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Structure and properties of tool gradient materials reinforced with the WC carbides

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Properties

ABSTRACT

Purpose: The purpose of the paper is to describe sintered Tool Gradient Materials manufactured by powder metallurgy process. The Powder Metallurgy method has been chosen to manufacture tool gradient materials with high disproportion of cobalt matrix portion between core and surface layer.
Design/methodology/approach: Forming methods were developed during the investigations for tungsten carbide and cobalt, making it possible to obtain materials wits five layers in their structure.
Findings: : High diversification of cobalt matrix portion in comparison to hard phases in subsequent layers of gradient materials leads to their deformation in as sintered state. In case of all gradient materials, mean hardness was equal about 1750 HV1. Whereas, hardness of lower cobalt matrix rich layers is about 1548 HV1 and increased up to 2154 HV1 for lower layer of material rich with hard carbide phases. The porosity decreases along with the carbon content in these layers.
Practical implications: Material presented in this paper is characterized by very high hardness of the surface and relative ductility of core. TGM with a smooth changes of the cobalt phase in the material.
Originality/value: The obtained results show the possibility of manufacturing of TGM on basis of different portion of cobalt reinforced with hard ceramics particles carried out in order to improve the abrasion resistance and ductility of tool cutting materials.
Keywords: Cemented carbides; Tool gradient materials; Powder metallurgy; Sintering

1. Introduction

Functionally Gradient Materials (FGM) are a new group materials having intresting properties. Different gradient can be formed in FGM`s [3-8.]

Functionally gradient cemented carbides have drawn the interest of hard material industries. These tools materials are harder and more wear resistant than traditional tungsten carbide – cobalt alloys. The chance mechanical, electrical properties, etc. can be obtained [1,2,5].

The gradient tool materials also find new applications in metal cutting, metal forming and wear resistant parts.

The main method used in the production of these materials is powder metallurgy. Powder metallurgy technique allows producing tool materials with high mechanical properties using almost whole material, without scraps. Produced and subsequently formed powders make materials with high mechanical strength, hardness and low abrasive wear [12-15].

Powder metallurgy is the best way to develop new materials, then the cemented carbides industry is considered as the most stable activity of powder metallurgy [8-11].

2. Materials and methods

The investigated materials were made according to the layered FGM model. Tests were conduced on WC – Co cemented carbide. The investigated powders used for researches were WC tungsten carbide and cobalt as a binder

Powders were weighted in proper proportions and mixed dry. Mixtures were milled in a Shaker mixer/ mill (Spex 8000) through 180 min (Fig. 1 and 2). The weigh ratio of balls to powders was 1:1.

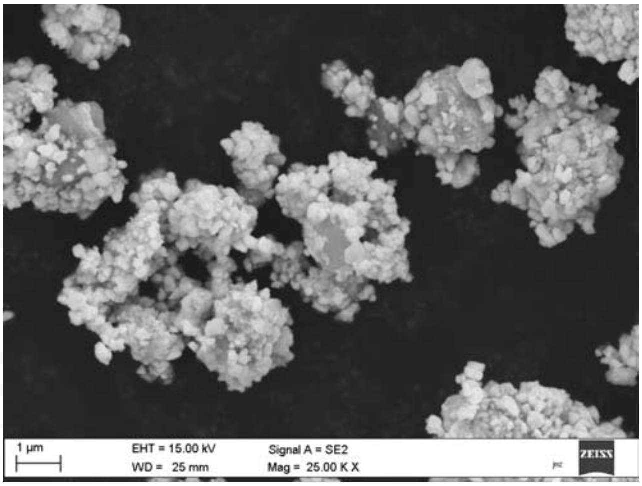

Fig. 1. Microstructure of WC 85% + Co 15% after milling.

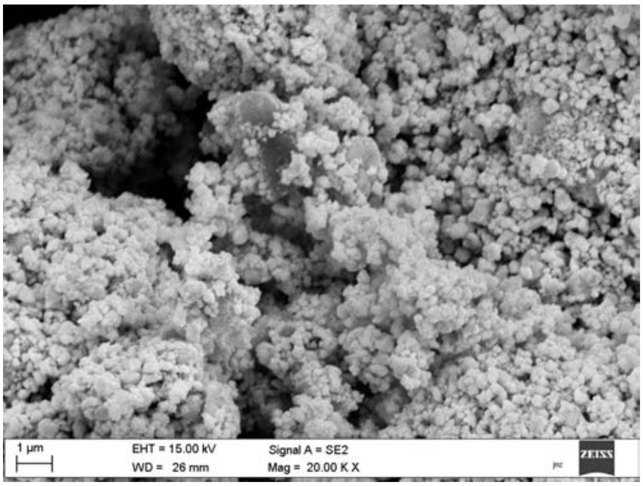

Fig. 2. Microstructure of WC 97% + Co 3% after milling.

Connection of layers (Table 1) is achieved through uniaxial and unilateral pressing under pressure about of 340MPa, for 1 min. In to such prepared powder mixes of hard phases and cobalt, in order to increase sliding between grains and the grains and die during pressing, 2% of paraffin has been added.

Table 1.
Chemical composition of TGM samples

Sample	Chemical composition		
	WC [%]	Co [%]	Paraffin [%]
A2	97	3	2
	96	4	
	95	5	
	94	6	
	93	7	
A4	97	3	
	94	6	
	91	9	
	88	12	
	85	15	

Compacts with dimensions 25mm x 5mm were sintered in vacuum furnace, in the temperature of 1460^{o}C and the top temperature holding times were 1 hour (fig. 3).

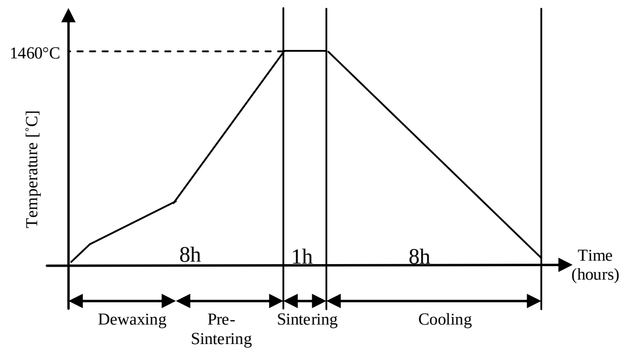

Fig. 3. Relation between time and temperature during the technology cycle

All obtained samples of gradient materials were then tested with:

- hardness test (Vickers),
- light and scanning microscopy (Zeiss Supra 25 and Opton DSM 940 scanning electron microscopes, using the accelerating voltage of 5-20 kV) for microstructure studies,
- the open porosity of investigated samples was calculated on the base of the equation:

$$P_o = \frac{m_n - m_s}{m_n - m_w} \cdot 100\% \qquad (1)$$

P_o - open porosity [%]
m_s – dry sample mass [g]
m_n – saturated water sample mass [g]
m_w – mass of sample weigthed in water [g]

- the total porosity of investigated samples was calculated on the base of the equation:

$$P_c = \frac{d - d_p}{d} \cdot 100\% \qquad (2)$$

d-reality density of sample [g/cm^3]
d_p-relative density [g/cm^3]

- the relative density of investigated samples was calculated on the base of the equation:

$$d_p = \frac{m_s}{m_n - m_w} \cdot d_c \quad (3)$$

where:
d_p - relative density [g/cm^3]
d_c - water density on measurement temperature [g/cm^3]

3. Results

Changes of microstructure and mechanical properties were investigated. Microscopic observations indicate that sintering process caused decay of clear boundaries between the layers. Therefore, for further researches of material, three main layers have been considered: upper layer, with maximum participation of hard ceramic phases, central and lower layer with maximum amount of cobalt.

The sintered samples A2 and A4 were tested with the Vickers indentation method. The tests were made under the load of 4.9 N. Indents were made on the microsections inside the layers so as to give an answer to the question how the properties of the received sample change on the way from lower cobalt matrix rich layers to upper layer of material rich with hard carbide phases. It was observed the increase of hardness from 1750HV op to 2154 HV, respectively.

Figure 4 shows a graph of the hardness Tool Gradient Materials layers vs Co content. However from the whole graph it is obvious that the hardness decrease. Hardness of the sample A2 is much higher than the sample A4.

The samples A2 and A4 produced by powder metallurgy method, the main parameter of the structure are open porosity and total porosity (Fig. 5) and relative density presented fig. 6.

The contribution of hard phases, present in gradient material, has also an influence on porosity. According to metallographic tests on of sintered samples of gradient materials it was stated, that low porosity was obtained for layers WC 97%+Co 3%.

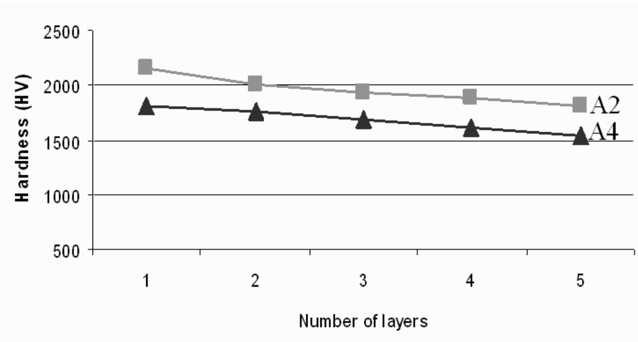

Fig. 4. Tool Gradient Materials layers hardness vs Co content

Large and heterogeneous pores in gradient material, are present only locally and can be created because of improper samples preparation, inappropriate conditions of powder mixing. Gradient material was obtained using dry method, which led to connection of powder mixes with paraffin in a wrong way. The degradation of paraffin causes formation of big pore, not possible to remove during sintering process. Basing on Vickers hardness testing it was revealed, that the highest hardness was achieved for sinter WC +Co.

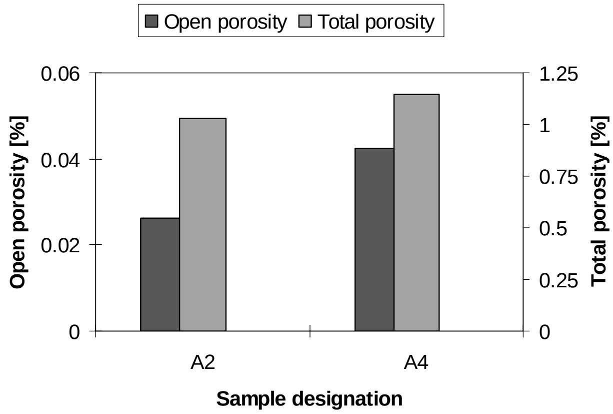

Fig. 5. Porosity in the sample A2 and A4

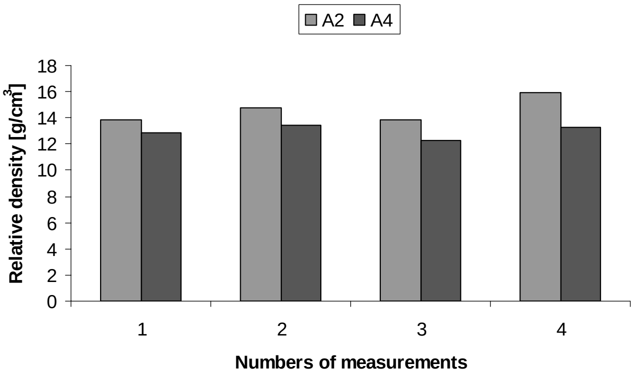

Fig. 6. Relative density in the sample A2 and A4

This layer is characterized by great portion of pores but with small sizes, what influences the increase of hardness. Generally, as a result of hardness and porosity, it was found that there is a correlation between hardness and porosity. Layers with highest porosity and layers with pores with large surfaces obtained low hardness values.

In both gradient materials, in TGM A2 type and A4 (Fig. 7-9) type, was observed the shrinkage, caused by high participation of cobalt in comparison to hard carbide phases.

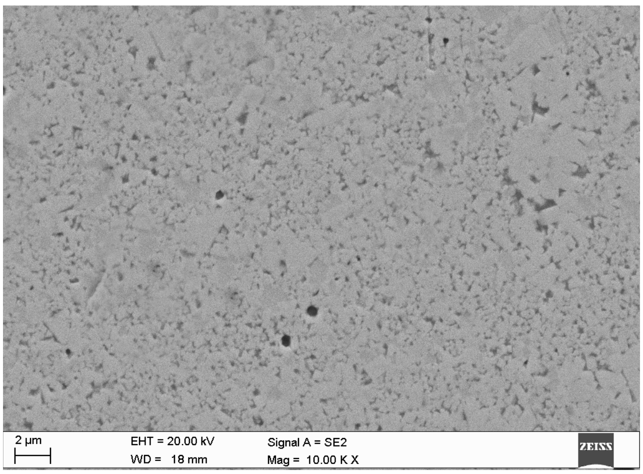

Fig. 7. Structure of A 4, layer1 (WC 97% + Co 3%)

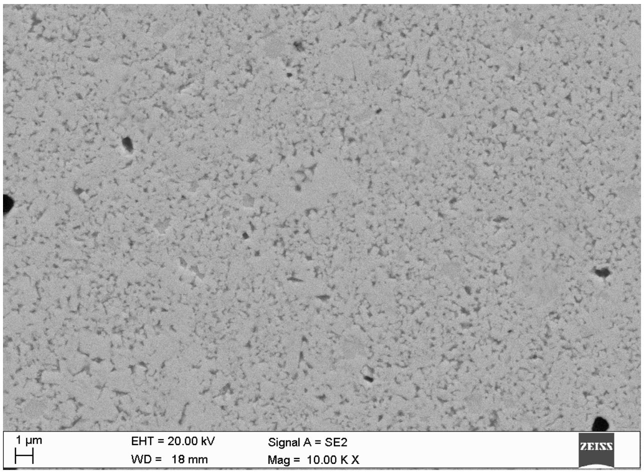

Fig. 8. Structure of A 4, layer 2 (WC 94% + Co 6%)

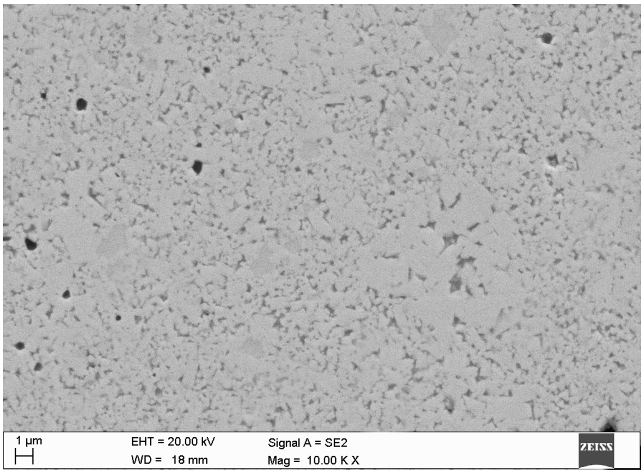

Fig. 9. Structure of A 4, layer 4 (WC 88% + Co 12%)

The shrinkage is an unwanted phenomenon, because it causes deformation of material. Hence, gradient materials should be designed in a way that doesn't allow the disproportion in participation of cobalt between layers and creating local shrinkage and deformation of sinters.

4. Conclusions

On the base of obtained investigation results it was found that by the use of powder metallurgy method is possible to obtain gradient of the microstructure. In samples A2 and A4 examined there is clearly visible gradient zone in material.

The hardness of sample A4 is lower than sample A2, so the aim of the present work- obtaining a hard – soft ceramic TGM material, has been obtained. The mean hardness, in the case of all investigated gradient materials, was equal about 1749 HV1. The hardness of lower layers, rich with cobalt matrix, was equal about 1548 HV1 and increased up to 2154 HV1 in upper layer of material rich with hard carbide phases.

Acknowledgements

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