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Structure and properties of HS6-5-2 type HSS manufactured by different P/M methods

G. Matula [a], L.A. Dobrzański [a,*], G. Herranz [b], A. Várez [c], B. Levenfeld [c], J.M. Torralba [c]
[a] Division of Materials Processing Technology, Management and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
[b] Materials Science and Engeenering Department, ETSII, Universidad de Castilla La Mancha, Avda. Camilo José Cela s/n. 13071, Ciudad real, Spain
[c] Materials Science and Engeenering Department, Universidad Carlos III, Avda Universidad, 30. E-28911 Leganés, Madrid, Spain
* Corresponding author: E-mail address: leszek.dobrzanski@polsl.pl

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Materials

ABSTRACT

Purpose: It has been demonstrated in the paper structure and properties of of high speed-steel HS6-5-2 type manufactured by different method of powder metallurgy.
Design/methodology/approach: Light microscope, SEM, image analysis, hardness tests, density examination, transverse rupture strength tests, analysis of chemical composition by LECO apparatus.
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 of 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 modern methods of powder metallurgy gives the possibility to manufacturing tools materials on the basis of high speed-steel which characterised very good properties with their final shape.
Originality/value: In the paper the manufacturing by modern PM methods of tool materials on basis of high speed-steel manufactured carried out in order to improve the structure and properties of tool materials and to produce tools with their final shape.
Keywords: Tool materials; High speed steels; Powder metallurgy; Sintering; Heat treatment

1. Introduction

Research centres dealing with the tool materials problems strive since many years to fabricate the “ideal” tool material, characteristic of the high ductility, resistance to dynamical loads, and high abrasion wear resistance [1-3]. 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. 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 [5, 6]. Division of Materials Processing Technology and Computer Techniques in Materials Science, has long time experience and many achievements in this area [7-10]. 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 [11-15].

The goal of this project is to investigate the effect of manufacturing methods from powder of the HS6-5-2 type high-speed steels on structure and their properties and comparison with the commercial steel brand of the ASP 23 type.

2. Materials and research methodology

The investigated specimens were fabricated using the powder injection and the pressureless forming methods, as well as on the traditionally compacted and sintered ones. The powder density measured with the AccuPyc 1330 type pycnometer was 8.17 g/cm^3. The powder grain size does not exceed 16μm in 80% and its chemical composition is presented in Table 1. For test pieces formed with the pressureless method a binding agent was used in the form of thermosetting acryl resin, fluid at ambient temperature, density of 1.0 g/m3, polymerizable at 80-95^{o}C in the time period of approximately 22h. The metal powder was mixed with the binding agent in the ratio 40:60%, in a mechanical mixer for one hour. The slurry was poured into forms and subjected to binding agent degradation in an electric chamber furnace at the temperature of 90^{o}C. After removing from the forms, the cast profiles were subjected to thermal debinding in the pipe furnace at the temperatures of 300-450^{o}C in steps of 50^{o}C, in the atmosphere of the flowing argon and sintered immediately in the N_2-10%H_2 atmosphere. The heating rate was selected experimentally basing on the initial debinding and sintering test results. The injection moulded test pieces were mixed with the binding agent composed of 50% high density polyethylene (PE-HD) and 50% paraffin (PW). The density of such binding agent is 0.93g/m^3. Both binding agent components and the metal powder were initially mixed in a spin mixer at ambient temperature for one hour, and then extruded twice in the Rheomex CTW100p dual-screw extruder in order to obtain homogeneous granulate material. The granulated material was formed by the Arburg 220-S extruder. Thermal debinding was carried out in the furnace under argon or N_2-10%H_2 gas mixture at the temperatures of 400, 450, 475, and 500^{o}C. Mechanical properties of specimens after thermal debinding were tested with the three-point bending method. The compacted and sintered specimens were made from the water sputtered powder with the grain size below 120 μm. Compacting was carried out in the uniaxial unilateral die, under the pressure of 750 MPa. Regardless of the manufacturing method, sintering was carried out in the pipe furnace at the temperature between 1210 and 1290^{o}C in steps of 10^{o}C, in the atmosphere of the flowing N_2-10%H_2 mixture of gases within 30 min. The specimens sintered in the optimum conditions and specimens from the ASP 23 type steels were next heat treated. All specimens in the sintered state were subjected to density tests with the Archimedes method. Carbon concentration, depending on the binding agent degradation and sintering temperatures, was measured with the LECO CS-200 type apparatus. Structure examination and the X-ray qualitative microanalysis were made on the Philips XL30

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

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

3. Results and discussion

The thermal debinding carried out in the argon or N_2-10%H_2 gas mix atmosphere fails to protect the surface of the cast profiles from metal powder oxidation. Irrespective of the atmosphere, the increase in the degradation temperature causes the decrease in the carbon concentration down to the level of the carbon concentration in the high speed steel powder.

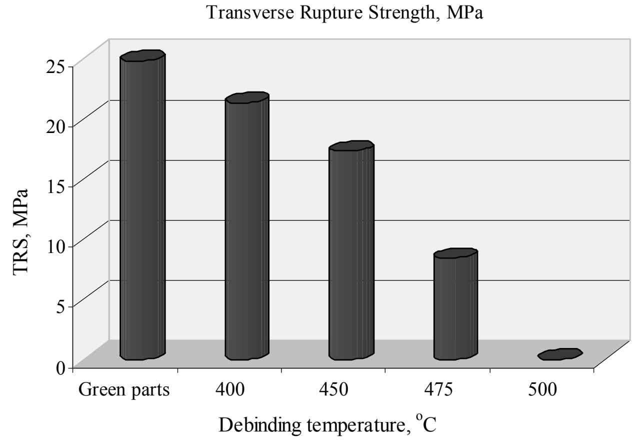

Fig. 1. Mechanical properties of green and brown parts deduced from the three point bending test

The thermal debinding at the temperature of 500^{o}C allows for maximum reduction of the carbon concentration in the cast profile to 0.86% of the value of carbon concentration in the steel powder. It was found, on the basis of test results of the influence of the degradation temperature on the carbon concentration and mechanical properties, including bending strength of injection moulded steels, presented in fig. 1, that the optimum degradation temperature, which retains the minimum mechanical properties and reduces the carbon concentration to the value comparable to the carbon concentration in the steel powder, should be in the 450°C – 475°C. At the temperature of app. 500°C total degradation of the binding agent takes place, which excludes the potential moving, shifting or any kind of sample manipulation and, at the same time, measuring the bending strength. Incomplete degradation at the temperature of 400°C causes an increase in the carbon concentration to the value of 1.06% after sintering, which reduces the steel hardness following heat treatment. The steel structure following the degradation at the temperature of 500°C and sintered at 1240°C is characterized by high carbide and matrix dispersion. Lowering the degradation temperature to 475, 450°C or 400 °C causes the carbides, while sintered at the same temperature of 1240°C, to grow and coagulate due to higher carbon concentration in the sintered steel causing a drop in its solidus temperature. As a result of the density tests of steel sintered at 1240°C depending on the degradation temperature in the range 400 – 500°C, it was found that the highest density (app. 98% of theoretical density) is demonstrated by the steel with the highest carbon concentration, i.e. (1.06%) obtained at the lowest temperature of 400°C. The density test results and the results of carbon concentration tests depending on the degradation temperature for steels made with the powder injection moulding method is shown in fig. 2. Basing on the density test results for the steel subjected to thermal debinding at the temperature of 450°C in the N_2-10%H_2 atmosphere and sintered in the 1210-1290 °C temperature range in steps of 10°C, it was found that in the 1240-1260 °C temperature range the steel reaches the density approximating the theoretical one. The density test results for steel made with the injection moulding method, the pressureless method and compacting and sintering method are shown in fig. 3. The microstructural investigation of steel sintered in the above temperature range in steps of 5°C proves that the optimum sintering temperature providing high density and homogeneous structure with fine primary carbide precipitations should not exceed 1255°C. The maximum heating rate of specimens made with the pressureless forming up to the debindig temperature, selected experimentally, should not exceed 3.5°C/min, whereas the heating rate within the debinding temperature should be reduced to 0.3°C/min, which prevents cracking. In pressurelessly formed steels one can see with the naked eye, large, spherical pores which, due to their size, cannot be eliminated in the sintering process. They are air blisters formed when mixing the resin with the steel powder. The blister can be removed by forming the slurry under pressure or increasing the binding agent content, which increases the flowing power of the slurry and helps bring the air blisters to the surface. The increased binding agent content however, makes the degradation process longer and increases the contraction of the sintered material. The Carbon concentration in the pressurelessly, subjected to degradation at the temperature of 450°C and sintered is approximately 1.8%C and is 0.9%C higher than in the case of the injection moulded steel and subjected to thermal debinding and sintering in the same conditions. The structure and density investigations of steels in the sintered state made with the pressureless forming method and subjected to degradation at the temperature of 450°C shows that the temperature which provides the maximum density of the specimens is lower in comparison with the temperature of injection moulded steels and is approximately 1230°C. In the case of injection moulded steels also subjected to degradation at the temperature of 450°C, the optimum sintering temperature, providing high density and homogeneous structure with fine precipitations of the primary carbides is approximately 10-15°C higher.

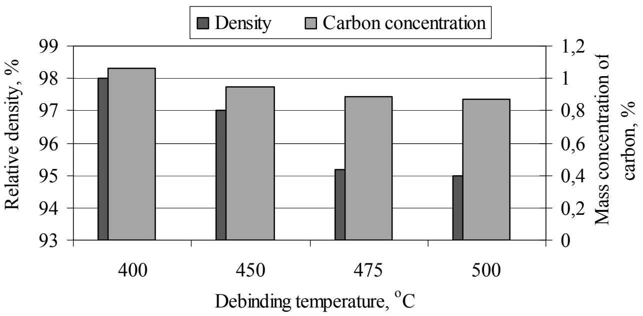

Fig. 2. Relative density and carbon concentration of samples sintered at 1240°C after thermal debinding at temperature: a) 400, b) 450, c) 475, d) 500°C

Irrespective of the production method, the increase in the optimum sintering temperature providing maximum density and the structure formed of fine carbide precipitations in the alloy ferrite matrix, may cause an uncontrollable growth and coagulation of the primary carbides. In the case of compacted and sintered steels, the density investigations and structure analysis in the sintered state show that the optimum sintering temperature is approximately 1280°C and should not exceed 1285°C due to the growth and coagulation of the primary carbides.

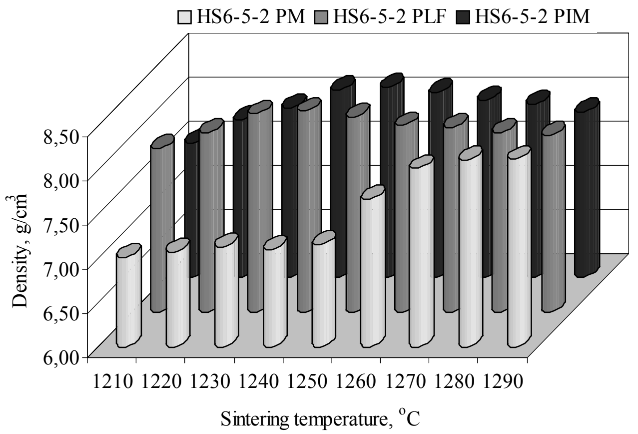

Fig. 3. Density versus sintering temperature of high speed-steel formed by powder injection moulding (PIM), pressureless forming (PLF) and compacted and sintered (PM)

Irrespective of the production method, all the steels sintered in the conditions ensuring high density and homogeneous structure with fine precipitations of the primary carbides, subjected to heat treatment demonstrate increased hardness in comparison with hardening from the temperature of 1180°C is demonstrated by the injection moulded steel (PIM). Its value is comparable to the hardness of app. 66HRC of the commercial type ASP 23 steel hardened from the same temperature. In both cases the hardness increases by app. 1HRC after double tempering at the temperature of 570°C. The lowest hardness of app. 54HRC after hardening from the temperature of 1210°C is demonstrated by the presurlessly formed steel (PFL). The hardness of the compacted and sintered steel (PM) after hardening from the same austenitizing temperature is app.63 HRC and increases to the value of app. 64HRC after double tempering at the temperature of 570°C. The highest hardness increase after tempering is demonstrated by the pressurelessly formed steel (PLF). The detailed investigation results of the pressureless formed steel were already published in [7, 8]. Such behaviour of the investigated steels is undoubtedly caused by the difference in carbon concentrations in these steels after sintering. In the injection moulded steels, regardless of the debinding temperature, the carbon concentration in the sintered specimens is comparable to the carbon concentration in the steel powder used. This value is about 0.9%C lower than the carbon concentration in steels formed with the pressureless method, hence the big hardness difference following heat treatment in the investigated materials.

4. Conclusions

The main advantage of PIM method is the obtainability of a profile of a more elaborate shape, higher density and homogenous distribution of the powder in the binding agent matrix. The pressureless forming method (PLF) apart form the furnace for binding agent degradation and sintering does not require any other equipment, which is an obvious advantage.

The density, hardness and structure changes depending on the binding agent degradation and sintering conditions, as well as the chemical composition analysis of steel made with the powder injection method (PIM), lead to the conclusion that the thermal debinding should be performed at the possible highest temperature, i.e. 450-475°C, which ensures retaining the minimum mechanical properties to enable the profile to be transported between the pieces of heating equipment during the technological process. Sintering at the temperature of 1240-1255°C ensures a homogeneous structure characterized by even distribution of fine, spherical carbides in the steel matrix. The high hardness of the injection moulded steel (PIM) in the heat treated state, comparable to the commercial ASP 23 type steel hardness, indicates the viability of the powder injection moulding method for making high-speed steels. An unquestionable advantage of this method is the fact that it offers a possibility of making finished tools, i.e. there is no need for plastic forming and machining, necessary in the case the ASP 23 type steel. Moreover, hot isostatic sintering of the ASP 23 type steel is more expensive than voluntary sintering, occurring in the powder injection moulding process. The tools made with this method may be characterized by complex shapes and surface. Furthermore, sintering in the atmosphere rich in nitrogen causes the formation of fine spherical carbonitrides, stable in the high sintering and austenitizing temperatures.

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