Technical Trends in Debinding and Sintering Furnace for MIM

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SYNOPSIS
SHIMADZU Vacuum Debinding and Sintering Furnace is designed for debinding and sintering of the green parts of MIM (Metal Injection Molding). The furnace is not contaminated by the vapor of the binder during the debinding process and it realizes clean atmosphere in the sintering process. The user set a high valuation on this feature as equipment for mass-production of MIM parts. We present recent technical trends of the furnace based on our results of the supplies.

KEY WORDS
MIM, furnace, debinding, densification, HIP

1 Introduction

MIM is a process to mass-produce complex parts of various metals in high precision. It has been passed about 10 years since the mass production of the MIM parts was started. It has been applied to the parts like watch, OA equipment, sewing machine, and camera. The market growth rate was 10 to 20 % a year and the world market scale is about 400 million US dollars. In the future, it will be applied to more wide area of the parts like optical communication and car equipment and the growth of the market will continue.

In the globalization, the competition becomes more and more severe and the parts manufacture needs to reduce the costs and improve the quality of the products. We believe that MIM process is one of the answers to this requirement and its success depends heavily on the debinding and sintering furnace.

2 Debinding and sintering of MIM parts

The MIM parts contain about 40 vol.% of binder so that debinding is usually the most time consuming and critical process in the total MIM process.

Typical debinding methods and their features are as follows:

(1) Debinding oven
The heating by oven in the air is the most common method but it is applied only to the metal that is not sensitive to the oxygen.

(2) Solvent debinding
The green parts are soaked in the solvent and binder is extracted from the parts. This method is effective for parts of large size and the debinding time is short, but disposition of the used solvent has problem from the environmental point of view.

(3) Catalytic debinding
This method uses acid gas as catalyst to decompose the polyacetal binder. The debinding speed is fast but the disposition of the exhaust gas should be careful.

(4) Vacuum debinding
This method uses vacuum furnace and the debinding is done in vacuum condition. Paraffin vaporize fast in high vacuum, but heat transfer occurs only by radiation in vacuum, it takes long time to get uniform temperature in the effective area.

(5) Reduced pressure debinding
This method also uses a vacuum furnace and the debinding is done in reduced pressure with career gas. Heat transfer occurs by radiation and convection, so that the temperature uniformity is better in the effective area.

After the debinding, the parts are moved to the sintering stage. Total debinding is a premise to successful sintering. If the binder remained in the work, it causes the carbonization of the parts. If the binder remained in the furnace chamber, it revaporizes during sintering stage and it makes the carbonizing atmosphere. Therefore the inside of the furnace should be clean before sintering starts.
The green parts of the MIM contain about 40 vol.% of binder, so that the dimensional shrinkage in the sintering process becomes about 15% by calculation. Therefore, if the temperature or gas flow in the furnace is not uniform, the density of the work becomes different and the dimension of the work scatter.

### 3 Features of SHIMADZU furnace

The specifications of the furnaces for MIM (VHS series) are shown in Table 1 and the external appearance of the furnace is shown in Fig. 1.

The evacuation system is shown in Fig. 2 and fundamental process pattern is shown in Fig. 3.

<table>
<thead>
<tr>
<th>Model</th>
<th>VHS gr</th>
</tr>
</thead>
<tbody>
<tr>
<td>30/30/60</td>
<td>40/40/400</td>
</tr>
<tr>
<td>50/50/100</td>
<td>500×500×1200</td>
</tr>
<tr>
<td>Box outer dimension W×H×L mm</td>
<td>300×300×600</td>
</tr>
<tr>
<td>Charge mass (gross)</td>
<td>100 kg</td>
</tr>
<tr>
<td>Power source</td>
<td>80 kVA</td>
</tr>
<tr>
<td>Temperature</td>
<td>Max. 1600°C, Nor. 1500°C</td>
</tr>
<tr>
<td>Temp. Uniformity</td>
<td>±5°C</td>
</tr>
<tr>
<td>Ultimate Vacuum</td>
<td>7×10^{-1} Pa</td>
</tr>
<tr>
<td>Gas</td>
<td>N₂ or Ar</td>
</tr>
<tr>
<td>Debinding Method</td>
<td>Evacuate the vapor directly from inside of the box.</td>
</tr>
</tbody>
</table>

Fig. 1 External appearance of VHSgr 30/30/60-M.
Using this furnace following process can be possible.
(1) For small MIM parts with current binder, It is possible to process debinding and sintering continuously in 24 hours.
(2) The post-debinding and sintering are possible for MIM parts which are already pre-debound by some means.

The features of VHS series are as follows.
(1) Combination of the tight box and liquefying binder trap makes both inside of the furnace chamber and the evacuation system clean (U.S. Patent 5614029).
(2) The tight box and trays in the box make uniform carrier gas flow which bring the vapor of the binder from the work in the box completely. The carrier gas also prevents the vapor of the binder getting out of the box and contaminating the insulation and inside of the furnace chamber. This assures clean atmosphere in the sintering. Also the life of the heater and insulation becomes long.
(3) The liquefying binder trap makes trapping and liquefying continuously and binder is retrieved in the tank, so that the trap efficiency keeps high during debinding. The trap efficiency is more than 95% for paraffin. This trap reduces the evacuation loading and makes the maintenance of the evacuation pump easy.
(4) Axis-symmetrical arrangement of the heater, cylindrical insulation and indirect heating through the tight box makes excellent temperature uniformity throughout the debinding and sintering process.
(5) The furnace is compact, energy saving and has easy maintainability.

4 Typical process by SHIMADZU furnace
The standard process for the parts of SUS316L using VHS furnace is as follows.
(1) Debinding
Evacuate from inside of the tight box by the rotary pump and flow N₂ gas as carrier from outside of the box.
Increase the temperature near the melting point of the binder and after that gradually increase the temperature. The increasing rate of the temperature can be accelerated according to the progress of the debinding.
(2) Degassing
After the debinding is over, stop the carrier gas and evacuate the furnace thorough main duct by mechanical booster pump to make degassing of the work. The diffusion
pump is not necessary for usual material like iron or stainless steel, because no binder remains in the chamber and it is clean after debinding.

(3) Sintering

Keep the furnace at vacuum and increase the temperature. During the latter half of the sintering, flow the inert gas like Ar and increase the pressure in the furnace about 1k~5kPa to prevent the vaporization of the metals.

(4) Cooling

After the sintering is over, decrease the temperature gradually less than the sintering temperature and after that start the forced cooling fan.

5 Technical Trends in Debinding and Sintering Furnace

If the debinding and sintering were done by different equipment, one has to move the work from the debinding equipment to the sintering furnace.

The work is affected by the oxygen and humidity in the air, also get the damages during transportation.

Therefor to keep the quality of the work, continuous process of debinding and sintering is preferable.

Therefor the furnace should have the capability to take off all the binder not only from the work but also from the chamber, otherwise remained binder vaporizes at sintering stage and contaminates the work.

The development of the new binder is continuing and the time needed for debinding becomes shorter. Now for small parts the debinding and sintering can be processed within 24 hours in the furnace, but for big parts some kind of pre-debinding may be necessary to improve the efficiency of the furnace.

In near future, the binder will improve and all the parts can be processed from debinding to sintering continuously in the furnace.

If the debinding time balance with the sintering time, twin type furnace is possible. It means that two chambers share the one electric power module and evacuation system. This configuration improves the efficiency of the batch process.

We summarize the merits of the continuous debinding and sintering as follows.

(1) Transportation of the work is not necessary and labor saving is possible.
(2) The work does not get contact with air and control of the quality is easy.
(3) Installation area for the equipment can be reduced.
(4) Various kind of material can be processed in vacuum and gas environments.
(5) Cost reduction can be achieved totally.
To increase the density of the product is basic need for the sintering process. In the hard metal area, HIP (Hot Isostatic Pressing) process by 6MPa over-pressure is very effective to get rid of the pores in the work and get high density and highly reliable products.

The external appearance of Sinter HIP furnace for this purpose is shown in Fig.4.

To apply HIP process and increase the quality of the product will be valuable for the MIM parts that are required especially high reliability.

6 Conclusions

To reduce the product cost of the mechanical parts, MIM process is getting much more expectation than ever from wide area of manufacturing industry. We believe that the point is the sintering furnace with debinding function and also good binder.

We are making continuous effort to reply to the customers needs such as better cost performance, optimum process condition for specific binders, application for the kind of metals with higher added values.

We hope that SHIMADZU furnace presented here will contributes to the widespread of MIM process.

Acknowledgments

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References