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The computer simulation of internal stresses of tool gradient materials reinforced with the WC-Co

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ABSTRACT

Purpose: The general topic of this paper is the computer simulation with the use of finite element method for determining the internal stresses in tool gradient materials WC-Co obtained in the powder metallurgy process in different temperatures of 1400°C + HIP and 1460°C + HIP.

Design/methodology/approach: The following research studies have been carried out a new group of sintered tool gradient materials, tungsten carbide with cobalt matrix, modeling of stresses was performed used of finite elements method in ANSYS environment, and the experimental values of stresses were determined basing on the X-ray diffraction patterns.

Findings: The developed model of the tool consists of four layers with different contents of tungsten carbide and the concentration of cobalt by using the finite element method allows to simulate the impact of sintering temperature on the stress occurring in the material. On the basis of the model, it was found that by properly controlled treatment technology, able to induce compressive stresses in the surface layer of material, thus increasing the resistance of the material on the formation and propagation of cracks.

Research limitations/implications: It was confirmed that using of finite element method can be a way for Computer simulation of stresses, strains and displacements of the fabricated gradient material depending on the sintering temperature. Results reached in this way are satisfying and in slight degree differ from results reached by experimental method. However for achieving better calculation accuracy in further researches it should be developed given model which was presented in this paper.

Originality/value: The obtained results show the possibility to manufacture TGMs on the basis of different portions of cobalt reinforced with hard ceramics particles in order. The computer simulation is based on the finite element method, which allows to better understand the interdependence between parameters of process and choosing optimal solution.

Keywords: Cemented carbide; Powder metallurgy; Finite Element Method

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METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

A rapid development of the industry, technology and know-how induces the introduction of higher standards to meet the requirements which the sintered tool materials have to satisfy with respect to mechanical properties and resistance to wear. The functional properties of many products and of their components depend not only on the ability to transfer mechanical load through the whole active section of the component, on its physicochemical properties but also on the structure and properties of the material. The common fault of the operating tools is their tendency to crack, which in most cases eliminate the tool from further service, and the wear gradually and progressively diminishes its operating efficiency. Hence the resistance to cracking is a basic property, since the occurrence of minute microstructural defects results in the formation and propagation of cracks, whereas the resistance to wear stays unchanged [1-4].

A considerable share of cobalt matrix results in high ductility of the core, since the propagation of a crack through cobalt is connected with the dissipation of relatively high energy. In contrast, transcrystalline cracks through carbide grains have the character of low energy brittle cracks. The combination of high hardness and resistance to abrasive wear with high resistance to brittle cracking is unobtainable in one homogeneous material. The acquisition of tool materials (Tool Gradient Materials (TGMs)) fabricated with the use of powder metallurgy method, in effect of the gradient change of binding cobalt phase and the reinforcing phase of tungsten carbide, aims to solve the problem involving the combination of high hardness and resistance to abrasive wear with high resistance to brittle cracking, and consequently, to ensure their optimal synergy with operating conditions. The cutting edges of drill bits should combine in themselves these two contradictory properties where the surface layer is resistant to abrasive wear and the base is characterized by raised resistance to brittle cracking [5-9].

2. Experimental

2.1. Material and preparation of specimens for analysis

The analysis was carried out on specimens produced with the conventional method of powder metallurgy which consists in compacting in a closed moulding the successive, added layers having a gradually changing volumetric share of cobalt and tungsten carbide. In the research studies, we applied the powders of tungsten carbide (Fig. 1) and of cobalt (Fig. 2). When selecting the material, we accepted the requirements involving its application in agreement with the Standard PN-ISO 513:1999. Then the compacts from wolfram carbide with cobalt matrix were formed, coating the moulding with successive layers of variable phase composition (Table 1).

Using the obtained mixtures, WC-Co compacts were prepared for analysis in which, from the surface side of the layer, successive transit layers were formed with progressively lower share of wolfram carbide down to the base [10-13]. The pressure during the pressing was being selected experimentally, pressing the powders in a closed moulding on a uniaxial hydraulic press under the pressure changing within the range from 300 to 450 MPa.

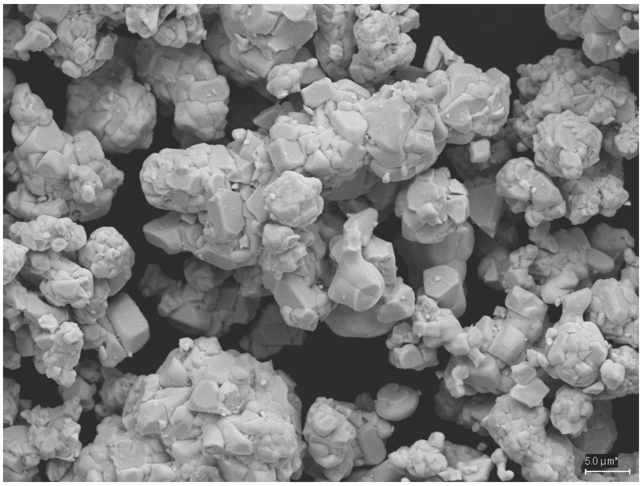

Fig. 1. Tungsten carbide powder

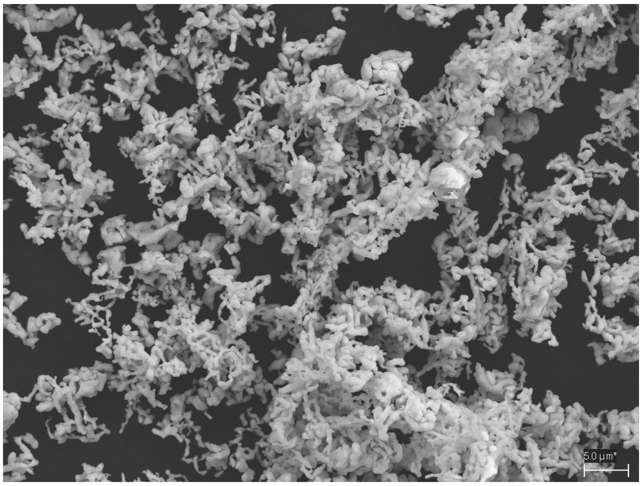

Fig. 2. Cobalt powder

Table 1.
Denotation of WC-Co tool gradient material specimens

Designation	3-9Co/97-91WC_4
Layers	3%Co+97%WC
	5%Co+95%WC
	7%Co+93%WC
	9%Co+91%WC

The specimens were sintered in a vacuum furnace in the conditions presented in the Table 2. In order to obtain better densification level, after the ultimate cementing, the compacting of sinters through hot isostatic pressing - HIP) was applied at the temperature of 1425°C and under the pressure of 200 MPa.

Table 2.
Cementing conditions for the newly elaborated tool gradient material 3-9%Co/97-91%WC

Cementing type	Cementing conditions		
	t_{sp}, min	T_{sp}	
Unbound	30	1400°C 1460°C	
With isostatic compacting	90	1400°C 1460°C	1425°C

2.2. Methodology

In the tests on the tool gradient materials of carbide, the finite elements method was applied for the computer simulation of internal-stresses [14-16]. The true model of the tool gradient material was designed in the program Inventor 11, and the strength analysis was carried out using the program ANSYS 12.0. On account of the predicted simulation range, parametric input files were elaborated which allow to carry out the analysis comprehensively [17].

In order to carry out the simulation of internal-stresses of the tool gradient material, the following boundary conditions were accepted:

- the change of cementing temperature is reflected by the cooling process of the specimen from 1400°C and 1460°C to the ambient temperature of 22°C,
- for the fabricated material, the material properties were accepted basing on the characteristics cards of MatWeb catalogue which were presented in Table 3.

The model which the main aim is to determine internal-stresses of tool operation was worked out using the finite elements method, taking into consideration the true dimensions of the specimen(Fig. 3), where:

- the first layer – 3%Co+97%WC,
- the second layer – 5%Co+95%WC,
- the third layer – 7%Co+93%WC,
- the fourth layer – 9%Co+91%WC.

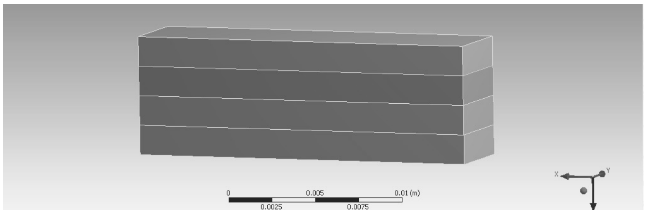

Fig. 3. True model of the fabricated material consisting of four layers of different share of tungsten carbide and of different cobalt concentration

The true model was subjected to digitization (Fig. 4). The calculation model consists of 4968 nodes and 760 elements.

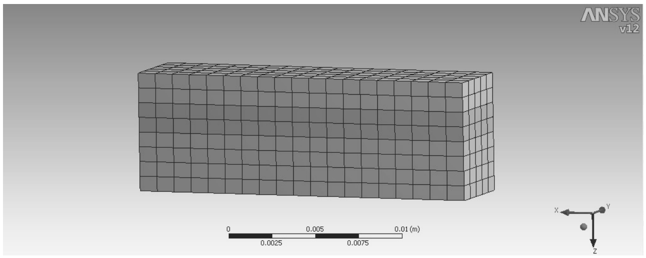

Fig. 4. True model of the fabricated material consisting of four layers of different share of tungsten carbide and different cobalt concentration after digitization

Table 3.
List of mechanical and physical properties accepted in the computer simulation of internal-stresses occurring in the fabricated material consisting of four layers of a difference share of tungsten carbide and of different cobalt concentration [18]

Properties	Phase composition of the layers of tool gradient material			
	3%Co+97% WC	5%Co+95% WC	7%Co+93% WC	9%Co+91% WC
Young modulus, Pa (10^9)	665	640	615	590
Poisson factor	0.2809	0.2815	0.4774	0.5338
Density, kg/m^3 (10^3)	15.4	15.1	14.8	14.5
Thermal expansion, 1/C (10^{-6})	4.1	4.3	4.5	4.7
Thermal conductivity, W/ Mc	98	90	82	76
Specific heat, J/kgC	138.7	144.5	150.3	156.1
Resistivity (specific resistance), Ωm	5.4252	5.442	5.4588	5.4756
Tensile strength, Pa (10^6)	1670.75	1641.25	1611.75	1580.25

The computer simulation was carried out in in three stages:

- the first stage involved the simulation of internal-stresses of the sinter consisting of four layers of different share of tungsten carbide and cobalt depending on the cementing temperature,
- the second stage included the comparative analysis of the computer simulation of the internal-stresses of the tool gradient material with the experimental results,
- the third stage involved the computer simulation of operation strains of the fabricated tool gradient material applied for example in mining machinery.

The model where of main objective is to determine internal-stresses of the fabricated material was made using the finite elements method, assuming the true dimensions of the specimen (Fig. 5).

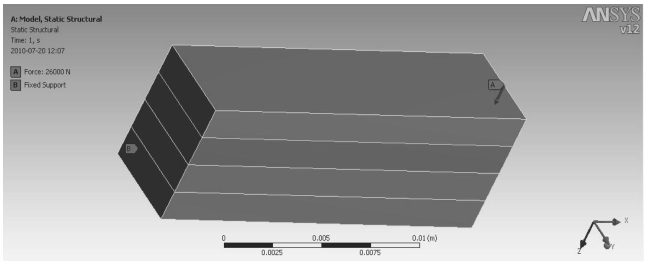

Fig. 5. True model of the fabricated material consisting of four layers of different share of tungsten carbide and of different cobalt concentration with the applied boundary conditions

In order to verify the obtained results experimentally through the modeling with the finite elements method on the basis of measurements carried out by means of X-ray spectrometry, the true internal-stresses in the investigated materials were calculated. The calculations were carried out with the use of sin2ψ method, basing on the brand-name program X'Pert Stress Plus. The program has a data base with data indispensable to calculate the values of material constants. Then, the comparative analysis of computer simulation with experimental results was carried out.

3. Investigations results

Figure 6 presents the results of numerical analysis using the finite elements method gathered in the form of maps of stress distribution in the tool material consisting of four layers of different concentration of tungsten carbide and cobalt for the sintering temperature of 1400 and 1460°C. The elaborated model of the tool allows to simulate the influence of sintering temperature on stresses (Fig. 6).

The calculation results of internal-stresses in the investigated materials obtained on the basis of reflex shift analysis (201) using the sin2ψ method carried out to verify the modelling results are presented in Figs. 7,8 and in Table 4.

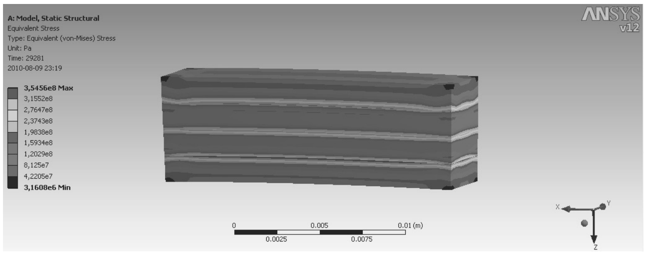

Fig. 6. The distribution of simulated internal-stresses occurring in the cutting edge of a tool consisting of four layers of different share of tungsten carbide and cobalt for the sintering temperature of 1460°C

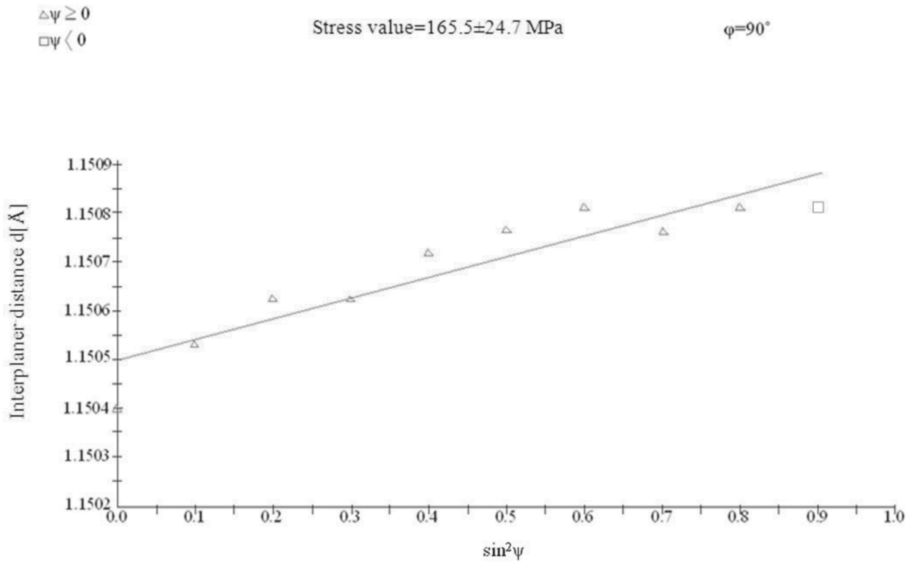

Fig. 7. Changes of interplanar distance d of the reflex (201) in the function of $\sin^2\psi$, sintering temperature of 1460°C, 3%Co+97%WC

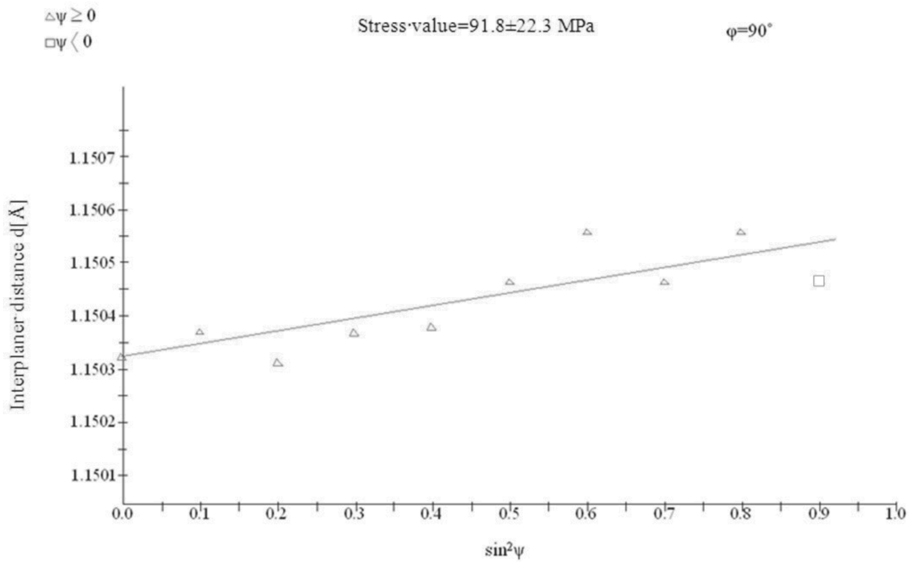

Fig. 8. Changes of interplanar distance d of the reflex (201) in the function of sin2ψ, sintering temperature of 1460°C, 9%Co+91%WC

Basing on the carried out investigation studies it was demonstrated that the highest stress values are characteristic of the material sintered at the temperature of 1460°C. They occur in the surface layer and equal 165 ± 24 MPa, and the simulated stresses equal 170MPa. The base is characterized by lower stresses as compared to the upper layer. The stresses determined experimentally equal 91±22 MPa and the simulated stresses 80MPa. The lowest stresses determined experimentally and with the use of computer simulation occur in the tool gradient material sintered at the temperature of 1400°C. The value of these stresses determined experimentally in the upper layer is 123±24 MPa, and the value of simulated stresses equals 116 MPa. The calculated values of stresses in the base are 41±9 and 36 for the simulated stresses.

The results of internal-stresses obtained with the computer simulation using the finite elements method are in agreement with the results of stress measurements obtained with the use of sin2ψ method (Table 4).

Table 4
Comparison of stresses obtained experimentally with the results of computer simulation

	Sintering temperature, °C	Stresses determined experimentally, MPa	Simulated stresses, MPa
Upper layer 3%Co+97%WC	1400	123 ± 24	116
	1460	165 ± 24	170
Bottom layer 9%Co+91%WC	1400	41 ± 9	36
	1460	91 ± 22	80

Figures 9-11 present the results of the computer simulation of the fabricated material, allowing for the mechanical loads simulating operating conditions (in mining or drilling machines), gathered as the maps of shifts, strains and stresses distribution.

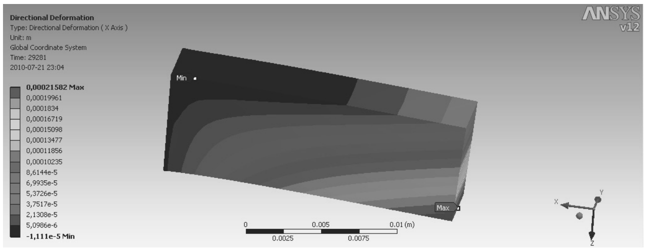

Fig. 9. Distribution of the simulated shifts occurring in the cutting edge of a tool consisting of four layers of different share of tungsten carbide and cobalt for the sintering temperature T_{sp}=1460°C

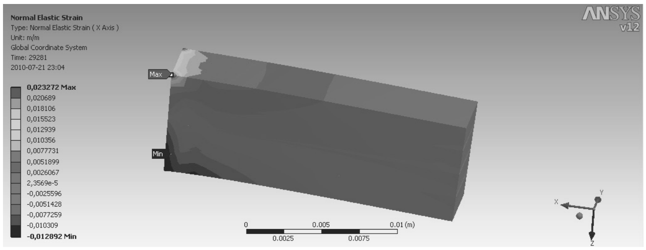

Fig. 10. Distribution of the simulated strains occurring in the cutting edge of a tool consisting of four layers of different share of tungsten carbide and cobalt for the sintering temperature T_{sp}=1460°C

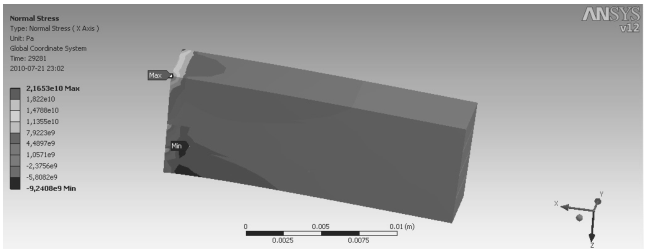

Fig. 11. Distribution of the simulated stresses occurring in the cutting edge of a tool consisting of four layers of different share of tungsten carbide and cobalt for the sintering temperature T_{sp}=1460°C

It was showed, basing on the elaborated model, that through appropriately applied technological procedures, it is possible to evoke tensile stresses in the surface layer of the material, which will increase the resistance of this material to the formation and propagation of cracks. The difference in the value of heat expansion coefficient in the material is introducing tensile internal-stresses on the surface of the material after its cooling from the sintering temperature to the ambient temperature.

Basing on the analysis of the obtained results: among others such as hardness, brittle cracking and abrasive wear it has been demonstrated that this novel method makes it possible to fabricate tool gradient materials resistant to abrasive wear with high resistance to brittle cracking.

4. Conclusions

The goal of this work was the application of finite elements method on tool gradient materials. However it can use model internal-stresses generated in the newly elaborated tool gradient materials in effect of sintering, having the influence on the properties of these materials. Due to it the stress values determined through computer simulation are close to those determined experimentally, it is well-founded to apply calculation methods to estimate stresses and to draw conclusions about the trends involving the changes of the properties of the investigated tool gradient material, which necessitates further research.

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