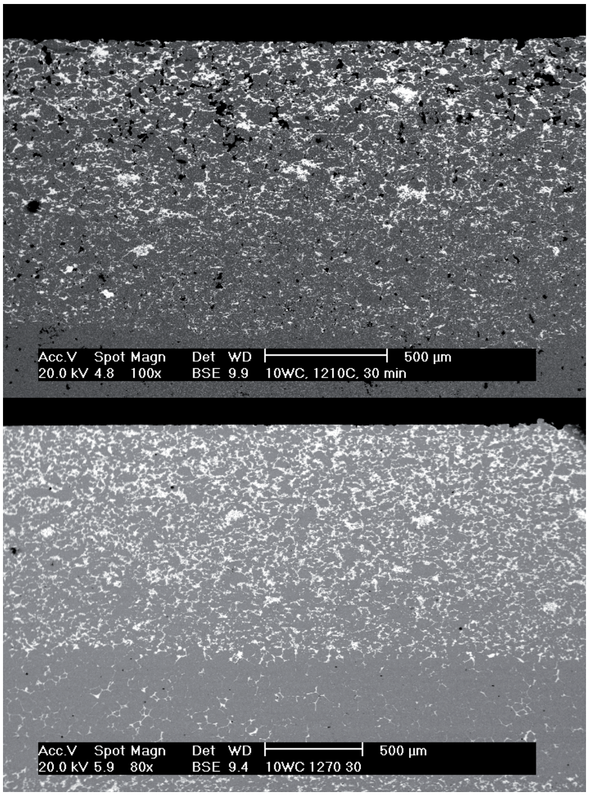

Fig. 7. SEM - microstructure of the high-speed steel reinforced with the tungsten carbide (90%vol.HS6-5-2 +10%vol. WC in the surface layer), sintered in vacuum at the temperature of a) 1210°C for 30 min, b) 1270 for 30 min

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