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Structure and properties of the gradient tool materials of unalloyed steel matrix reinforced with HS6-5-2 high-speed steel

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ABSTRACT

Purpose: The goal of this work is to obtain the gradient materials based on the non-alloyed steel reinforced high-speed steel using the pressureless formed method.

Design/methodology/approach: The non-alloyed steel was fabricated by mixing iron powders with graphite. The unalloyed steel contains 0.5% carbon. The pressureless powder forming was used for manufacturing the materials.

Findings: It was found out, basing on the hardness tests, that the layer built of steel without any alloy elements demonstrates very low hardness in comparison with the transition layer and the HS6-5-2 high-speed layer. It was also found, that the density rises with increasing temperature. The portion of pores in the particular layers of the gradient materials decreases along with the carbon concentration increase in particular layers.

Practical implications: The material presented in this paper has layers, at one side consisting of the non-alloy steel with hardness growing with the increase of carbon content, and at other side the high-speed steel, characterized by a high ductility. Developed material is tested for turning tools.

Originality/value: A forming methods were developed for high-speed and non-alloy steel powders, making it possible to obtain materials with three layers in their structure. Investigations included determining the sintering conditions, especially the temperature and treatment cycle, as well as examining selected mechanical properties.

Keywords: Gradient tool materials; Pressureless powder forming; High-speed steel; Non-alloyed steel

MATERIALS

1. Introduction

Functionally graded materials (FGMs) are composites consisting of two different materials with a gradient composition. Such materials are attracting attention because they can provide new combined functions that surpass the characteristics specific to each element [1]. The material properties can change continuously, gradually or discreetly (abruptly) [2]. They are made, among others, with the powder metallurgy methods (connected with the differentiation of grain size in the cross-section, the temperature gradient during sintering or the liquid phase presence), laser aided and plasma discharge methods. The use of the powder metallurgy method offers a combination of high abrasion resistance (characteristic of sintered carbides and cermetals), high ductility (corresponding to high-speed steels and traditional carbide-steels) and lower production costs. The main advantage of these materials is extremely high abrasion resistance combined with relatively high ductility of the core material, which is

particularly important in materials designed for die tools, hot-work plastic forming tools, heavy duty machining tools for high-speed operation and shape machining tools. The main objective of this work is to develop modern gradient materials through the powder metallurgy methods in order to ensure the required properties and structure of the designed material [3, 4, 15].

2. Materials for research

The experiments were carried out on specimens produced using the pressureless forming method followed by sintering. The powders used for specimen production are listed in Table 1. The chemical composition of HS6-5-2 high speed-steel is presented in Table 2. The particles of the gas-atomized HS6-5-2 high-speed steel, as well as iron and carbon particles are shown in Fig.1

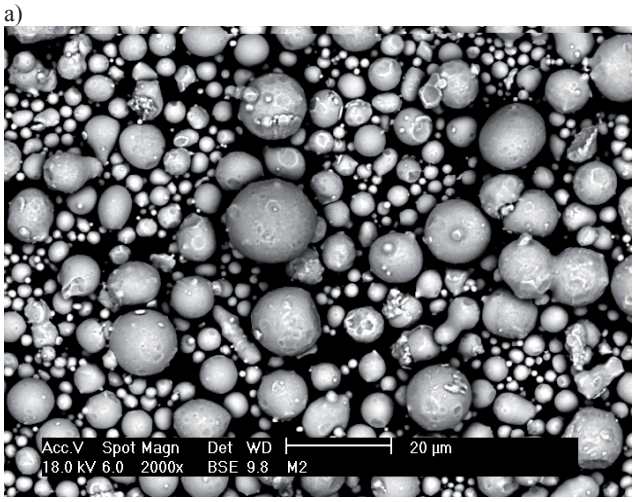
Table 1.
Powders used for fabricating the materials

Powder	Grain size, μm	Additional information
HS6-5-2	>21	High-speed steel powder, gas atomized, from OSPREY METALS, Neath, UK
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	0.82-0.92
Mn	≤0.4
Si	≤0.5
P	≤0.030
S	≤0.030
Cr	3.5-4.5
Ni	≤0.4
Mo	4.5-5.5
W	6.0-7.0
V	1.7-2.1
Co	≤0.5
Cu	≤0.3
Fe	Rest

a)



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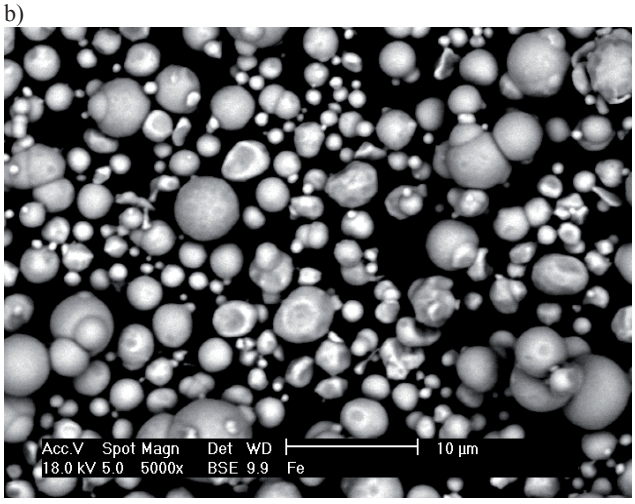

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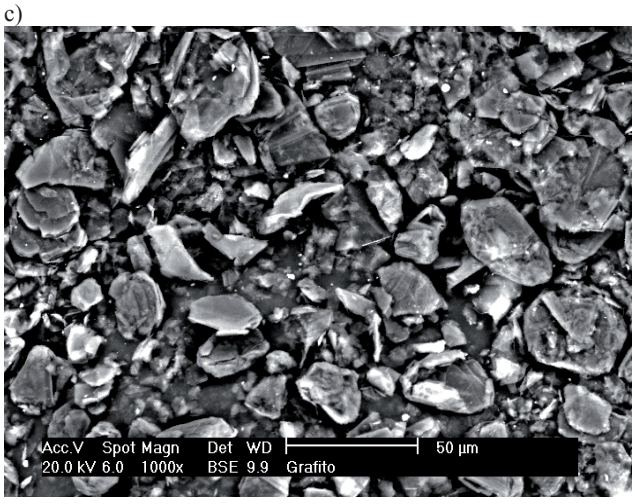


Fig. 1. Powder morphology: a) HS6-5-2 atomised with water, b) iron, c) carbon

The pressureless powder forming method consists in mixing the binding agent with metal powders. The following powders were used for making the greens: HS6-5-2-Osprey and the unalloyed steel powder. The metal powder volume fraction was 60% (Fig. 2). The Loctite PMS 90E thermo-setting resin was used as the binding agent. Polymerization process was performed in an electric, chamber furnace at the temperature 90°C over the period of 15 minutes. The binding agent density was 1.0 g/cm^3. The polymer/powder profiles thus obtained were removed from the glass moulds and subjected to thermal binding agent degradation in a chamber furnace in the atmosphere of the flowing argon N_2-10%H_2. Carbon concentration analysis, depending on the binding agent degradation and sintering temperatures, was carried out with the LECO CS-200 type apparatus

The specimens in the sintered state, obtained through various powder forming methods, were then subjected to density, hardness and porosity testing, and were observed on a scanning electron microscope (SEM) additionally furnished with a backscattered electron detector and energy dispersive analyzer (EDAX D4). The density testing was performed with the Archimedes method consisting in measuring the specimen virtual mass immersed in water. Hardness was measured using the Vickers hardness tester with the intender load of 9.8N. The measurements were taken across the whole width of the sample section with seven measurement points for each layer.

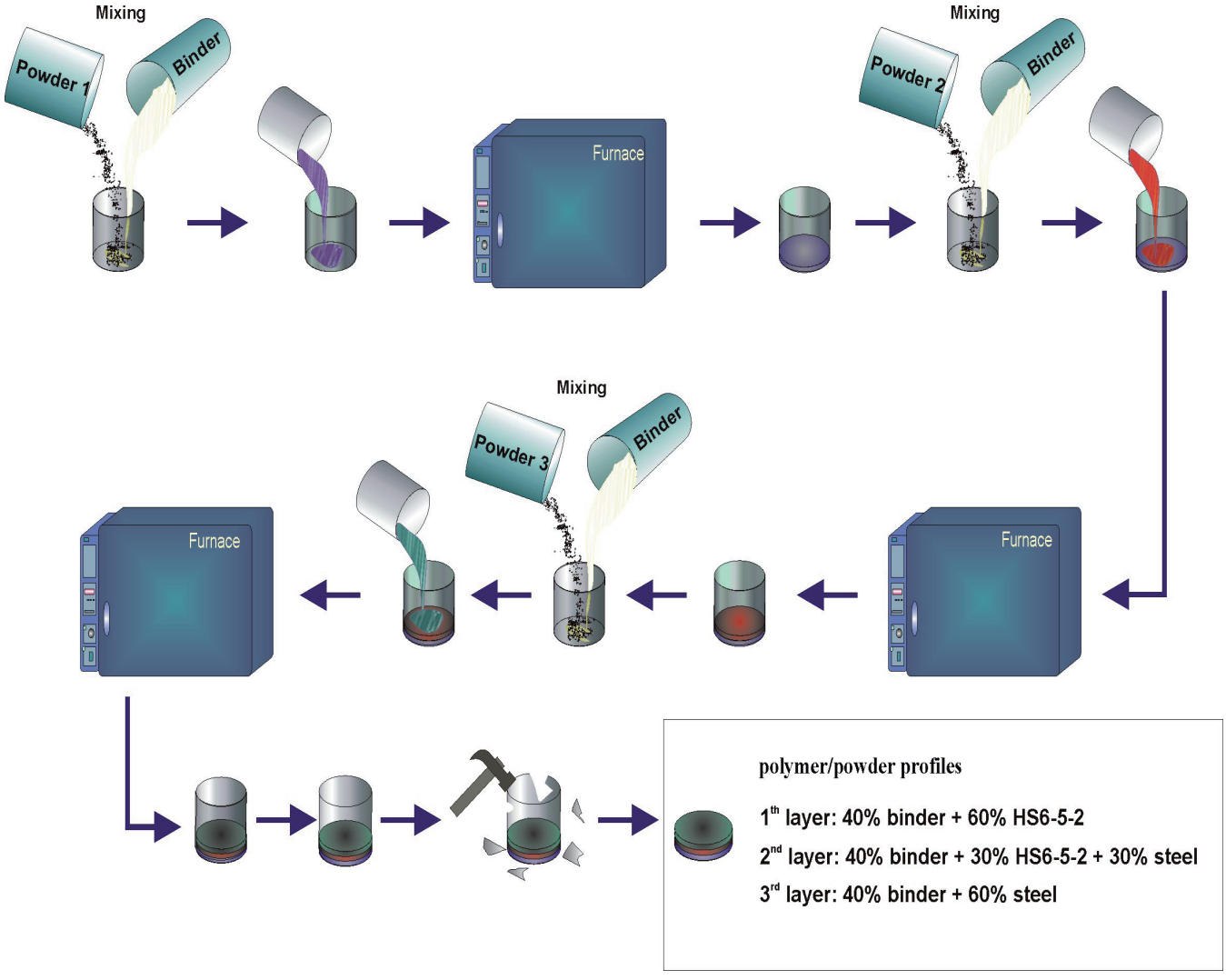


Fig. 2. The pressureless powder forming method consisting in mixing the binding agent with metal powders

3. Description of achieved results of own researches

Basing on the thermogravimetric examination, the binding agent thermal degradation cycle was selected for the specimens with thermosetting resin (Fig. 3). The degradation of the binding agent starts at the temperature of 200°C. Within the 300-500°C range the process accelerates. Above 500°C complete degradation of the binding is observed. Due to the above the degradation cycle was selected to include three isothermic stops lasting 30 minutes each (Fig. 4). The first stop starts at the initial degradation temperature, i.e. 200°C, the next one at 300°C, and the third at 400, 450 or 500°C. The heating rate from ambient temperature to the first isothermic stop, and from the first to the second isothermic stop was selected experimentally at 1°C/min. Between the first and the second isothermic stop the heating rate is 2°C/min. After the completion of the binding agent degradation cycle, cooling down to ambient temperature. The cooling rate is 5°C/min. The heating and cooling rates were selected to prevent cracking caused by increasing gas pressure inside the forming pores [3-5].

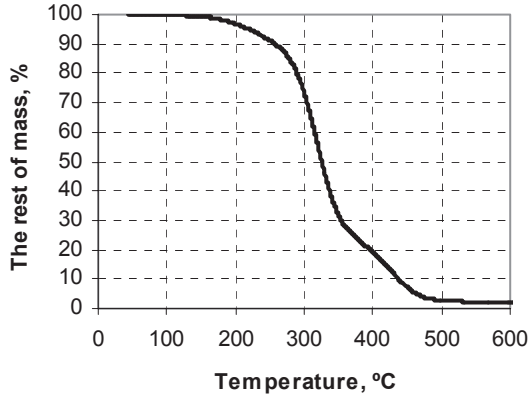


Fig. 3. Thermogravimetric analysis of the binding agent used

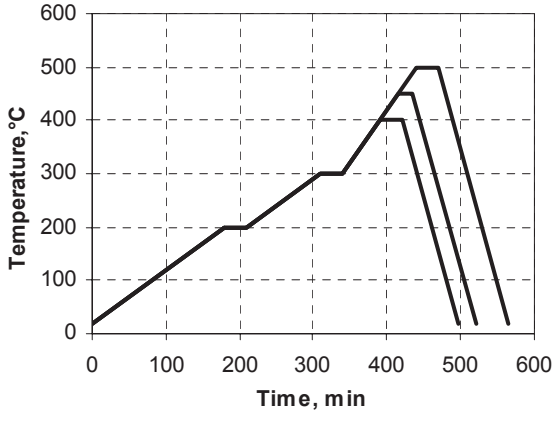


Fig. 4. The degradation of the binding agent cycle

The specimens made with the pressureless forming method were found to contain the highest carbon concentration after degradation at 350°C (Fig. 5). Carbon concentration depends on the binding agent degradation temperature, the green arrangement in the furnace and on the flow direction of the gas used [3-5].

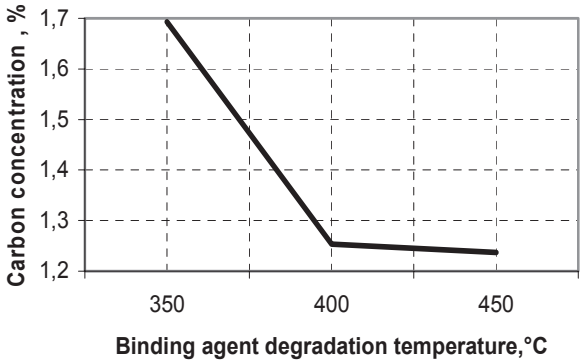


Fig. 5. The impact of the binding agent degradation temperature on carbon concentration in pressurelessly formed specimens

Mean hardness values for the specimens made with the pressureless forming method are shown in Fig.6. The layer built of steel without any alloy elements demonstrates very low hardness in comparison with the transition layer and the HS6-5-2 high-speed layer.

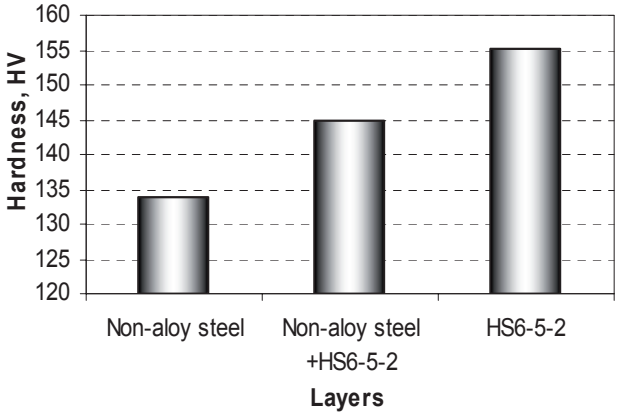


Fig. 6. Mean hardness values for the specimens made with the pressureless forming method (for three layers)

The density of the specimens subjected to thermal debinding and sintered at 1150, 1250 or 1350°C depends on the sintering temperature. The density rises with increasing temperature. The density examination results for pressurelessly formed steels are shown in Fig.7 [3-5].

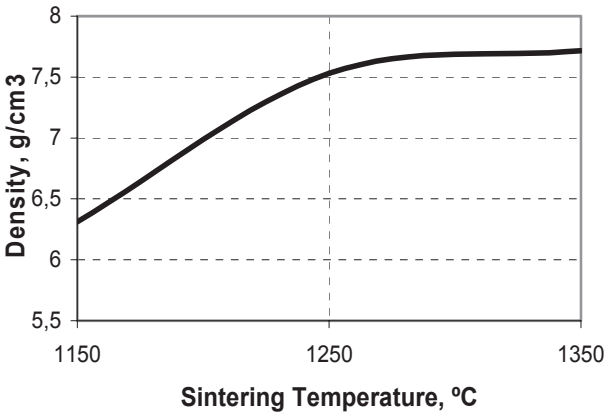


Fig. 7. The density/sintering temperature chart for the specimens made with the pressureless forming method

For the specimens sintered at the temperature of 1250°C, three gradually changing layers in the material volume are observed (Fig. 8). The pores visible in the unalloyed steel layers indicate an incomplete sintering process. These pores disappear when the sintering temperature is increased. The pores are smaller in the high-speed and transition layers at the temperature exceeding 1250°C. Basing on the microstructure examination it was found that the sintering temperature which ensures high density and homogeneous structure with fine primary carbide precipitations, should not exceed 1250°C [3-5].

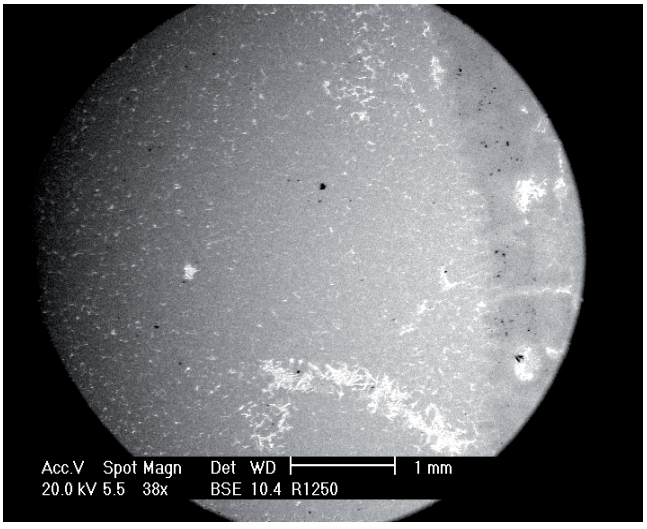
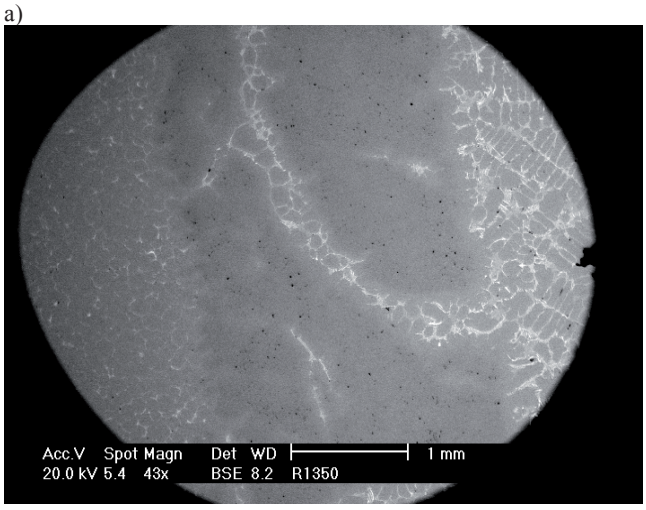


Fig. 8. The structure of specimens made with pressureless forming and sintered at the temperature of 1250°C

For the pressurelessly formed specimens, the high-speed and transition layers were found to contain finely distributed carbides. As a result of the increase in the sintering temperature, carbide coagulation and melting leading to eutectic formation occur (Fig.9).

a)



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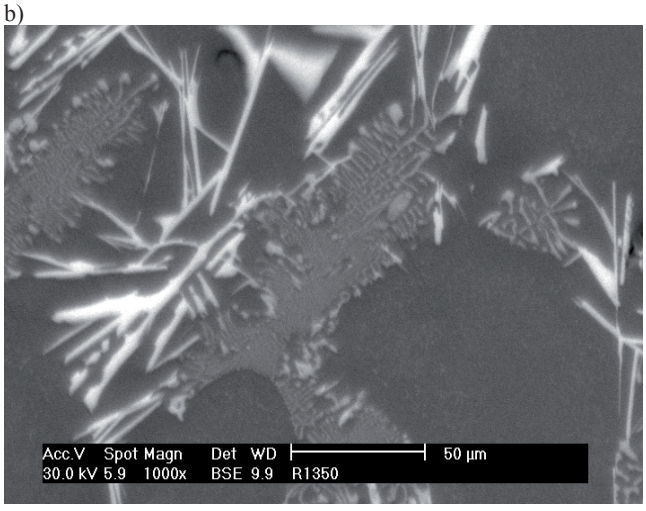

Fig. 9. Structure of the specimen made with pressureless forming and sintered at the temperature of 1350°C: a) all layers, b) the HS6-5-2 high-speed steel layer

4. Summary

It was found out basing on investigations of the fabricated 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. Also it was found that the pressureless forming method is economical. Apart form the furnace for binding agent degradation and sintering no other equipment is required. Another advantage of this method is the possibility of obtaining a profile of high density and a homogeneous powder distribution in the binding agent matrix. High high-speed steel density in pressurelessly formed materials is caused by a higher carbon concentration. The carbon, being a product of binding agent degradation, surrounds the high-speed steel powder grains and, by diffusing into the layers of surface

grains, lowers the sintering temperature and initiates the sintering process Hence, the sintering temperature corresponding to the maximum density of the pressurelessly formed materials is lower in comparison with the materials made using traditional powder metallurgy methods [3-14].

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References

[1] K. Ichikawa, Functionally Graded Materials in the 21st Centary A Workshop on Trends and Forecasts, Kluwer Academic Publishers, 2001.

[2] M.B. Bever, P.F. Duwez: Gradients in composite materials, Materials Science and Engineering 10 (1972) 1-8.

[3] L.A. Dobrzański, A. Kloc, G. Matula, J.M. Contreras, J.M. Torralba, The impact of production methods on the structure and properties of gradient tool materials of unalloyed steel matrix reinforced with HS6-5-2 high-speed steel, Proceedings of th 11th International Scientific Conference on the Contemporary "Achievements in Mechanics, Manufacturing and Materials Science" CAM3S'2005, Gliwice-Zakopane, 2005, 223-229.

[4] L.A. Dobrzański, A. Kloc, G. Matula, J. Domagała, J.M. Torralba: Effect of carbon concentration on structure and properties of the gradient tool materials, Journal of Achievements in Materials and Manufacturing Engineering, 17 (2006) 45-48.

[5] A. Kloc, L.A. Dobrzański, G. Matula, J.M. Torralba, Effect of manufacturing methods on structure and properties of the gradient tool materials with the non-alloy steel matrix reinforced with the HS6-5-2 type high-speed steel, International Conference on Processing & Manufacturing of Advanced Materials, Processing, Fabrication, Properties, Applications THERMEC'2006, Vancouver- Canada, 2749-2754, (CD-ROM).

[6] L.A. Dobrzański., G. Matula, G. Herranz, A. Várez, B. Levenfeld, J.M. Torralba, Injection Moulding of HS12-1-5-5 high-speed using a PW-HDPE based binder, Proceedings of the 12th Scientific International Conference "Achievements in Mechanical and Materials Engineering" AMME'2003, Gliwice-Zakopane, 2003, 237-240.

[7] L.A. Dobrzański, G. Matula, A. Várez, B. Levenfeld, J.M. Torralba, Structure and properties of the heat_treated High-Speed Steel HS6-5-2 and HS12-1-5-5 produced by Injection Molding Process, Materials Science Forum 437-438 (2003) 133-136.

[8] L.A. Dobrzański, G. Matula, A. Várez, B. Levenfeld, J.M. Torralba, Structure and mechanical properties of HSS HS6-5-2 and HS12-1-5-5 type steel produced by power injection moulding process, Journal of Materials Processing Technology 157-158 (2004) 658-668.

[9] L.A. Dobrzański, G. Matula, B. Levenfeld, A. Várez, J.M. Torralba, Influence of heat-treatment on structure and properties of the HS6-5-2 and HS12-1-5-5 high-speed steels produced by PIM process, 7th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology" TMT'2003, Lloret de Mar, Barcelona, Spain (2003) 185-188.

[10] L.A. Dobrzański, G. Matula, A. Várez, B. Levenfeld, J.M. Torralba, Structures and chemical compositions of primary carbides in HS6-5-2 and HS12-1-5-5- high speed steels manufactured with PIM method, 10th International Conference on Composities/Nano Enfineering (ICEE), New Orleans, 2003, 147-148.

[11] E.C. Lee, C.Y. Nian, Y.S. Tarng, Design of a dynamic vibration absorber against vibrations in turning operations, Journal of Materials Processing Technology 108 (2001) 278–285.

[12] N. Khattab, J. M. Torralba, E. Gordo, V. Trabadelo, I. Iturriza, Development of HCxO stainless steel - based materials for its application as valve seat inserts in diesel engines, Proceedings EuroPM2003, Valencia – Spain, 2003, 225-231.

[13] G. Matula, L.A. Dobrzański, A. Várez, B. Levenfeld, J.M. Torralba, Sintering under different atmosphere of T15 and M2 HSS produced by a modified MIM process, "Advances in Materials and Processing Technologies" AMPT01", Leganes-Madrid – Spain, 2001, 758-761.

[14] A. Varez, B. Levenfeld, J.M. Torralba, G. Matula, L.A. Dobrzański, Sintered in different atmospheres of T15 and M2 high speed steels produced by modified metal injection moulding process, Materials Science and Engineering 366 (2004) 318-324.

[15] J. Wessel, The Handbook of Advanced Materials: Enabling New Designs, Materials Technology Series, 2004.