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Structure and properties of FGM manufactured on the basis of HS6-5-2

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Materials

ABSTRACT

Purpose: It has been demonstrated in the paper structure and properties of tool gradient materials manufactured by powder metallurgy on the basis of high speed-steel HS6-5-2 type.

Design/methodology/approach: Light microscope, SEM, image analysis, microhardness tests, density examination.

Findings: Basing on the investigations of the HS6-5-2 type high-speed steels reinforced with ceramics particles fabricated with Powder Metallurgy it was found that density of sintered samples depend on reinforced particles, temperatures and atmosphere of sintering. Increasing of sintering temperature increase the density of sintering samples. Moreover the sintering under N_2-10%H_2 atmosphere produce samples with higher quality than using argon atmosphere and prevent of surface oxidation during sintering.

Practical implications: The Powder Metallurgy gives the possibility to manufacturing tools gradient materials on the basis of high speed-steel which characterised very high hardness on the surface.

Originality/value: In the paper the manufacturing of tool gradient materials on basis of high speed-steel reinforced with hard ceramics particles carried out in order to improve the tool cutting properties.

Keywords: High speed steels; Functional gradient materials; Powder metallurgy; Sintering

1. Introduction

Research centres dealing with the tool materials problems since many years strive to fabricate the "ideal" tool material, with the high ductility, resistance to dynamical loads, and high abrasion wear resistance. Fabricating such tool, in spite of its high price would cut significantly manufacturing costs of engineering materials connected with their machining, and especially with stoppages of production caused the need to replace the worn out tool. Even high costs of investigations of properties and applications of the contemporary tool materials and their manufacturing costs do not obstruct this development. Fabricating a tool in which such properties are merged like the relatively high ductility, and abrasion wear resistance has become possible lastly, thanks to technologies making it possible to put down coatings onto the finished tools with the PVD and CVD methods. Division of Materials Processing Technology and Computer Techniques in Materials Science, has long time experience and many achievements in this area. However, the profound knowledge of problems and vast experience pertaining to many groups of tool materials, and especially the widely used high-speed steels, makes it possible to begin investigations of the contemporary tool materials made with this steel type matrix. The main research direction in this area is employment of the modern forming methods for the high-speed steels powders [1, 2]. 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 Functional Gradient Materials (FGM) based on high-speed steels reinforced with the ceramic particle with the growing portion in the direction to the tool surface, has become fully justified. The quick development pace of investigation of the functional gradient tool materials pertains mostly to the cobalt matrix sintered carbides [3, 4]. Low amount of information in literature on gradient materials fabricated basing on high-speed steels is caused - most probably - 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 [5-7]. However, employing the high-speed steel as the gradient materials matrix yields 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 hardening phases and their diffusion to the matrix may, apart from lowering the sintering temperature, change the carbon equivalent coefficient C_E which should be lower than carbon concentration by about 0.1% [8]. Destabilization of C_E coefficient or increase of carbon content affect adversely the phase transformations during the heat treatment and service properties of the finished tool.

The goal of this project is to investigate the effect of the hard ceramic particles and their portion on structure and properties the gradient materials based on the HS6-5-2 type high-speed steel.

2. Materials and methods

The experiments were made on test pieces, fabricated in the uniaxial unilateral die and were sintered in the tube kiln in the atmosphere of the flowing protection gas. The powder from the HS6-5-2 type high-speed steel made by Höganas was used as matrix, being atomised with water and annealed in the form showed in Figure 1. The powder used is very convenient for the uniaxial compacting in the closed die, due to its developed surface and free flowing. The powder density measured with the AccuPyc 1330 type pycnometer is 8.17 g/cm^3. The powder grain size distribution is shown in Fig. 2, and its chemical composition is given in Table 1. The VC and WC carbides and powder of the HS12-1-5-5 type high-speed steel with the elevated concentration of alloying elements were used as the reinforcement particles. The maximum portion of particles reinforcing the matrix from the HS6-2-5 steel was selected experimentally basing on the criterion of forming without any lubricants. This consisted in compaction of the powders mix and examining the prepreg with the unaided eye.

Defects in the form of cracks or damaged prepreg corners eliminated the possibility to use the mix with such portion of the reinforcing powder. The reinforcing phases' portion was lowered next, up to the value making forming the mix possible. To form the gradient material, the die was filled with five layers successively, with the increasing portions of reinforcing phases, levelling each time the surfaces of layers being about 1 mm thick.

Table 1
Chemical composition of steel powder HS6-5-2 type

Mass concentration of elements, %								
C	Cr	W	Mo	V	Si	Co	Mn	Fe
0.86	3.97	6.54	4.81	1.95	0.35	-	0.36	rest

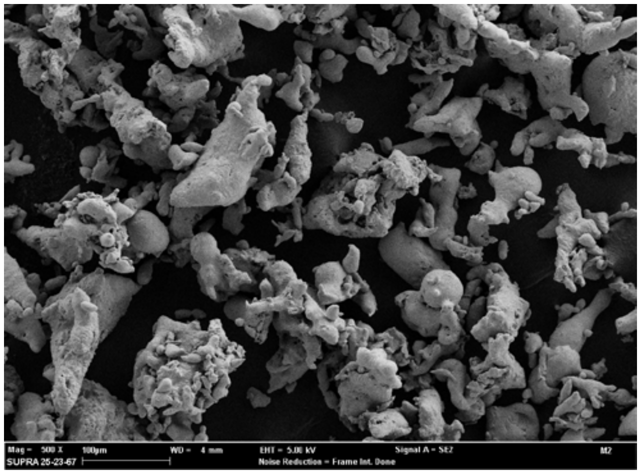

Fig. 1. Powder of high speed-steel HS6-5-2 type, atomised by water

The first layer was the high-speed steel with no reinforcing powder additions about 3 mm thick. The layer with the maximum portion of the reinforcing particles, with poor flow was put as the last one, using the maximum compacting pressure during the unilateral forming, in the zone directly under the pressing stamp. Table 2 shows the portion of the reinforcing powder in the consecutive layers of the gradient material in the HS6-5-2 steel matrix. All layers of the gradient material were compacted simultaneously under the pressure of 700 MPa. Prepregs' density measurements were made using the Archimedes method basing on the product mass and the apparent loss of mass during immersion in water according to standard. The results were compared with the theoretical density of the gradient material calculated basing on the theoretical density values for the ceramic phase and for the high-speed steel. Prepregs were sintered for 30 min at temperatures of 1270 and 1290^{o}C in the atmosphere of the flowing N_2-10%H_2 gas mixture and at the temperature of 1280^{o}C in the atmosphere of the flowing argon. The test pieces in the as sintered condition were subject again to the apparent density test and the measurement of the surface pores portion was made with the image analysis method on the Leica type light microscope using Leica Qwin software on the non-etched microsections. Portion of pores was examined in 10 areas of each layer of the gradient material and its average value and standard deviation were calculated. Portions of carbides in each layer were calculated with the same method in microsections etched in ferric chloride.

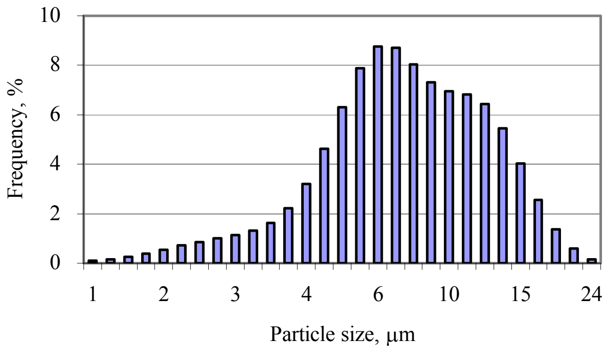

Fig.2 Distribution of the grain size of the HS 6-5-2 high-speed steel powder, atomised with argon

Table 2
Portion of the ceramic powder in the particular layers of the gradient material in the HS6-5-2 steel matrix

Layer number	Mass concentration of the reinforcing powder, %		
	VC	WC	HS12-1-5-5
5	60	50	50
4	50	40	40
3	40	30	30
2	20	20	20
substrate	100% of HS6-5-2		

Hardness tests of the sintered test pieces were made with the Vickers method on Wilson Wolpert 401 MVD Microvickers device with the load of 5 N making 10 measurements for each layer and calculating their average value. Structure examination and the X-ray qualitative microanalysis as well as examination of the surface distribution of elements were made on the Opton DSM-940 scanning microscope with the 20 kV accelerating voltage.

3. Results

It was found out, basing on the experiments of forming the matrix powders from the HS6-5-2 high-speed steel and reinforcing particles like powders from vanadium and tungsten carbides and also from the HS12-1-5-5 type high speed steel, that the maximum mass portion of the WC and VC carbides and of the HS12-1-5-5 high-speed steel that can be compacted uniaxially in the die without the addition of any lubricants is 65% for the ceramic powder and 45% for the HS12-1-5-5 steel powder, respectively. Mixes selected in this way, with the maximum mass portions of the reinforcing particles featured the surface layer of the gradient material formed. Examining of the apparent density basing on Archimedes method for the laminar- or gradient material make sit only possible to determine the average density of the entire material; however, it does not answer the question what is the density of the particular layers of the investigated material. However, it is known that the metallic materials should be characteristic of density of at least 65% of their theoretical density. This value should not be less than about 40% in case of the ceramic materials. Therefore, it was assumed that the average density of the investigated prepregs from the gradient materials should not be less than 5.31g/cm^3, being 65% of the theoretical HS6-5-2 high-speed steel density. Density of gradient materials, depending on the ceramic powders used, after compacting and in the sintered state, are presented in Table 3.

Table 3
Density of the gradient materials prepregs depending on the ceramic powder used

Reinforcing powder type	VC	WC	HS12-1-5-5
Reinforcing powder density, g/cm^3	5,71	15,7	8,19
Compacted gradient material density, g/cm^3	6,56	8,17	7,2
Sintered gradient material density, g/cm^3	6,93	8,31	7,68

Examination of the test pieces porosity, made on the light microscope, may yield more information about consolidation of the material during sintering. This way we can determine the portion of pores in the particular layer of gradient materials. Table 4 presents the portions of pores in the investigated gradient materials in the particular layers. It was found out that gradient materials reinforced with the VC type ceramic particles are characteristic of the lowest porosity, regardless of the portion of these particles (Fig. 3). Structure examinations on the scanning microscope and analysis of the surface distribution in the micro-areas have revealed that the most homogeneous structure is characteristic for gradient materials reinforced with vanadium carbide. It was found out basing on Vickers micro-hardness tests made on the sintered test pieces that the highest hardness is characteristic of the gradient materials sintered in N_2-10%H_2 atmosphere, which is undoubtedly caused by the capability of reduction of this atmosphere's oxides and by the resulting capability of better compaction of the system of the particles sintered freely in the supersolidus phase. Moreover, nitrogen makes forming possible of the fine carbonitrides precipitations distributed homogeneously in the steel matrix, which increases the material hardness (fig.4).

Table 4
Portions of pores in the particular layers of gradient materials

Layer number	Average portion of pores in the particular layers, %		
	1	3	5
VC	4,9	13,1	18,92
WC	9,02	11,35	30,29
HS12-1-5-5	6,82	12,93	25,67

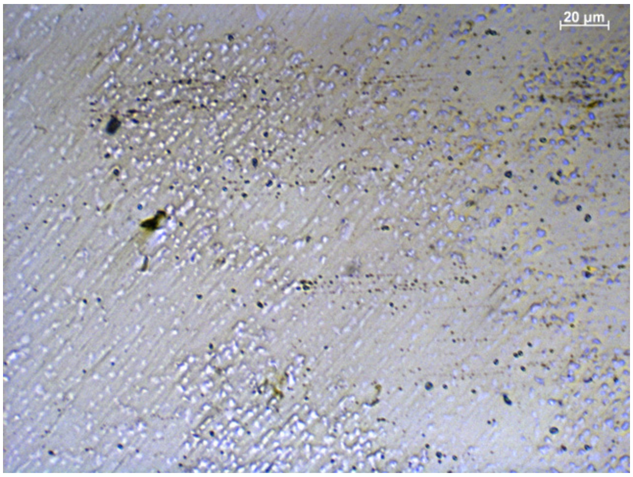

Fig. 3. Microstructure of FGM reinforced by VC sintered under argon at 1280^{o}C

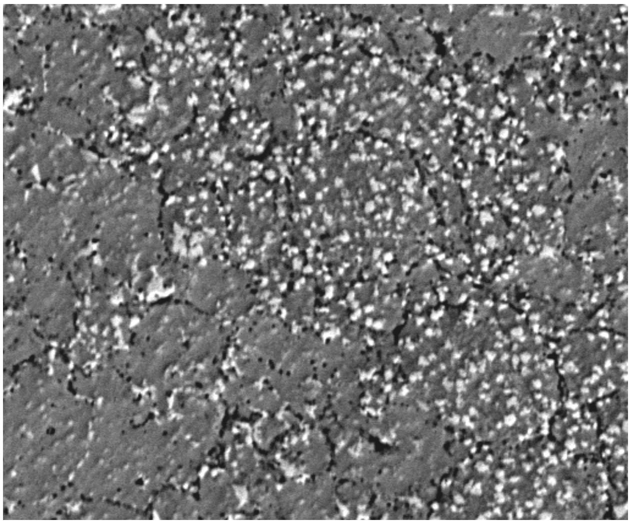

Fig. 4. Microstructure of FGM reinforced by VC sintered under N_2-10%H_2 at 1270^{o}C

4. Conclusions

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 HS6-5-2 type high steel matrix and there are no clear boundaries between the particular layers compacted in the die.

The growing portion of pores in layers rich in WC carbide and deformation of the test piece in areas rich in this phase attests to partial remelting of these layers during sintering. This is connected with dissolving of the WC carbide during sintering and lowering of the solidus temperature by carbon and tungsten diffusing into the matrix, which is connected with the necessity to decrease the WC phase in the HS6-5-2 matrix to the level which will not result in lowering the sintering temperature.

It was found, basing on hardness tests that gradient materials sintered in the N_2-10%H_2 atmosphere, reinforced with the VC carbide, are characteristic of the maximum hardness. Hardness of the surface layer reaches about 1200 HV0.5. Gradient materials reinforced with the HS12-1-5-5 high-speed steel powder have the minimum hardness of about 240 HV0.5, which should however increase significantly after their heat treatment.

The surface distribution of elements and X-ray analysis in micro-areas revealed that tungsten and molybdenum are the main elements that form the bright big precipitations of carbides corresponding with their chemical composition to the M_6C carbides. Fine and dark precipitations of the carbide phases are rich in vanadium, which may mean that they are of the MX type phases in case of sintering in the N_2-10%H_2 atmosphere or of the MC type in case of sintering in argon.

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References

[1] L.A. Dobrzański, G. Matula, A. Várez, B. Levenfeld, J.M. Torralba, Fabrication methods and heat treatment conditions effect on tribological properties of high speed steels, Journal of Materials Processing and Technology 157-158, 2004 s. 324-330.

[2] G. Matula, L.A. Dobrzański, A. Várez, B. Levenfeld, J.M. Torralba, Comparison of structure and properties of the HS12-1-5-5 type high-speed steel fabricated using the pressureless forming and PIM methods, Journal of Materials Processing Technology, Vols. 162-163, 2005, p. 230-235.

[3] M. Collin, S. Norgren, Hardness gradients in WC-Co created by Local addition of $Cr_3C_2$16th International Plansee Seminar, p.277, 2005.

[4] A. Eder, W. Lengauer, K. Dreyer, H. Van Den Berg, H.-W. Daub, D. Kassel, Phase Formation During Sintering of Functionally Graded Hardmetals, Plansee Seminar, p.81, 2005.

[5] Ruiz-Navas E.M, Garcia R., Gordo E., Velasco F.J., Development and characterization high – sped steel matrix composites gradient materials, Madrid 2006.

[6] J. L. Johnson, R. M. German, Liquid Phase Sintering of Functionally Graded W-Cu Composites, 16th International Plansee Seminar, 2005.

[7] A. Delanoe, J.M. Missiaen, C.H. Allibert, S. Lay, E. Pauty, Effects of the C potential and Cr doping on the densification of alloys WC-Co, 16th International Plansee Seminar, p.642, 2005.

[8] L.A. Dobrzański, E. Hajduczek, J. Marciniak, R. Nowosielski, Physical metallurgy and heat treatment of tool materials, WNT, Warszawa, 1990 (in Polish).