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Gradient tool WC/HS6-5-2 materials produced using the powder metallurgy method

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ABSTRACT

Purpose: The goal of this work is development of the new group of the gradient cermets with the high-speed steel matrix, reinforced with the hard carbides phases of the WC types.

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 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 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

MATERIALS

1. Introduction

High requirements laid down to the contemporary tool materials, subjected to mechanical-, thermal- or chemical loads result in the growing need for search of new design and technological solutions. The goal of every tool materials designer is development and fabrication of the "ideal" tool material that would demonstrate both the high wear resistance in service and the high toughness. Fabrication of materials with the layered structure features one of such search possibilities [1-5]. The powder metallurgy method provides the relatively easy in practice, compared to other methods, distribution control of the reinforcing phase particles in the matrix and repeatability of the obtained results. This method has found wide application in tool materials production, above all of the high-speed steels, as it makes it possible to avoid the inhomogeneous structure resulting from the crystallization process during the conventional steel casting [6-9].

The goal of this work is development of the new group of the gradient cermets with the high-speed steel matrix, reinforced with the hard carbides phases of the WC types, development of their fabrication technology, and determining their structure and properties, characteristic of the high core ductility and high abrasion wear resistance of the working surfaces of the tool.

2. Experimental procedure

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 of compacting the powder in a closed die, and subsequent sintering. Chemical compositions and main properties of these powders are presented 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	> 1.8
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) in following proportions. Powder mixes were poured one after the other into the die yielding layers with the gradually changing percentage volume portions of carbides in the high-speed steel. For concentration in the surface layer of 10% WC the next intermediate layers were constituted containing 7% and 4% of these carbides respectively. The 10%WC contents are the maximum WC percentages in the surface layer for the pieces. The WC percentages for the remaining layers were chosen experimentally [10-15]. The proportions of the constituents for the four-layer test pieces are presented in Fig. 1.

The test pieces were compacted under the pressure of 500 MPa. Selection of the sintering parameters was made experimentally by variation of the green compacts sintering temperature, time, and atmosphere. The test pieces were sintered in the furnace with the flowing atmosphere of nitrogen with addition of N_2 + 5%H_2, at the temperatures of 1210, 1230, 1250, and 1270°C, for 30 and 60 minutes.

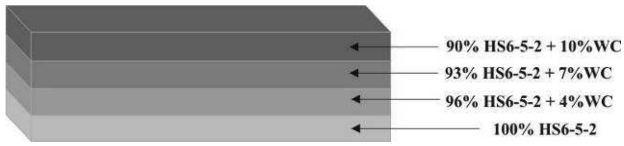

Fig. 1. The proportions of the constituents of the compacted and sintered four-layer test pieces

The sintered test pieces were subjected to examination of density and hardness. The effect of the sintering parameters on structure of the fabricated gradient materials was observed on the scanning electron microscope (SEM) at the accelerating voltage from 15 to 20 kV, at magnifications 2500 x, using detection of the secondary electrons (SE) and of the back scattered electrons (BSE). The test pieces were examined also using the X-ray qualitative phase analysis (EDX). Archimedes method was used to measure the density, consisting in measurement of the apparent test piece mass when immersed in water. Hardness tests with Rockwell method in scale A were made with the initial load of 98.07 N and total load of 588.4 N. HRA hardness was measured on faces of the surface layers. Ten measurements were taken on face surfaces of each test piece.

3. Results

The density measurement results obtained for the gradient cermets sintered in the furnace with the atmosphere of the flowing nitrogen with the addition of hydrogen (N_2+5%H_2) are presented in Figure 2.

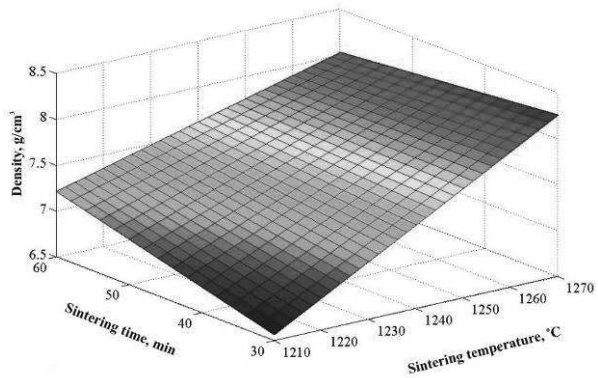

Fig. 2. The density / sintering temperature / sintering time regression chart for PM speciments sintering in the furnace with the atmosphere of the flowing nitrogen with the addition of hydrogen (N_2+5%H_2)

It was found out, based on density measurements, that the density of sinters grows with the sintering temperature and time. Density of the test piece changes from ca. 6.42 g/cm³ for

T_s=1210°C, to ca. 8.09 g/cm^3 for T_s=1270°C. Extension of the sintering time to 60 minutes does not result in a significant density growth.. The HRA hardness test results obtained for the face surfaces of the gradient cermets sintered in the furnace with the atmosphere of the flowing nitrogen with the addition of hydrogen (N_2+5%H_2) is presented in Figure 3. Addition of the WC carbides to HSS increases the hardness of the material. The significant effect of the sintering temperature on hardness is observed. The minimum average hardness (ca. 56.7 HRA) was obtained for the test pieces sintered at Tsp =1210°C; whereas, the maximum one (ca. 80.6 HRA) for Tsp =1270°C.

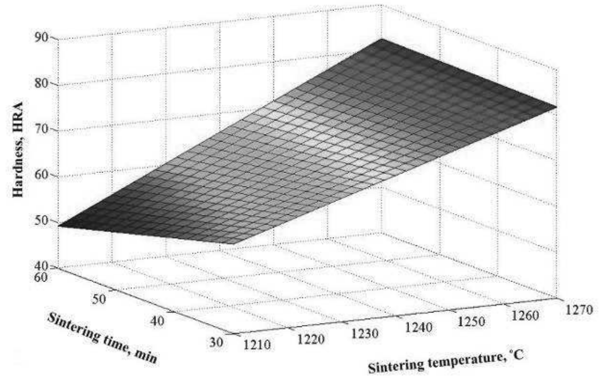

Fig. 3. The hardness / sintering temperature / sintering time regression chart for PM speciments sintering in the furnace with the atmosphere of the flowing nitrogen with the addition of hydrogen (N_2+5%H_2)

Structure photographs of the four-layers gradient materials sintered at the temperatures of 1230°C, for 60 minutes, taken on the scanning electron microscope, are shown in figures 4. A SEM BSE micrograph of the sintered test specimens is shown in figure 5a, whereas the EDAX microanalysis results of this layer are illustrated in figure 5b. Effect of temperature and time in materials are shown in Figure 6. 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. 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. The bright precipitate rich in tungsten, molybdenum and iron is the carbide M_6C, which was confirmed in prior research. Structure change of the layer with the high-speed steel is discernible for T_s=1230°C and T_s=60min in test pieces with the 10%WC in the surface layer. Some carbides occupy areas with the concave surfaces and have the shape characteristic of the eutectic ones. These areas originated from the liquid state and crystallised as the last ones, among the austenite grains. Temperature increase causes growth and coagulation of the primary carbides. The structure appears characteristic of the remelted high-speed steel. Big carbides are distributed mostly at grain boundaries; whereas, the fine carbides are distributed inside the grains. More and more areas with the eutectic carbides are observed upwards from the temperature of 1250°C and time of 60 minutes. For T_s=1270°C only the elongated narrow carbides are observed distributed at some grain boundaries.

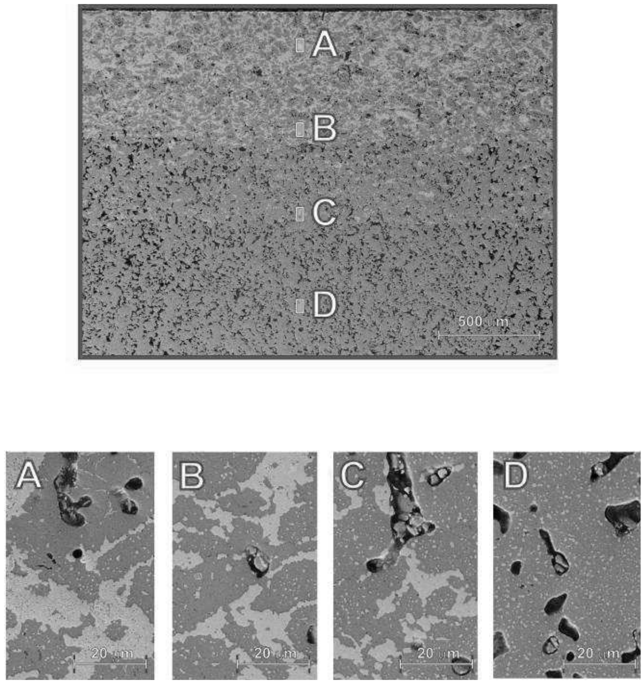

Fig. 4. Structure photographs of the four-layers gradient materials sintered at the temperatures of 1230°C, for 60 minutes, taken on the scanning electron microscope

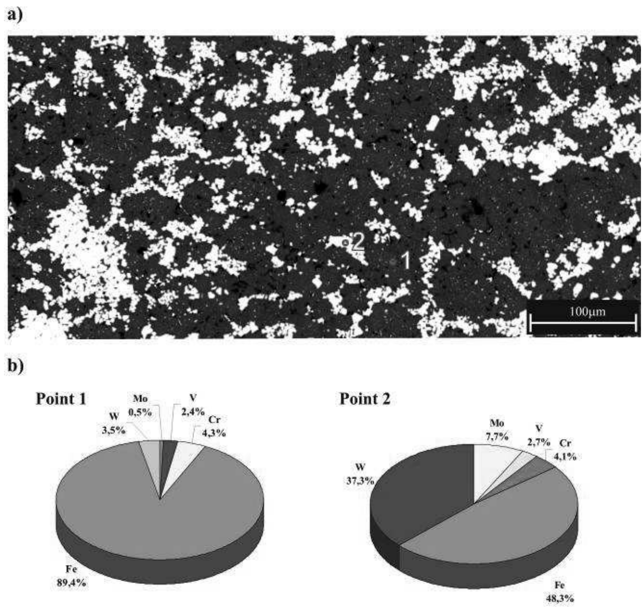

Fig. 5. Results of the X-ray analysis (EDX) of the 90M2/10WC test piece sintered at temperature T_s=1250°C for t_s=60 min: a) structure with analysed points, b) results of X-ray microanalysis (EDX) representing atomic concentrations of elements in selected points

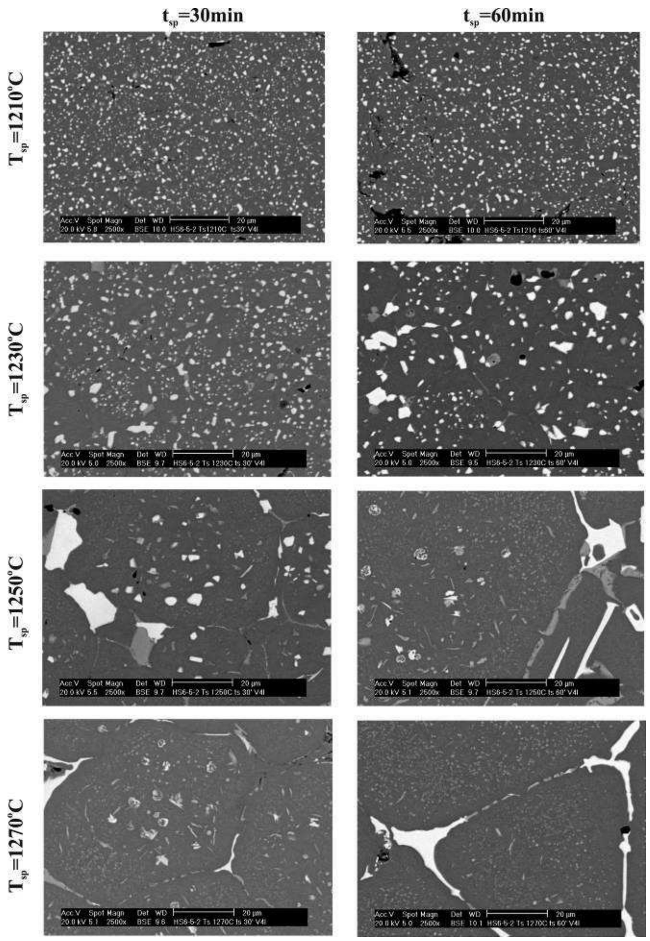

Fig. 6. The effect of temperature and sintering time on structure of the surface HS6-5-2 layers

4. Summary

It was found out, based on the investigations of the gradient materials with the high-speed steel matrix reinforced inside its volume with the hard carbide phases of the WC type, that fabrication of the gradient materials with the conventional powder metallurgy method may decrease the carbide phase portion in favour to the ductile matrix portion increase. Moreover, the proposed fabrication method ensures the relatively simple in accomplishment distribution control of the reinforcing phases particles in the matrix and also repeatability of the obtained results. The possibility of easy dosing and mixing the matrix material with the hard carbide phases improves significantly its mechanical properties maintaining the required high ductility of the tool core. These carbides, depending on the sintering parameters are evenly distributed in the matrix, are subject to coagulation at the grain borders or develop big precipitations at the grain borders. The visible pores in the layers indicate to the incomplete sintering process. The pores disappear along with the high speed steel content growth in the particular layers.

Acknowledgements

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