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Comparison of structure and properties of the HS12-1-5-5 type high-speed steel fabricated using the pressureless forming and PIM methods

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Abstract: Structure and mechanical properties of the HS12-1-5-5 type high-speed steels manufactured by powder injection moulding and with the pressureless forming were investigated and compared in the project. Basing on the structure examinations, occurrences of big spherical pores in the pressureless formed test pieces were revealed, that could not be eliminated in the debinding and sintering processes. The specimens fabricated with the powder injection forming method are characteristic of the higher density and uniform distribution of the high-speed steel powder in the binding agent matrix. In addition, employing the bicomponent binding agent in the form of paraffin and polyethylene made cutting the debinding and sintering time possible by about 10 hours in comparison to manufacturing the steel with the pressureless forming method. Hardness tests in the as quenched state of the HS12-1-5-5 type steel specimens have demonstrated that the pressureless formed steels display lower hardness compared to steels manufactured with the PIM method. This is, undoubtedly, caused by a higher carbon concentration, which lowers the M_s and M_f temperatures of the martensitic transformation and increases the contents of the retained austenite.

Keywords: High Speed Steels, Powder Injection Moulding, Pressureless Forming

1. INTRODUCTION

The continuous development of powder metallurgy and especially employment of newer and newer forming methods, as well as modernisation of those existing so far, have led to the significant lowering of the manufacturing costs of the sintered materials. These changes are quite clearly evident in the high-speed steels case for which the price of tools made with the conventional casting is comparable with the sintered tools cost. The need to use the powder metallurgy in case of the high-speed steels was dictated by the inhomogeneous structure resulting from casting the molten steel. The costly plastic forming of the ingots cannot break fully the lattice of carbides, which is often observed as the band-like segregation of the primary carbides [1]. According to the trend observed in the last years, i.e., forming the elements with their final shape, or with the near-net-shape, the development of such methods like Powder Injection Moulding and Pressureless Forming, seems to be justified. Both these methods are widely used for manufacturing small elements with complicated shapes and complex surface [2-4]. Therefore, research was initiated on using them for manufacturing tool materials.

The aim of this work is investigation and comparison of structure and properties of the HS12-1-5-5 type high-speed steel fabricated using the pressureless forming and PIM methods.

2. EXPERIMENTAL PROCEDURE

The investigations were carried out on specimens fabricated using the powder injection and the pressureless forming methods. In both cases the HS12-1-5-5 type high-speed steel spherical shaped powder was used, sputtered with argon. The chemical composition of powder is shown in table 1.

Table 1.
Chemical composition of powder of HS12-1-5-5 type steel

Type of steel	Average composition, wt %							
	C	Mn	Si	Cr	W	Mo	V	Co
HS12-1-5-5	1,47	0,5	0,43	4,76	11,8	0,06	4,75	4,64

The powder grain size does not exceed 12μm in 80%. In case of the pressureless forming the thermosetting acryl resin was used as the binding agent, liquid at the ambient temperature, with the 1,0 g/cm^3 density. The metallic powder was mixed with the binding agent in portions of 40 to 60%. The prepregs were subjected to thermal degradation at the temperatures of 300, 350, 400, 450^{o}C in the atmosphere of the flowing argon. The heating up rate was selected experimentally basing on the degradation and sintering tests. Immediately after their thermal debinding the specimens were sintered at the temperature between 1210 and 1290^{o}C in steps of 10^{o}C, in the atmosphere of the flowing N_2-5%H_2 mixture of gases. As the binding agent for the injection formed specimens the high density 50% polyethylene and 50% paraffin were used. The density of the binding agent selected in this way was 0.93g/cm^3. The optimum volume portion of the powder examined using the torque rheometer was 68%. Both binding agent constituents and the metallic powder were initially mixed in the mixed rotating at the ambient temperature for one hour to obtain the homogeneous mixture. Next the material was extruded twice in the Rheomex CTW100p double screw extruder to obtain the homogeneous material in the form of granulate. Granulate obtained in this way was injected on the Arburg 220-S injection moulding machine into the die making it possible to form three specimens at a time with various shapes. Thermal debinding was carried out in the Goceram AB GCDV-50 type pipe furnace in the atmosphere of 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. The 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. Regardless from the fabrication method for the sintered specimens their density measurements were made using the Archimedes method. Carbon concentration, depending on the binding agent degradation and sintering temperatures, was measured with the LECO CS-200 type apparatus.

3. RESULT AND DISCUSSION

Basing on structure examinations of the prepregs after both injection and pressureless forming, it was found out that specimens formed with the PIM method are characteristic of the homogeneous distribution of the high-speed steel powder in the binding agent matrix (Fig. 1a). In case of the pressureless formed steels one can observe with the naked eye the big spherical pores that - due to their sizes - cannot be eliminated in the sintering processes (Fig. 1b).

Table 2.
Mechanical properties of green and brown parts deduced from the three point bending test

Debinding temperature, ^{o}C	Green parts	400	450	475	500
TRS (MPa)	22,1	18,9	16,7	7,7	-

They are the air filled blisters developing during mixing the resin with the steel powder. These blisters can be removed by forming the slurry under pressure or increasing the binding agent portion, which improves the flowing power of the slurry and makes it possible to carry them away to the surface. However, more binding agent means a longer debinding process and bigger contraction of the sintered material. Comparing the debinding and sintering processes of steels formed with the pressureless method and steels fabricated with the powder injection forming it was found out that the degradation and sintering times for injection formed steels is shorter by about 10 hours. The debinding process time is rather short because of using two binding agent components, i.e., paraffin and the high density polyethylene. The paraffin softening temperature is only 58^{o}C. Because of this the debinding paraffin opens pores in the entire prepreg volume, which next promotes the polyethylene decay process. The fabricating process of the steel formed with the pressureless method is much longer than in case of the PIM method because of such slow, experimentally selected, thermal debinding, connected with using a single binding agent type. Both in case of the injection formed steels and steels formed in a pressureless method the binding agent degradation temperature growth causes lowering the carbon concentration in steel. The narrow tolerance range pertaining to the carbon concentration in the high-speed steels is connected closely with the carbon equivalent index. Therefore, selection of the binding agent and its degradation should be carried out in such way so that they do not influence the carbon concentration increase in the sintered specimens. Therefore, debinding should be carried out at the possibly highest temperature, to decrease as much as possible the carbon concentration growth, being the binding agent decay product. On the other hand, employing the incomplete binding agent degradation is forced often by the necessity to transfer the specimens between the debinding and sintering operations, which makes it possible to maintain the minimum mechanical properties of the prepreg allowing to move it. It was found out basing on the investigations of the effect of the thermal debinding temperature on carbon concentration and mechanical properties of the injection formed steels, presented in Table 2, that the optimum debinding temperature should be within the 450 to 475^{o}C range.

The total binding agent degradation takes place at the temperature of about 500^{o}C, which excludes the eventual transferring, moving, or any other manipulation with the specimen and, therefore, measurement of the bending strength. On the other hand, the incomplete debinding at the temperature of 400^{o}C may cause the significant carbon concentration increase. It was found out basing on hardness tests of the steel in the as sintered state that the maximum hardness of steels formed with the pressureless method is higher by about 5 HRC compared to the maximum hardness of steels manufactured with the PIM method. As a result of quenching from the temperature of 1150^{o}C the injection formed steel has hardness higher by about 7 HRC than the steel formed with a pressureless method. Such behaviour of the investigated steels is undoubtedly caused by the difference of carbon concentrations in these steels after sintering. The higher carbon amount remaining after degradation of steels formed with the pressureless method causes development of the bigger amount of carbides during sintering, which increases hardness of this steel.

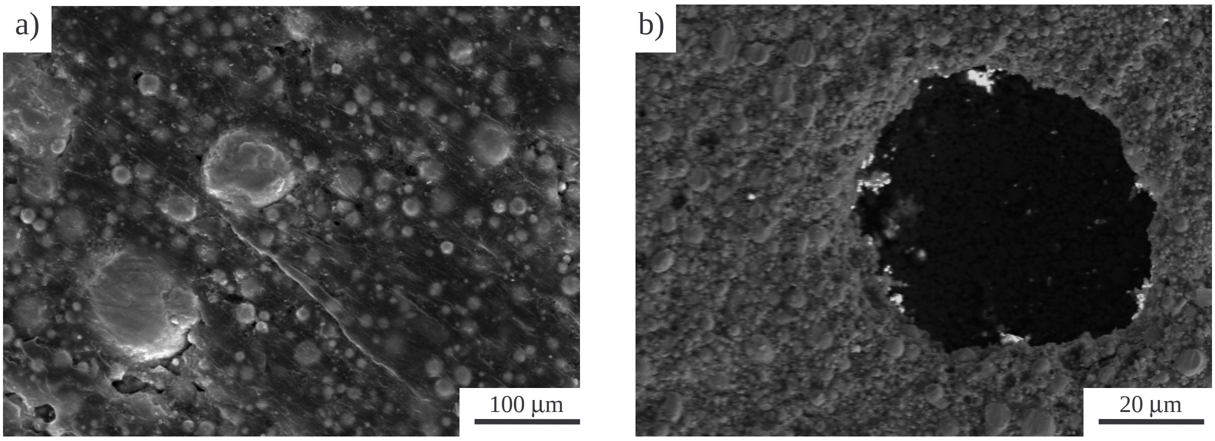

Fig. 1. a) Spherical pore in HS12-1-5-5 HSS formed with the pressureless forming method, b) distribution of binder and powder of HS12-1-5-5 HSS formed with the PIM method

A lower hardness after quenching is connected with the higher content of the retained austenite, also connected with the increased carbon concentration [4].

4. CONCLUSIONS

Basing on the investigations carried out of the HS12-1-5-5 type high-speed steels fabricated with the injection and pressureless forming methods one may conclude that the PIM method is more justified economically, in spite of the need to use the expensive srew injection moulding machines. The main advantage of this method is the possibility of obtaining the prepregs with the more developed surface, higher density and homogeneous distribution of the powder in the binding agent matrix. In addition, the debinding and sintering time is about 10 h shorter than in case of the pressureless forming, which is caused by employing the bi-component binding agent in the PIM method. Yet, pressureless forming has also its advantages. This method does not require practically any additional equipment apart from the furnace for thermal degradation of the binding agent and for sintering.

Results of the density measurements, hardness tests, and observations of the structure changes depending on the binding agent degradation and sintering conditions, and also the chemical composition analysis for steels fabricated using the PIM method, make it possible to state that the thermal debinding should be carried out at the possibly highest temperature, i.e.,450 – 475^{o}C, ensuring maintaining the minimum mechanical properties.

Hardness higher by about 7 HRC after quenching of the steel made with the PIM method indicates to its higher abrasive wear resistance, which is exceptionally important in case of the tool material.

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