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

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Materials

ABSTRACT

Purpose: 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.
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 the HS6-5-2 high-speed steel and non-alloy steel powders, making it possible to obtain materials with three layers, and later - after their further modification - with six layers in their structure.
Findings: It was found out basing on the microhardness tests that hardness of test pieces grows along with the sintering temperature and with carbon content in the interface and non-alloy layers. It was also observed that porosity decreases along with the carbon content 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 non-alloy steel with hardness growing with the increase of carbon content, and on the other side the high-speed steel, characteristic of the high ductility. Such material is tested for turning tools.
Originality/value: The layers were poured in such way that the first layers consisted of the non-alloy steel and the last one from the high-speed steel, and were compacted next. The layers inside the material are mixes of the high-speed steel and non-alloy steel powders in the relevant proportions.
Keywords: Tool materials; Powder metallurgy; High-speed steel; Sintering

1. Introduction

Manufacturing of gradient materials yields the possibility to control the initial prepreg composition to obtain the sinter with the variable composition of phases in the material volume. The sinter is fabricated from the prepreg formed from powders of two different phases. The polycrystal of one phase is transformed in a continuous way into the other phase's polycrystal. This is connected with forming of the specific product properties (gradient of properties). Such materials are called the functional gradient materials (FGM). The controlled change of the phase composition in the material volume occurs in gradient materials. Such material composition makes it possible to obtain the specific properties depending on service conditions of the elements, e.g.: a hard material layer us used where the product is subject to abrasion, and in others, where it may be more subject to impacts one may use materials characteristic of a high ductility [9,13,16]. 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 o 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 [12]. 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 compaction the powder in the closed die and finally sintering it. Powders used for fabricating the test pieces are listed in Table 1. The HS6-5-2 high-speed steel powders atomised with water and powders from iron and carbide are presented in Figure 1. The HS6-5-2 high-speed steel powder chemical composition atomised with water is presented 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 HOGANAS
Fe	>50	Company Eckagranules, Sénécorut, F-60140 Baileval
C	99,5%<40 50%<18	Natural carbon, laminar class EDM96-97, ISMAF

Table 2.
Chemical composition of the Hoganas HS 6-5-2 steel powder

Element	Mass concentration HS 6-5-2, [%]
C	0.75÷0.90
Mn	0.20÷0.45
Si	≤0.45
P	≤0.04
S	≤0.04
Cr	3.75÷4.5
Ni	0.2
Mo	4.5÷5.5
W	5.50÷6.75
V	1.6÷2.2
Co	0.1
Cu	0.1

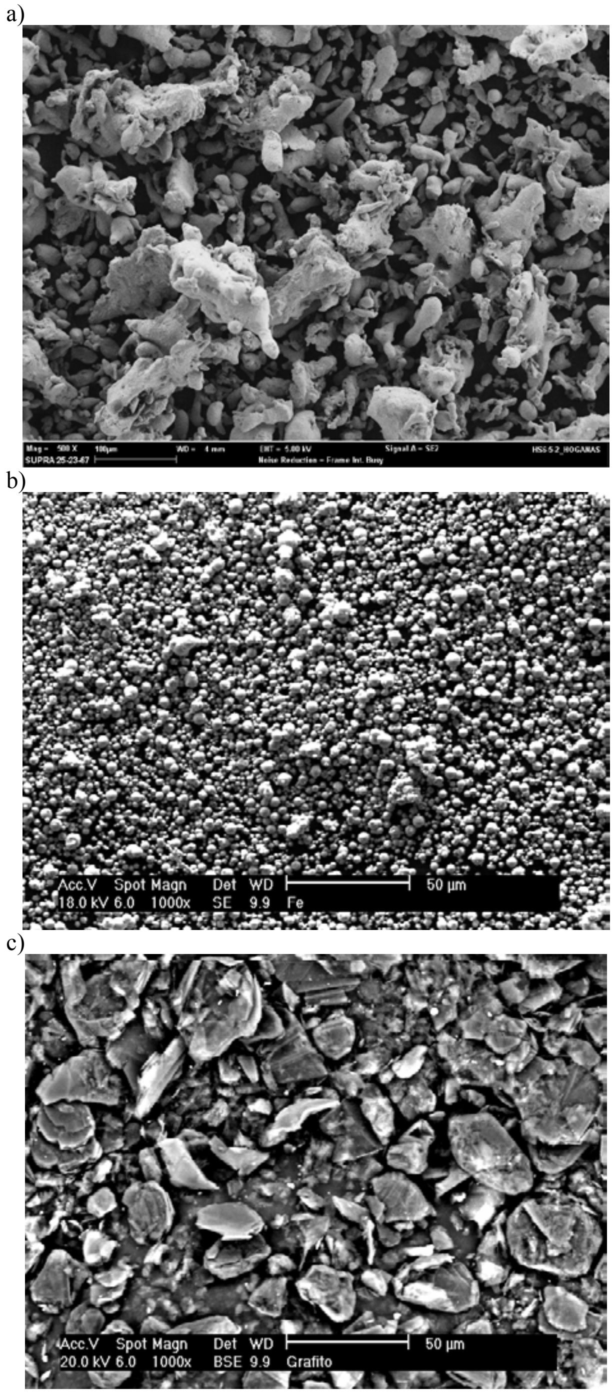

Fig. 1. Powder morphology: a) HS6-5-2 atomised with water, b) iron, c) carbon

The uniaxial compacting method was used for making the prepregs. The compacted and sintered test pieces were made from the HS6-5-2 powder and from the non-alloy steel powder with the different carbon content. Three layers were poured into the die in the first experiment. The first layer consists from the non-alloy steel powder with the carbon content 0.5%, the second - the so called intermediate layer - is the mix of the non-alloy steel and the HS 6-5-3 high-speed steel in proportion as shown in Figure 2; whereas the third layer consists from the HS 6-5-2 steel powder. Compaction was made in the uniaxial unilateral die, at the pressure of 500 MPa.

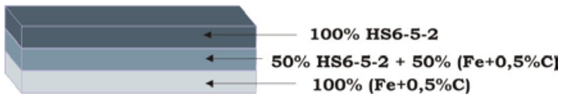

Fig 2. Uniaxial compacting - powders forming proportions

The compacted test pieces were sintered in the vacuum furnace at the temperatures of 1100÷1350°C every 50°C.

It was found out basing on investigations of the materials that the portion of pores in the particular layers of the gradient materials decreases along with the carbon concentration increase in particular layers. An increase of carbon concentration lowers the sintering temperature in all layers. Therefore, five test pieces were made with various carbon contents to select the optimum value of carbon concentration and sintering temperature. The way in which the powder mix is poured was also modified. Test pieces with six layers were made to obtain the continuous gradient between the layers (Fig.3).

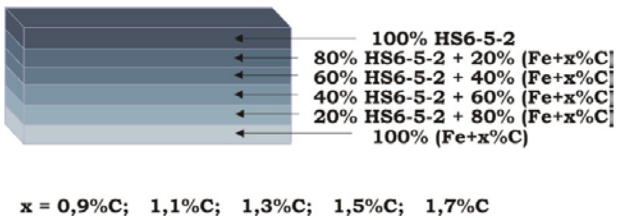

Fig. 3 Powder forming sequence and proportions uniaxially pressed

All modified test pieces were sintered in the vacuum furnace at the temperature of 1250°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 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. Microhardness was measured using the Vickers microhardness tester at the indenter load value of 9.8 N. The tests were made across the entire test piece transverse section. In test pieces with three layers, there are seven test points in each layer; whereas in test pieces with six layers there are about two test points due to impossibility to identify boundaries between the layers and small width of the particular layers. Porosity measurement was made using the optical microscope on the non-modified test pieces. Each time five random points from each layer were selected for tests.

3. Description of achieved results of own researches

Density of the compacted and sintered test pieces grows along with the sintering temperature increase (Fig. 4).

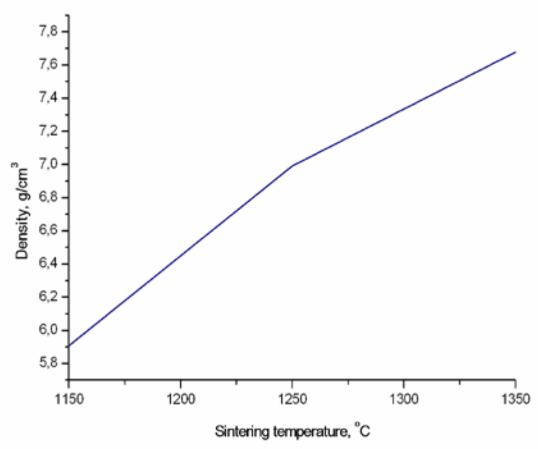

Fig. 4 The density/sintering temperature chart for PM speciments

Microhardness of the compacted and sintered test pieces grows along with the carbon concentration and sintering temperature increase. The layer from steel without any addition of alloying elements demonstrates very low hardness compared to the intermediate layers and the layer from the HS6-5-2 high-speed steel (Fig5).

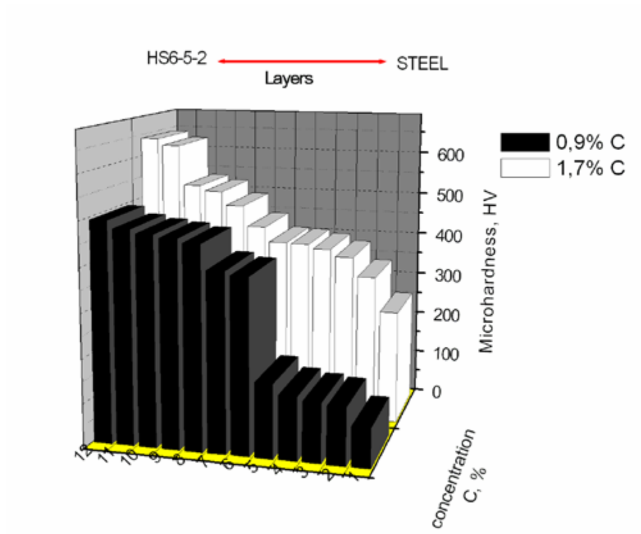

Fig. 5 Mean hardness values (for six layers) for PM specimens

In case of the test pieces sintered at temperature of 1250°C - with three layers - one may observe three layers changing gradually (in the material volume) - Fig.6a. In case of test pieces with a bigger number of layers the boundaries between layers disappear as the carbon concentration grows in the particular layers (Fig. 6b). In case of materials with the highest carbon content (1.7%) boundaries between the layers are no longer visible. The visible pores in layers with the non-alloy steel indicate to the incomplete sintering process. The pores disappear along with the sintering temperature and carbon content growth in the particular layers.

a)
b)

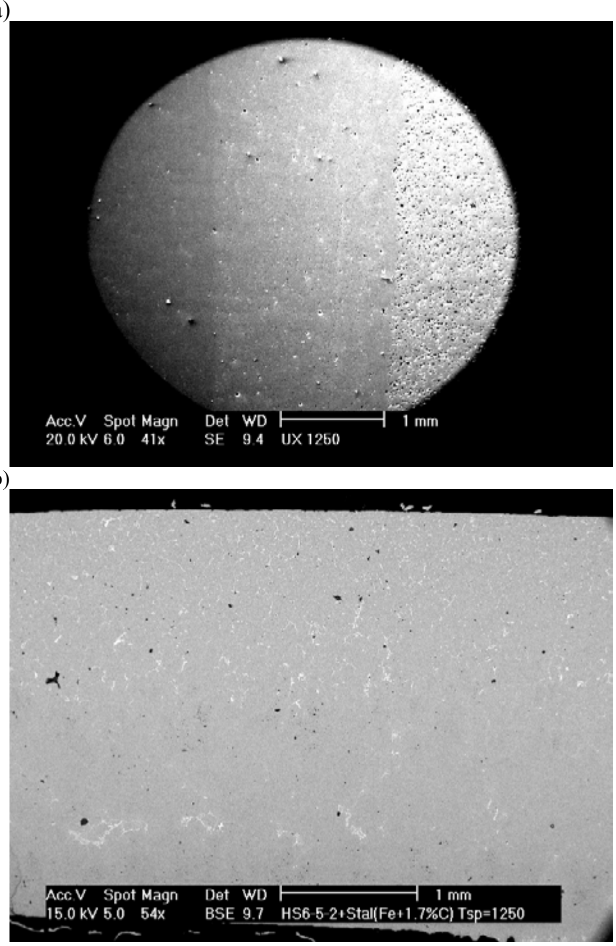

Fig. 6. The structure of specimens sintered at the temperature of 1250^{o}C after uniaxial pressing, a) with three layers, b) with six layers in their structure

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