Plasma Assisted Debinding and Sintering (PADS) – A Metal Injection Molding Case Study

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Abstract

This paper describes a Plasma Assisted Debinding and Sintering (PADS) equipment, which has been designed to process Metal Injection Molded (MIM) components. The use of a hybrid system combining a glow discharge with a conventional heating system makes debinding and sintering of MIM components, in the same heating cycle, a feasible industrial process. Characteristics as density, carbon content and mechanical properties are similar to traditionally processed MIM materials. The reduction of energy and gas consumption and shorter lead-times are economic advantages of PADS system. The clean environment of PADS is also an ecological advantage.

Keywords: plasma, powder injection molding, debinding, sintering, clean environment

1. Introduction

Its more widespread use of the metal injection molding (MIM) technology is limited due by the long processing times required for debinding and its subsequent sintering step [1]. Although sintering is carried out at a temperature much higher than debinding, its results can be strongly affected by variations in the latter one. For this reason it is important to remove every trace or deposits of binders during the debinding step prior to reaching final sintering temperatures. Such deposits might further contaminate the parts with carbon, which in case of MIM parts may form a eutectic with the metal alloy causing melting at lower temperatures than desired. Especially in the case of austenitic stainless steels this is undesired. Moreover, the heating elements might also suffer from contamination problems by the binder products, thus making furnace maintenance more expensive. Another interesting point reported by Robinson and Paul [2] is that in vacuum dewaxing processes the heating elements can metal injection molding (MIM) technology be up to 100 °C hotter than the load temperature. This can lead to cracking of the paraffin wax forming a carbon reach environment. It has been found that unless the top exit tube of a muffler type furnace is kept heated, the evaporated waxes and polymers often tend to condense and clog the gas exit pipe, which essentially removes the degraded products [3]. In the thermal debinding process, the removal of the binder can be achieved using a vacuum atmosphere with a partial pressure of gases to help sweep the binders. A reactive product might be added to help binder degradation. However, the wax as well as the degradation products of the plastics might reach the pumping system and cause it to breakdown. Some very clever solutions have been proposed to overcome most of the above-mentioned problems as reviewed by Bose [4]. Based on many shortcomings of existing commercial systems to pursue the one-cycle debinding and sintering process, we have systematically investigated the possibility of building an industrial-scale plasma reactor as reported elsewhere [5]. The result is a hybrid system which combines advantages of both conventional and plasma heating systems. A project to build a system to fully process the injected parts in order to have good quality sintered products has been conducted in cooperation with Steelinject Ltd. In this paper we present updated technical results of such a system operating in industrial scale.

2. Experimental and Results

The PADS process has been under development by a research team of the Federal University of Santa Catarina in cooperation with Steelinject Ltd since 1997. The main purpose was to explore the potencial of the reactive specimens of the plasma environment to breakdown the macromolecules of polymers, present in the binder system of MIM parts. Initialy the system concept was to perform only debinding. After a period of tests with positive results in debinding with no traps and with clean muffle walls after cycles, it was possible to improve the system to perform a complete cycle, i.e., debinding and sintering. At this point, due to the intrinsic characteristics of the abnormal plasma discharge at higher temperatures (above to 1000 ºC), Mo heating elements were aggregated to the system. Consequently, a hybrid system composed by Mo electrodes and Mo heating elements was assembled, allowing debinding and sintering of MIM parts to be performed in the same equipment. The Mo electrodes were responsible to create reactive specimens to break the polymer molecules of the binder as well as accommodate the parts on the anode. The Mo heating elements were responsible for the heating during the debinding and sintering steps. The MIM parts were disposed on the anode, on a dense ceramic plate (Al_2O_3). The cycles were performed controlling the parameters temperature, time, pressure, gas flow, plasma voltage and plasma current. An efficient plasma assisted debinding step can be obtained controlling adequately these parameters: pressure, plasma voltage, heating rate, gas flow and T_{on} (defined as the time on of the total time of the DC pulsed wave, measured in terms of plasma current).

In the PADS system it is possible to process different types of MIM materials, as metals, ceramics, composite materials, hard metals and others. PADS furnace has no traps, due to conversion of macromolecules into gaseous phase by the reactive specimens of the plasma. Due to this advantage, the furnace environment is always clean and makes debind and sinter MIM parts in the same equipment possible, without problems as carbon enrichment and/or distortions. Figures 1 and 2 show, respectively, the design of the equipment in a 3D cut isometric view and a picture of the PADS furnace.

The total cycle time (cooling included) to 2NiFe0,6C was 6 hours and 7 hours for 316-L. Comparing to traditional MIM processes (debinding in a positive hydrogen pressure and sintering in a vacuum furnace), the time decreases from 80 to 6 hours. The reduction of energy and gas consumption was very significant (energy from 800 kW to 500 kW and hydrogen from 120 m^3 to 30 m^3). The results in terms of metallurgical behavior are shown in table 1. Comparing to UFSC PADS pilot furnace [5], these results are similar or better, showing a process optimization since the beginning of the development.

The improvement of the mechanical properties of the 2NiFe0,6C low alloy steel was increased by a quench / temper heat treatment. The temper temperature was 415 ºC and the time 30 min.. PADS results were compared to commercial catalytic system results [3].

The reductions of energy and gas comsumption are economic advantages of the PADS system. The reduction in MIM process lead-time achieved with PADS increased significantly Lupatech's productivity. The clean environment of PADS is an ecological advantage, because there are no toxic residues been pumped out during the process. This advantage is very important, making PADS the cleanest MIM debinding process available nowadays.

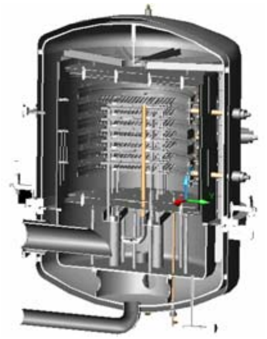

Fig. 1. Design of PADS furnace in a 3D cut isometric view

Fig. 2. PADS furnace

Table 1. Comparison of metallurgical variables of materials processed in PADS furnace and in a conventional route (catalytic debinding).

Alloy	Condition	Process	Density (g/cm3)	Carbon Content (%mass)	Hardnees (HV0,2 kg)	Ultimate Strenght (MPa)	Yeld Strenght (MPa)	Elongation (%)
2NiFe0,6C	sintered	PADS	7,65	0,58 - 0,62	170	575	480	4
		conventional	7,50	0,6 - 0,8	160	500	250	3
	tempered	PADS	7,65	0,58 - 0,62	350	1210	1180	2
		conventional	7,50	0,6 - 0,8	340	950	800	3
316-L	sintered	PADS	7,70	0,0015	170	505	290	54
		conventional	7,85	0,03 m? .	120	510	180	50

3. References

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