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Sintered composite gradient tool materials

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ABSTRACT

Purpose: Development of a new generation of the composite gradient tool materials with the core sintered with the matrix obtained using the powder metallurgy of the chemical composition corresponding to the HS6-5-2 high-speed steel reinforced with the WC and TiC type hard carbide phases with the growing portions of these phases in the outward direction from the core to the surface.

Design/methodology/approach: Powder Metallurgy, SEM, X-Ray Microanalysis.

Findings: Powder metallurgy processes were used to fabricate the proposed gradient materials, i.e., compacting in the closed die and sintering. The method of sequential pouring of the successive portions of the powder mixes into the die was used to ensure a high ductility of the fabricated material core with the HS6-5-2 steel matrix reinforced with the hard WC and TiC carbides phases, so that portions of powder with the high percentage of the hard carbides phases would form the outer layers of the prepreg.

Practical implications: Employment of powder metallurgy for fabricating the steel based tool materials gives the possibility to preserve properties characteristic of the traditional cemented carbides and with the high ductility characteristic of steel, yet better than the traditional sintered high-speed steels obtained with the ASP method.

Originality/value: Providing of high properties characteristic of cemented carbides with the high ductility characteristic of steel can be mostly because of the possibility of ensuring the gradients of the chemical composition and properties, cutting simultaneously fabrication costs thanks to savings made on the hard carbide phase, used in the tool surface layer only.

Keywords: Sintering; Composite materials; Gradient materials; Tool materials

MATERIALS

1. Introduction

Research on development and fabrication of the gradient tool materials with varying properties over the tool transverse section, i.e., high abrasion wear resistance of the surface layer characteristic of the cemented carbides coated with abrasion wear resistant layers while preserving a high ductility of their core, typical for tool steels, which is not achieved by carbides, cermets, and other ceramic materials, have added the significant interest in tools with gradient structure, which in theory are connected with possibility of designing new materials with the planned properties in their broad range.

The traditional powder metallurgy and its new variations, like pressureless forming or injection moulding, give the possibility to join easily particles of materials with different properties. Therefore, undertaking the research on fabrication of the gradient materials, and in particular those based on high-speed steels reinforced with the ceramic particles with the growing portion in the direction to the tool surface, becomes fully justified. The quick development pace of investigation of the gradient tool materials pertains mostly to the cobalt matrix sintered carbides. Low amount of information in literature on gradient materials fabricated basing on high-speed steels is caused with the complexity of problems that occur in the sintering and heat treatment processes, and with refraining from this research in favour of the sintered carbides mentioned above. Employing the high-speed steel as the gradient materials matrix yields, however, the possibility to control the matrix properties with heat treatment. The fact is that the narrow high-speed steel sintering window imposed the necessity to use the heating equipment with high precision and temperature stability. Introducing the reinforcing particles into the steel may change sintering conditions, increase the portion of pores connected with the poor wettability of the ceramic particles or decrease the sintering temperature due to diffusion of elements contained in the reinforcing phases into the matrix, lowering the solidus temperature. Decay of the reinforcing phases and diffusion of their constituents to the matrix may, apart from lowering the sintering temperature, change the carbon equivalent coefficient CE which should be lower than carbon concentration by about 0.1%. Destabilisation of the CE coefficient or carbon concentration growth affect adversely phase transformations during heat treatment and service properties of the manufactured tool, therefore, high-speed steel based gradient materials seem to be a more demanding investigation material compared to cobalt based gradient materials [1-16].

The goal of the work is development of a new generation of the composite gradient tool materials with the core sintered with the matrix obtained using the powder metallurgy of the chemical composition corresponding to the HS6-5-2 high-speed steel reinforced with the WC and TiC type hard carbide phases with the growing portions of these phases in the outward direction from the core to the surface.

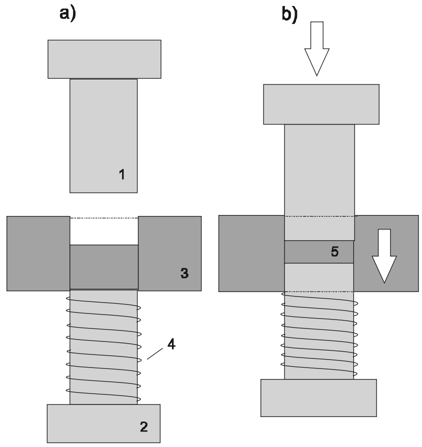


Fig. 1. Floating die compacting: a) filling with powder, b) compacting; 1 – upper punch, 2 – fixed lower punch, 3 – die, 4 – compacted spring, 5 – prepreg

2. Experimental procedure

The classic powder metallurgy, i.e., the unilateral uniaxial compacting was employed for fabricating the gradient materials. The HS-6-5-2 type high-speed steel powder was used as matrix with the average particle size of about 150 μm. The fine-grained tungsten carbide powder was used as the reinforcing phases, with the particle size of 0.85μm and of the titanium carbide powder with the particle size of 5μm.

Next, the steel and carbide powders were weighted and mixes were prepared with the chemical composition presented in Table 1. Powders were mixed without addition of lubricant in Turbula mixer during 1h.

Further, the powder mixes were formed in a die pouring it in sequence with the successive lots of mixes with the growing content of carbides, cut-and-fill balancing each time the surface of a layer about 1 mm thick. In each case the top layer had the maximum portion of the hard reinforcing phase. Microwax was used as lubricant to reduce friction during compacting. Compacting of the test pieces was done in the classic unilateral, uniaxial die.

Additionally, floating die compacting was carried out in the die shown if Fig. 1., ensuring better density distribution over the prepreg transverse section.

Thickness of the bottom layer, featuring simultaneously the gradient material core was bigger in each case and was about 50% of the total test piece height. The reason was to reduce the test pieces during sintering. A stable base, with the uniform contraction in each direction during sintering prevents deformation of the surface layers which depends on their chemical composition and thermal conductivity at the high sintering temperature.

All layers of the gradient material were compacted simultaneously under the pressure of 700 MPa. Compacting time was 30 seconds. Next the prepregs were sintered at the temperature from 1180 to 1300°C for 1 h.

Sintering was carried out in the pipe furnace in the N_2-5%H_2 protective atmosphere. The compacted and sintered prepregs' density measurements were made using the Archimedes method basing on the product mass and the apparent loss of mass during immersion in water.

Structure examination, qualitative and quantitative X-ray microanalyses were made on ZEISS SUPRA 35 scanning microscope with the accelerating voltage of 20 kV.

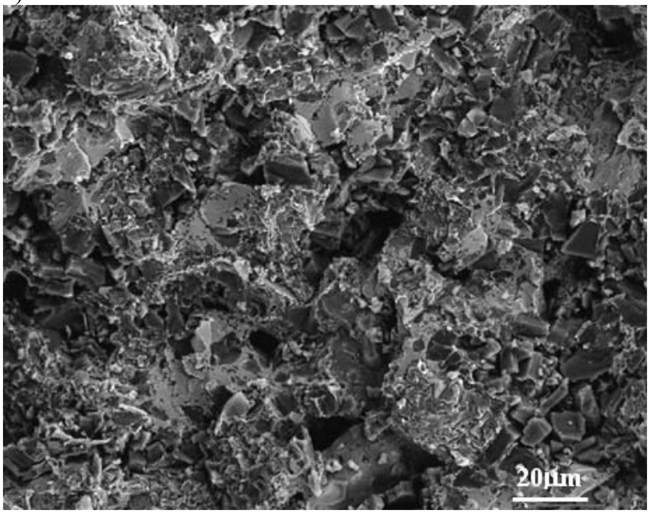
3. Discussion of results

Employment of powder metallurgy for fabricating the steel based tool materials gives the possibility to preserve properties characteristic of the traditional cemented carbides and with the high ductility characteristic of steel, yet better than the traditional sintered high-speed steels obtained with the ASP method, mostly because of the possibility of ensuring the gradients of the chemical composition and properties, cutting simultaneously fabrication costs thanks to savings made on the hard carbide phase, used in the tool surface layer only.

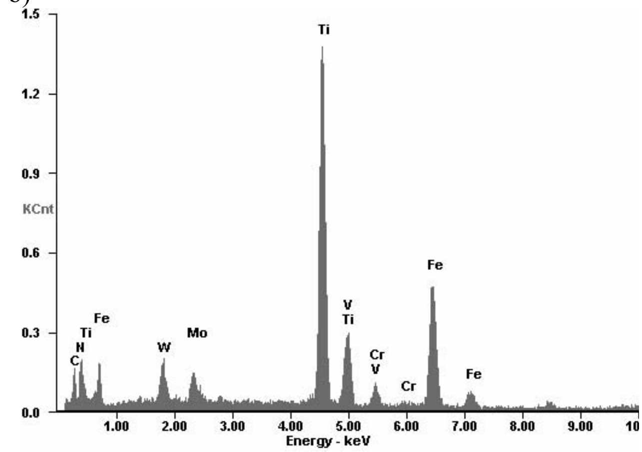
Table 1.
Gradient tool materials components

Component	Average particle size, μm	Volume fraction of component, %
HS 6-5-2	150	80-70 (materials A, B)
WC	0.85	20-30 (material A)
TiC	5	20-30 (material B)

a)



b)

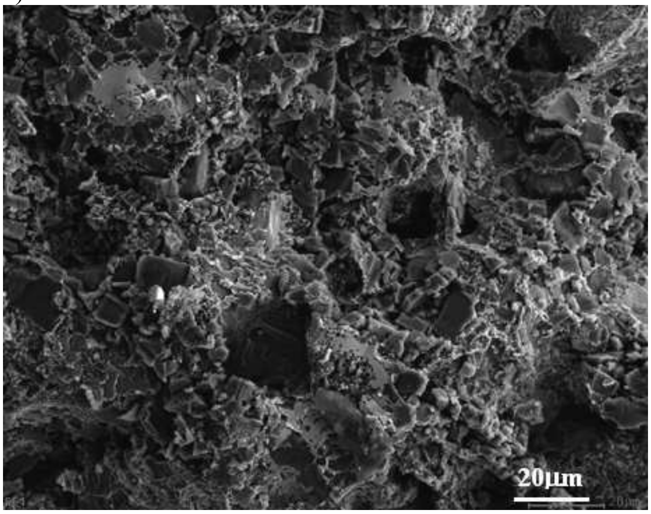


c)

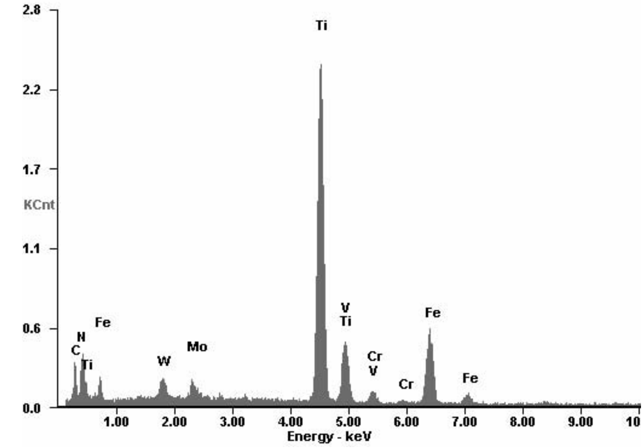
Element	Wt%	At%
C	09.91	29.85
N	06.26	16.17
W	08.21	01.62
Mo	03.81	01.44
Ti	37.94	28.65
V	03.29	02.33
Cr	02.77	01.93
Fe	27.82	18.02
Matrix	Correction	ZAF

Fig. 2. Area of low concentration TiC: a) fracture surface (SEM), b) chemical composition analysis (EDS), c) concentration of elements (EDS)

a)



b)



c)

Element	Wt%	At%
C	12.55	34.24
N	07.13	16.68
W	05.27	00.94
Mo	02.90	00.99
Ti	47.02	32.17
V	02.59	01.67
Cr	01.97	01.24
Fe	20.58	12.07
Matrix	Correction	ZAF

Fig. 3. Area of high concentration TiC: a) fracture surface (SEM), b) chemical composition analysis (EDS), c) concentration of elements (EDS)

To obtain the relevant density of prepregs modification was made of the die used for the uniaxial unilateral compacting, to employ the floating die, ensuring a smaller friction during compacting and a more uniform powder density distribution in the prepreg.

Sintering of prepregs with gradient structure in flow furnaces using the nitrogen rich mix of protective gases facilitates precipitation of carbonitrides in gradient materials with the unalloyed steel matrix, which in addition increases the abrasion wear resistance of the newly developed composite gradient tool materials.

It was found out, based on the fractographic examinations that all layers of the gradient material form a homogeneous, dense, well compacted structure over the entire fracture area. It was also found that regardless of the compacting method gradient structure was obtained in the fabrication process with the linear portion change of the used WC and TiC carbides. The qualitative and quantitative X-ray microanalysis confirmed the gradient change of the reinforcing phase portion in proportions assumed in the fabrication process (Figs. 2,3). Density of the fabricated gradient materials varies in range from 6.55 g/cm^3 in case of the material reinforced with the TiC powder to 8.95 g/cm^3 in case of the material reinforced with the WC powder and does not depend significantly on the employed compacting method.

4. Conclusions

Powder metallurgy processes were used to fabricate the proposed gradient materials, i.e., compacting in the closed die and sintering. The method of sequential pouring of the successive portions of the powder mixes into the die was used to ensure a high ductility of the fabricated material core with the HS6-5-2 steel matrix reinforced with the hard WC and TiC carbides phases, so that portions of powder with the high percentage of the hard carbides phases would form the outer layers of the prepreg. Density examinations results of prepregs compacted using floated die pressing and unilaterally did not prove using the floating die pressing of mixes from the high-speed steel powders and the WC or TiC carbides as well-founded. The relatively low height of the prepregs, high pressure, and high plastic properties of the HS6-5-2 steel powder make the prepregs density comparable regardless of their compacting method. It was demonstrated in the paper that in gradient materials formed from layers with the increasing portions of the reinforcing phases no delaminations occur in the high-speed steel matrix and there are no clear boundaries between the particular layers compacted in the die in the sintered state.

Acknowledgements

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