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Structure and properties of gradient tool materials with the high-speed steel matrix

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Materials

ABSTRACT

Purpose: This work concerns research on the structure and properties of gradient tool materials with the HS6-5-2 high-speed steel matrix reinforced by the tungsten carbide.
Design/methodology/approach: The materials were fabricated using the conventional powder metallurgy method, consisting in compacting the powder in a closed die, and subsequent sintering. All the sintered test pieces were subjected to examination of density, porosity, and hardness; observations were also made using the scanning electron microscope (SEM), equipped with the back-scatter electrons detector (BSE) and the dispersive energy analyser (EDAX D4).
Findings: The density of the compacted and sintered test pieces grows along with the sintering temperature increase. The porosity grows along with the WC content growth in the particular layers. It was observed that the sintering time has an effect on the porosity growth. The longer the sintering time is, the higher the porosity is. The HRA hardness of the compacted and sintered test pieces grows along with the sintering temperature increase. It was noted that application of a longer sintering time results in slight hardness lowering.
Practical implications: Developed material is tested for turning tools.
Originality/value: The material presented in this paper has layers consisting of the carbide-steel with growing hardness on one side, and on the other side the high-speed steel, characterized by a high ductility.
Keywords: Tool materials; Uniaxial pressing; Sintering; High-speed steel; Tungsten carbide

1. Introduction

Functionally graded materials (FGMs) are a new generation of engineered materials of which the composition and structure gradually change over volume, resulting in corresponding changes in properties of the materials [1,2,3]. The FGMs are not technically a separate class of materials but rather represent an engineering approach to modify the structural and/or chemical arrangement of materials or elements [4]. The concept was originally applied to create the fuselage exterior and engine materials for space planes which would take off like airplanes, cruise at Mach 5 to 25 in the atmosphere, subjected to severe frictional heating from the airflow. The optimal response of material properties to conditions in an actual environment is the main requirement in the design of FGMs. To fulfill this requirement the composition and microstructure are varied throughout the structure, and this yields a property gradient within the combined materials [5-9]. The manufacturing process of a FGM can usually be divided in building the spatially inhomogeneous structure (“gradation”) and transformation of this structure into a bulk material (“consolidation”). Gradation processes can be classified into constitutive, homogenizing and segregating processes. Constitutive processes are based on a stepwise build-up of the graded structure from precursor materials or powders. Advances in automation technology during the last decades have rendered constitutive gradation processes technologically and economically viable [10-15].

The main objective of this work concerns the research on the structure and properties of a sintered gradient tool materials with the HS6-5-2 high-speed steel matrix reinforced by the tungsten carbide.

2. Materials for research

The investigations were made using the test pieces made of the high speed steel type HS6-5-2 and tungsten carbide (WC) powders, fabricated by the conventional powder metallurgy method consisting in compacting the powder in a closed die, and subsequent sintering. The properties and the chemical compositions of the powders are listed in Table 1.

Table 1.
Properties and chemical composition of powders

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	rest
V	1.6÷2.2	0.19
Co	0.1	-
Cu	0.1	-
Fe	rest	0.003
Ca	-	0.003
Al.	-	≤ 0.002
Mg	-	≤ 0,001
K	-	≤ 0.001
Na	-	≤ 0.001
C free	-	0.02
Grain size, µm	> 150	> 0,86
Additional information	High-speed steel powder, atomised with water, made by HOEGANAES	Tungsten carbide powder made by reduction of tungsten oxides, made by Baildonit

In the first step the high speed steel and WC powders were mixed at the ambient temperature for 30 min in the special agitator (WAB–TURBULA–typeT2F). Each test piece is composed of the mix of the HS6-5-2 and WC in relevant proportions: HS6-5-2 + 10%WC, HS6-5-2 +25%WC, HS6-5-2 +50%WC, HS6-5-2 +75%WC. The mixtures were compacted 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 [15].

It results from the microstructure observation that the porosity grows along with the WC contents growth. The smallest porosity has the test piece with 10% content of WC (fig.1).

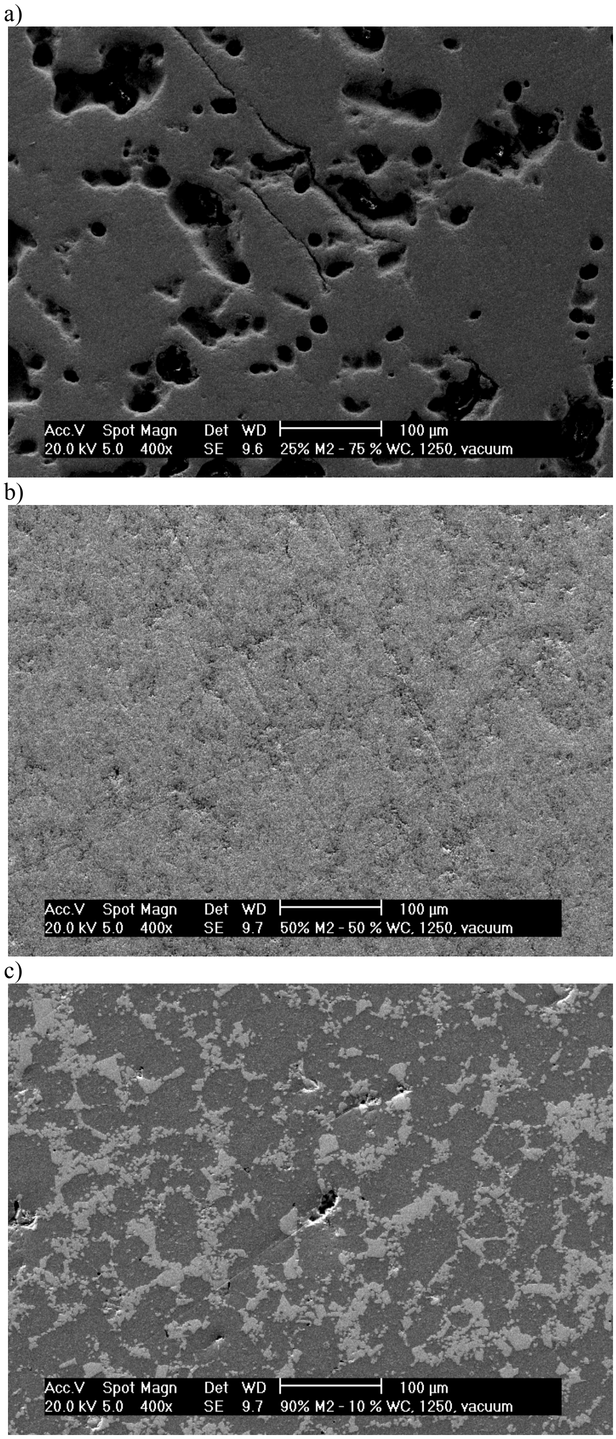

Fig. 1. Microstructures of carbide- steel sintered at 1250^{o}C consists: a) HS6-5-2+75%WC, b) HS6-5-2+50%WC, c) HS6-5-2 +10%WC

The test piece with 25% content of WC melted down. Probably, at the temperature of 1250°C eutectic point occurs. At the same temperature the test pieces with 10, 50 and 75% content of WC did not melted down. For further research the test pieces with 10% and 25%WC were chosen. This contents are the maximum WC percentages in the surface layer for the pieces. The WC percentages for the remaining layers were chosen experimentally. The proportions of the constituents for the seven-layer test pieces are presented in Fig. 2.

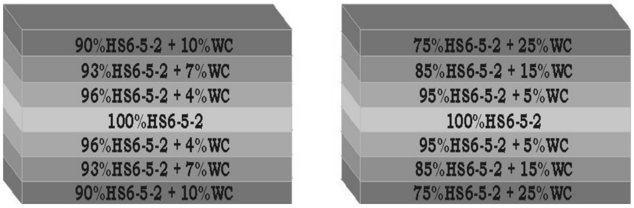
a) b)

Fig. 2. The proportions of the constituents of the compacted and sintered seven-layer test pieces

The mixtures were compacted under the pressure of 500 MPa. The green compacts with 25% content of WC in the surface layer were sintered in the vacuum furnace at the temperatures of 1210°C , 1230°C for 30 and 60 minutes. The green compact with 10% content of WC in last layer were sintered in the vacuum furnace at the temperatures of 1210°C , 1230°C, 1250°C and 1270°C for 30 and 60 minutes.

All the sintered test pieces were subjected to examination of density, porosity, and hardness. Observations using the scanning electron microscope (SEM), equipped with the back-scatter electrons detector (BSE) and the dispersive energy analyser (EDAX D4), were also made. The density was measured using the Archimedes method, consisting in the measurement of the apparent test piece mass when immersed in water. The hardness was measured using the Rockwell test. The test was made at the surface of the sinters at five randomly selected locations, in scale A, using CENTAUR hardness tester. The average values from the readings feature the final test results. Porosity measurement was performed using an 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

The density of the compacted and sintered test pieces grows along with the sintering temperature increase (Fig. 3). The hardness of the compacted and sintered test pieces, measured using the Rockwell method, grows along with the sintering temperature increase. It was noted that employing a longer sintering time results in slight hardness lowering (Fig. 4). Porosity grows along with the WC content growth in the particular layers. It was observed that the sintering time has an effect on porosity growth. The increase of sintering time causes the increase of the porosity (Fig.5).

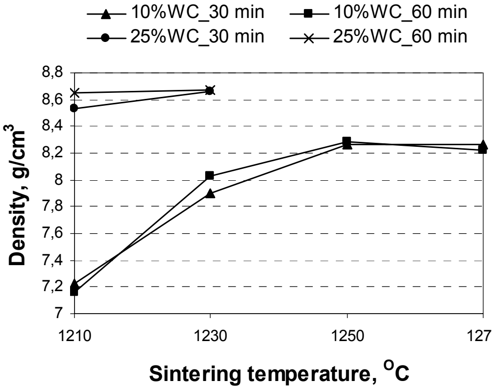

Fig. 3. The density/sintering temperature chart for PM speciments

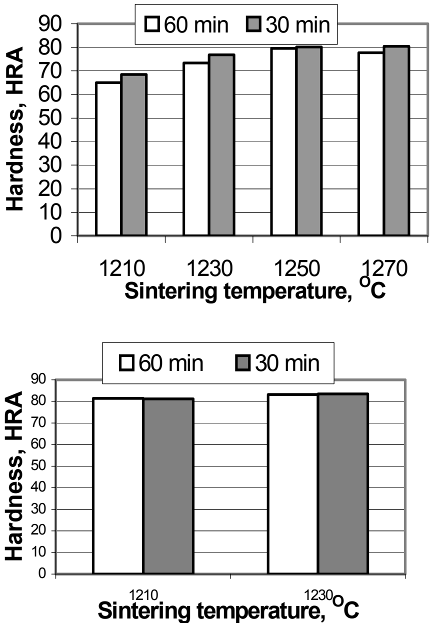
a)
b)

Fig. 4. Relationship of HRA hardness with the sintering temperature for test pieces with the surface layer: a)10%vol.WC + 90%vol.HS6-5-2, b) 25%vol.WC + 75%vol.HS6-5-2

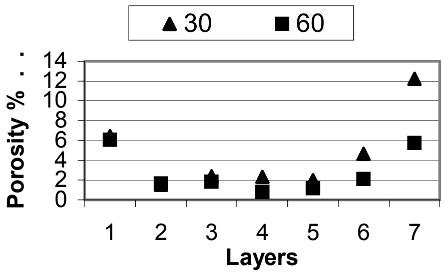

Fig. 5. Relationship of porosity with the layers for test pieces with the surface layer 10%.WC+90%HS6-5-2, sintered in vacuum in 1210^{o}C

The microstructures of the compacted and sintered test pieces are presented in Figure 6. The grey colour represents the matrix of the HS 6-5-2 high-speed steel, whereas the white colour corresponds to the tungsten carbides (WC) contained in the steel. One may notice that this test piece has the smallest porosity of its structure, demonstrating thus its higher density.

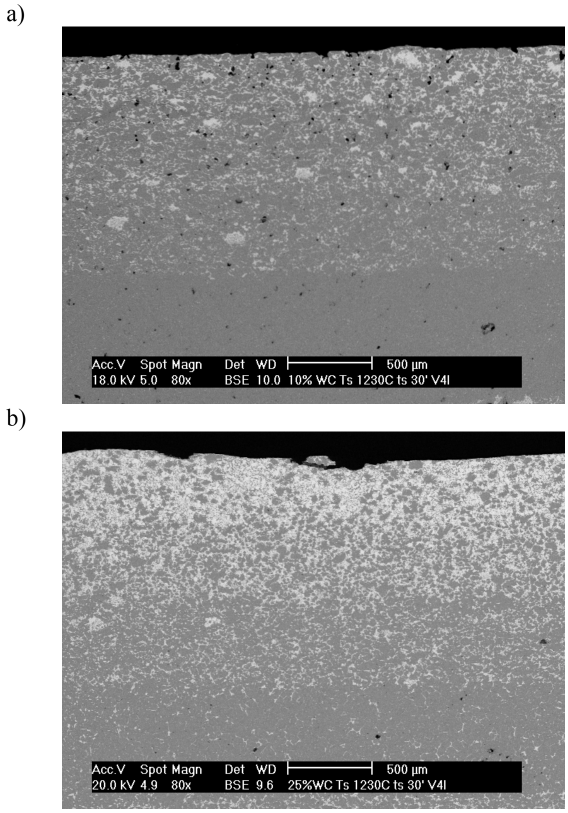

Fig. 6. Microstructure of the high-speed steel reinforced with the tungsten carbide, sintered in vacuum at the temperature 1230^{o}C for 30 min: a) 90%vol. HS6-5-2 +10%vol. WC in the surface layer b), 75%vol. HS6-5-2 +25%vol. WC in the surface layer

4. Conclusions

From the analysis of the obtained experimental data and microstructural observation it can be concluded, that as-sintered properties of gradient tool materials are strongly affected by the manufacturing process variables, and the tungsten carbide content as well. Addition of the WC carbides to HSS increases the hardness of the material. The hardness is increased with increased sintering temperature from 68HRA to 80,5HRA and from 79 HRA to 83 HRA for WC addition of 10% and 25% respectively. The highest hardness of 10%WC specimens was achieved for the sintering temperature 1270ºC and sintering time 30 min, meanwhile, the highest hardness of 25%WC specimens was achieved for the sintering temperature 1230ºC and sintering time 60 min. Microstructure analyses demonstrate, that for a higher sintering temperature better bonding of carbide particles with matrix is obtained, increasing the hardness of the material hardness.

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