Materials Science Forum Vols. 514-516 (2006) pp 569-573
online at http://www.scientific.net

Online available since 2006/May/15

Low-pressure Injection Molding Processing of AISI T15 High Speed Steel Powders

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Keywords: Powder injection molding; AISI T15 High Speed Steel; Solvente extraction.

Abstract. Low-pressure powder injection molding was used to obtain AISI T15 high speed steel parts. The binders used were based on paraffin wax, low density polyethylene and stearic acid. The metals powders were characterized in terms of morphology, particle size distribution. The mixture was injected in the shape of square bar specimens to evaluate the performance of the injection in the green state, and then sintered. The samples were injected under the pressures of 0.4, 0.5 and 0.7MPa and at temperatures varying from 110 to 150°C aiming the optimization of the process. The results of the variation of injection pressure were evaluated by measuring the density of the green parts. Debinding was carried out in two steps: first, the molded part was immersed in heptane to remove the major component of the binder and then heated to remove the remaining binder. A second step debinding and sintering were performed in a single step. This procedure shortened considerably the debinding and sintering time.

Introduction

The powder injection molding has been accepted as an appropriate process producing great volumes of small, complex near net shape parts with competitive costs. The technique involves the homogenization of the powder with a binder system, the injection in a mold, the removal of binder and then the sintering for the consolidation of the parts until its final density [1]. The control of each stage of this process and the appropriate selection of the initial materials, the metal powder and binder, are important factors for the total success of the process.
The binder supplies the powder with the necessary fluidity to fulfill the mold. It also influences the maximum solid fraction of the mixture that can be molded, the green strength of the parts molded and the properties of the final part after the extraction of the binder [2].
The process can be classified in high pressure, i.e., above 1,0 MPa and low pressure. The high pressure method has as advantage the production of large quantities of parts and as disadvantage the high cost of manufacture and mantainance of the dies. In low pressure injection molding the attainment of parts more than 10 cm long can be critical, depending on its mass and the geometry of the part. The main advantages of the low pressure process are the lower costs of the die and the proper equipment. The injection molding process allows the use of metallic, ceramic, composite and biomateriais for the production of parts [3, 4].
This work presents the results of an evaluation of the low pressure injection molding of AISI T15 high speed steel powders. This study analyzes making considerations about the characteristics of the metallic powder, the powder /binder system, the parameters of injection and the stages of debinder.

Experimental procedure

Gas atomized AISI T15 high speed steel powders with 80% of particles below 22µm supplied by Osprey Metals Ltd, UK were used in this study. Spherical morphology was observed as shown in

Fig.1. The nominal chemical composition (in wt %) was as follow: Fe – 1.55C – 4.5Cr – 4.75V – 12.5W – 5.0Co – 0.3Si – 0.4Mn, and its particle size distribution is given in Table1.

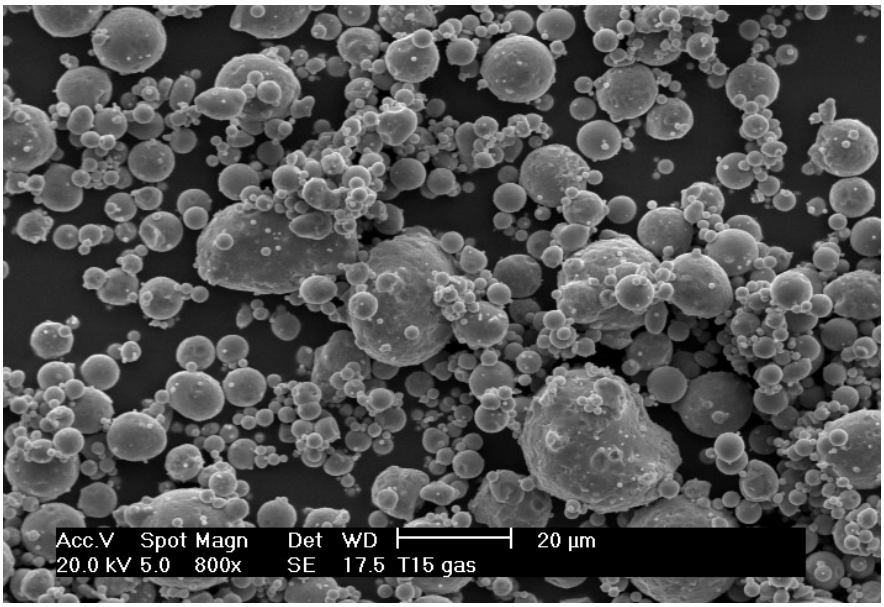

Fig.1 – Scanning electron micrograph showing the spherical morphology of the particles of the AISI T15 powders.

To the metallic powder was added a mixture of a thermoplastic binder composed of polyethylene wax (PE, 60%), paraffin wax (PW, 35%) and stearic acid (AS, 5%). The polyethylene wax was used to promote green strength and to prevent the sample to collapse during the transition stage between the solvent debinding and the thermal debinding. The paraffin wax reduces the metal-polymer system viscosity and corrects the rheological behavior during the injection. The stearic acid is responsible for the wettability of particles and acted as a desmolding agent. Table 2 presents the density and viscosity data of the binder components.

Table 1 - Particle size distribution of AISI T15 powder, manufacturer data.

Laser diffraction (Malvern).								
particle size, µm	<25.5	<23.1	<21	<15.6	<10.5	<5.27	>38	<38
fraction, %	90.6	86.5	81.0	58.5	30.2	7.3	1.2	bal.

Table 2 - Some physical properties of the binders used in this investigation.

Material	Density (g/cm^3)	Melting Point (°C)	Viscosity (Pa·s), at ref. temp.	Ref. temp. (°C)
polyethylene wax	0.91	114	0.79	130
paraffin wax	0.78	61.9	0.009	110
stearic acid	0.85	65 - 68	-	-

The critical load was determined from a given binder mass with a composition already known through successive additions of T15 high speed steel followed by determination of the resulting density. This procedure was repeated until the experimental density assumed a value inferior to the predicted density, theoretically, for the metallic powder fraction.

The feedstock produced was submitted to several test injections in a Peltsman MIGL-28A equipment, until optimum parameters of temperature, pressure and time were detected, and then used in the production of the green parts.
The green parts were submitted to a stage of extraction of solvent when about two third parts of the volume of the binder was removed. The parts were submitted to immersion in liquid heptane at 50°C and 1atm for 4h. Later the parts were dried at 30°C for 1h to the evaporation of the solvent from the pores. After solvent debinding, the parts were submitted to a thermal debinding with on a alumina powder bed inside ceramic tube furnace and vacuum of 10Pa completely removing all the organic binder by capillarity. The cycle consisted of a rate of heating of 3-15C/min until 440°C and holding for 2h. The sintering proceeded at 1250°C in vacuum, at 10min**.**

Results and Discussion

The final feedstock composition was obtained by determining the critical load, ϕ_{CR}, its curve is shown in Fig.2.
The curve presented in Fig.2 shows that for values higher than 63% in volume of high speed steel powder, the experimental feedstock density is lower than the predicted density, thus theoretically demonstrating that the so-called critical loading of the powder was reached for the binder system studied. The global composition of the feedstock studied was 94.28%wt AISI T15 high speed steel powder, 3.43%wt polyethylene wax, 2.00% paraffin wax and 0.29%wt stearic acid.

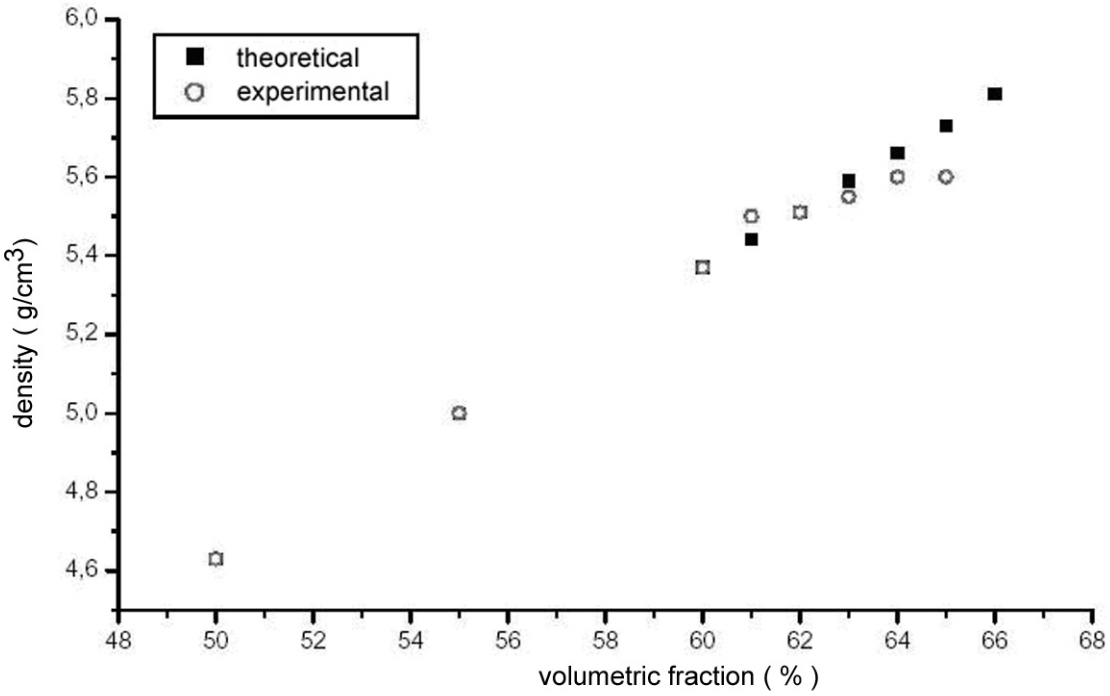

Fig. 2 – Critical load determination of the AISI T15 steel powder for the binder system used in the work.

Figure 3 shows the variation of the viscosity versus the shear rate. It is possible to observe a pseudo-plastic behavior, i.e, a reduction of viscosity with the shear rate, what it is favorable for the injection process [1, 5], and this behavior remained for a long period**.**

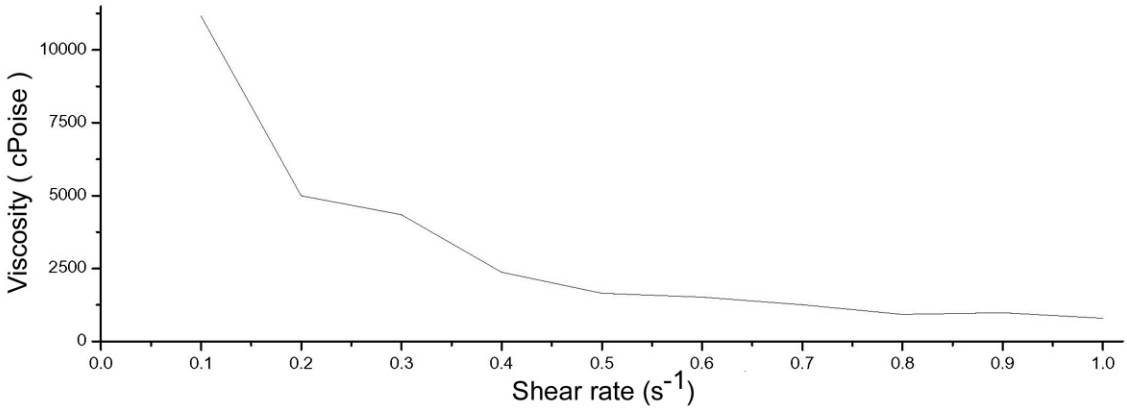

Fig. 3 - Rheological pseudo-plastic behavior of the feedstock remaining for a long period.

After some tests varying the pressure and temperature of injection it was determined that this feedstock was more easily molded in a temperature of 120°C and 0,7MPa. All the molded parts were free of defects such as: incomplete fulfilling, separation of the binder and crack in the surface. In Fig 4 it can be observed parts with problems of fulfilling due to the very high temperature or the very short time of injection.

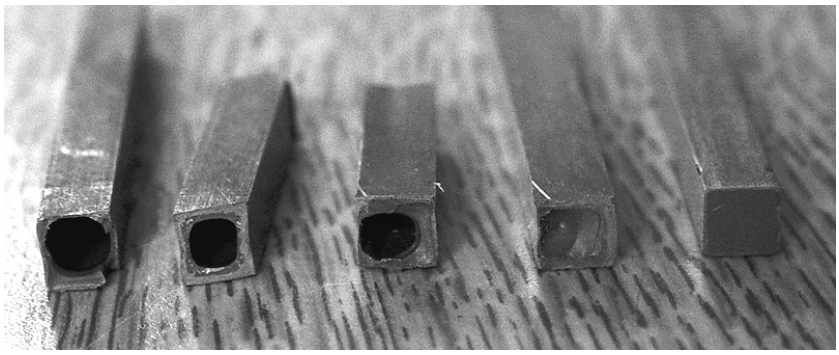

Fig. 4 - Irregular fulfilling of the mold indicating a very high temperature of injection.

In Fig.5 SEM micrograph of the surface fracture of a molded part is presented. It can be observed that the binder fills practically all the spaces between metallic powders particles forming a continue skeleton.

The distribution of the binder and the evolution of the porosity interconnected as a function of time for the duration of the immersion in heptano for some temperatures were observed using scanning electronic microscopy (SEM) allowed the determination of the loss of mass. Different areas of the molded part were examined including the external regions and the core of the breaking surface in order to monitor the progress of the process.

The paraffin wax became fluid in the heptano and started to form fine channels of pores. Increasing of the time of immersion increased the loss of weight of the paraffin wax and the channel of pores widened. After 4hs, almost all paraffin wax were removed. A polyethylene net remained; keeping joined steel particles, supplying enough strength to handling.

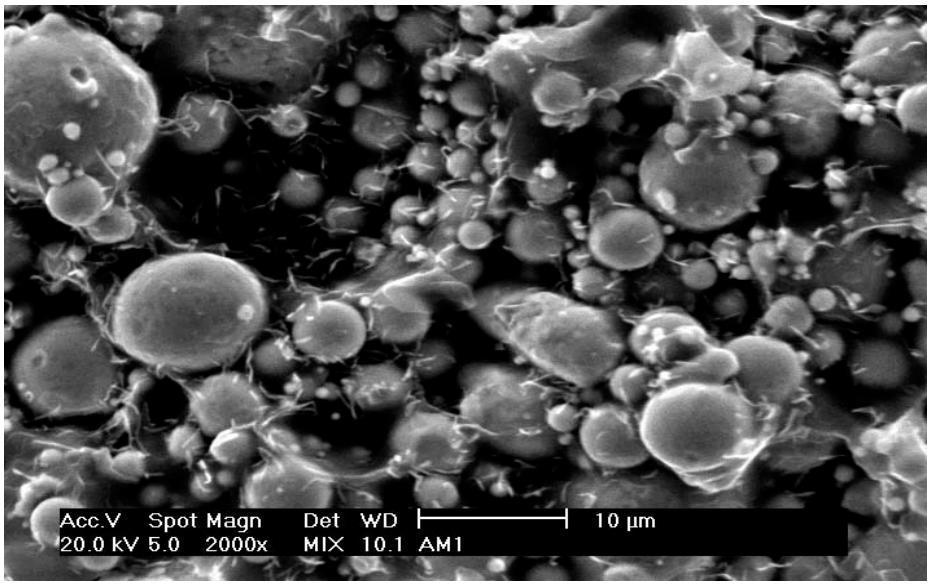

Fig. 5 - SEM micrograph of green part fracture showing the uniformity of the dispersal of the binder PW/PE/AS .

After 4hs of immersion cracking in the parts molded started to occur probably due to slow diffusion of the wax to the heptano which caused swelling and internal tensions.

Conclusions

The binder consisting of paraffin wax; polyethylene wax and stearic acid allowed good metal powder wettability characteristics by producing parts free of holes.
The solvent and wicking debinder process was beneficial to eliminate most of the binder at relatively low temperatures and to reduce the debinding time.
This study demonstrates that low pressure injection molding (LPIM) can be employed as a potential technique for manufacturing high speed steel components with small and complex shapes.

Acknowledgements

The authors are grateful to CCTM-IPEN, Brazil for the facilities and to Conselho Nacional de Desenvolvimento Cientifico e Tecnológico - CNPq for scholarship awarded to J.F.L. and O.O.A.F.

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Advanced Materials Forum III
doi:10.4028/0-87849-402-2
Low-Pressure Injection Molding Processing of AISI T15 High Speed Steel Powders
doi:10.4028/0-87849-402-2.569