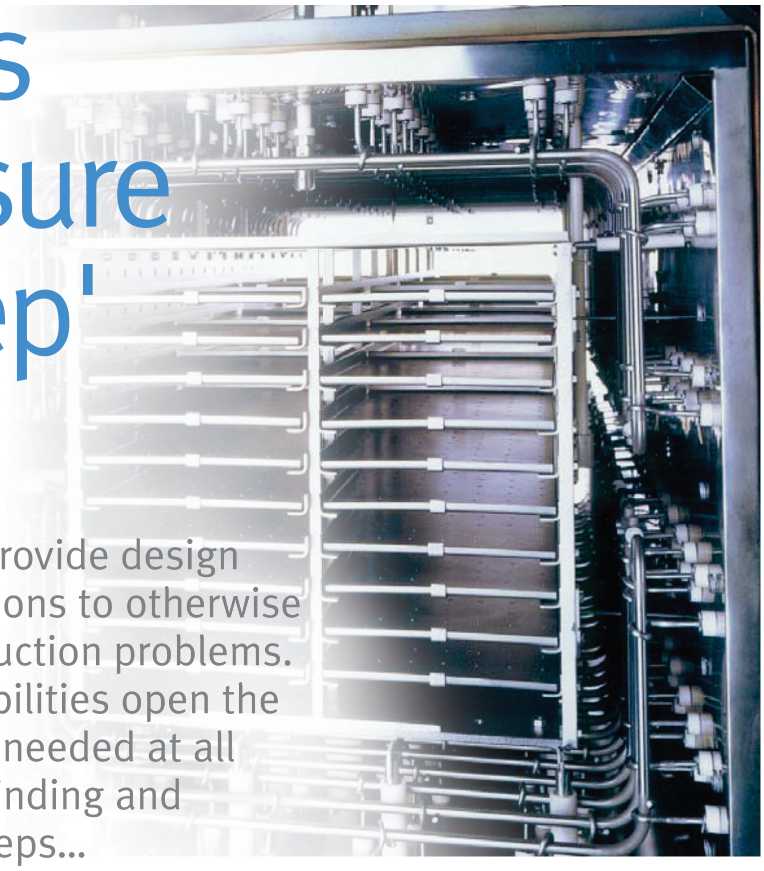
Laminar gas flows ensure 'clean sweep' in sintering



Metal injection moulding can provide design engineers with economic solutions to otherwise apparently insoluble part production problems. But although MIM's 'can-do' abilities open the way to design freedom, care is needed at all stages of the process. The debinding and sintering of parts are critical steps...

Powder injection moulding (PIM) is a manufacturing technique that encompasses metal powder injection moulding (MIM), ceramic powder injection moulding (CIM) and cemented carbide powder injection moulding (CCIM). All three processes combine the attributes of plastic injection moulding with the engineering and performance properties of metals, ceramics, and cemented carbides.

In this article **Claus Joens** of PVA MIMtech's Elnik Systems looks at some of the problems associated with the thermal debind and sinter technology of metal injection moulded parts - and their solutions.

MIM is a process where fine metal powders are mixed with a variety of binders to create thermoplastic feedstocks that can be injection moulded. They are then debound and sintered to full densities to attain the desired mechanical and physical properties.

The advantages of MIM are:

• Excellent shaping possibilities;

• Complex shaped parts can be manufactured with very little secondary finishing. For example, undercuts in parts, which are not possible with conventional sintering processes, can be easily achieved;

• Excellent surface quality when compared to precision cast parts. Finishing and polishing costs can be eliminated or greatly reduced;

• Excellent material properties;

• Parts reach densities of 96 per cent to 100 per cent of the theoretical material density;

• Very close tolerances. Parts are dimensionally accurate by a range of better than +/- 0.05 per cent; and

• A wide material selection. The great variety of metal powders and binders available cater for a broad spectrum of design needs. The harder it is for a part to be machined, the more advantageous the MIM process becomes.

The MIM process exhibits great cost effectiveness in producing complex parts. In fact, the more complex the part, the more suited this process becomes (and therefore the greater the cost savings.) Additionally, this process allows mixing of different metal powders with binders so that it is possible to engineer a part with very specific thermal, wear, magnetic and strength properties.

The MIM process also yields net shape components with little or no secondary operations. This simplifies production,

Figure 1. Critical issues in thermal debinding

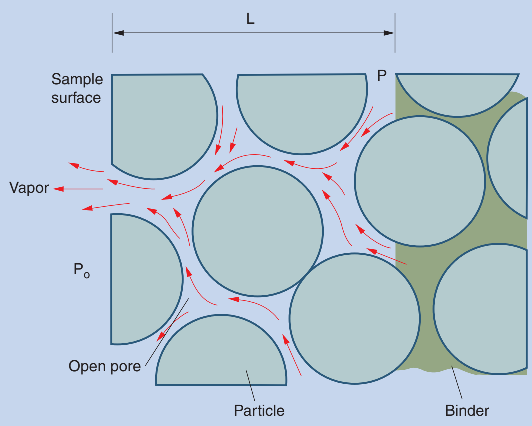
Debinding takes place by diffusion and permeation of the vapourised binder via the pores.

The thermal debinding process converts the binder to a vapour.

The transport distance 'L' of the vapourised binder to the surface increases over time.

Laminar gas flow ensures an even binder and no redeposition of binder on the part.

The thickest sections of the part limit the debind cycle time.



increasing yields and lowering the manufactured cost of the part.

The MIM process has four key manufacturing elements:

• The creation of the feedstock;

• The injection moulding cycle;

• The solvent/chemical debind cycle; and

• The thermal debind and sinter cycle.

During thermal debind and sinter, the component part is heated and may be subjected to undesired binder reactions with the powder along with shrinkage and thermal stresses. These are contributors to cracked, warped, chemically incorrect parts with poor density and of varying and incorrect sizes because the entire process requires very accurate and repeatable control.

The goal of the thermal debind step is to remove the majority of the binder which evaporates at low temperatures, leaving the backbone polymer to hold the powder particles in place so that the part can be sintered. This backbone polymer evaporates when the furnace goes up to sintering temperatures, then the part starts to sinter just before it densifies.

The thermal debind process converts the binder to a vapour that diffuses and permeates through the pores to the surface of the part. The critical issue here is an even binder evolution and a sweep of gas flow around the part to ensure no re-deposition of binder on the part.

An even flow all around that part ensures that all of the binder is extracted; during the sinter phase, when the pores begin to close, there is no binder left behind. With no excess binder to contaminate or distort the part no unwanted physical effects such as blistering are seen and no difficulties arise with density and chemical composition, such as carbon control in stainless steel.

In the early days of MIM processing it was quite usual to thermally debind the part in an air, vacuum or atmospheric nitrogen or hydrogen oven, depending on the material and the binder.

Today, there is another binder material which catalytically erodes the polyacetal used as the binder via nitric acid vapour. This requires a specially designed oven. The process works from the outside of the part to the inside, unlike the wax/polymer binder. However, both debinding times are a direct function of the thickness of the part. This means that the thickest part governs the total cycle time.

The problem with the ovens used originally was that there was no even gas flow. They also exhibit large thermal gradients. Both conditions create poorly debound parts through re-deposition of binder components on the parts and also contribute to contamination on the inside of the furnace.

This is not a problem with polyacetal binders since their removal is a chemical reaction. This binder is not offered for some metal powders and its removal requires a special catalytic debind oven. Parts after catalytic debinding are very fragile and their brown strength is a critical issue not found with wax/polymer binders. Damage to the brown parts during their transfer to the sinter furnace is an issue that merits consideration.

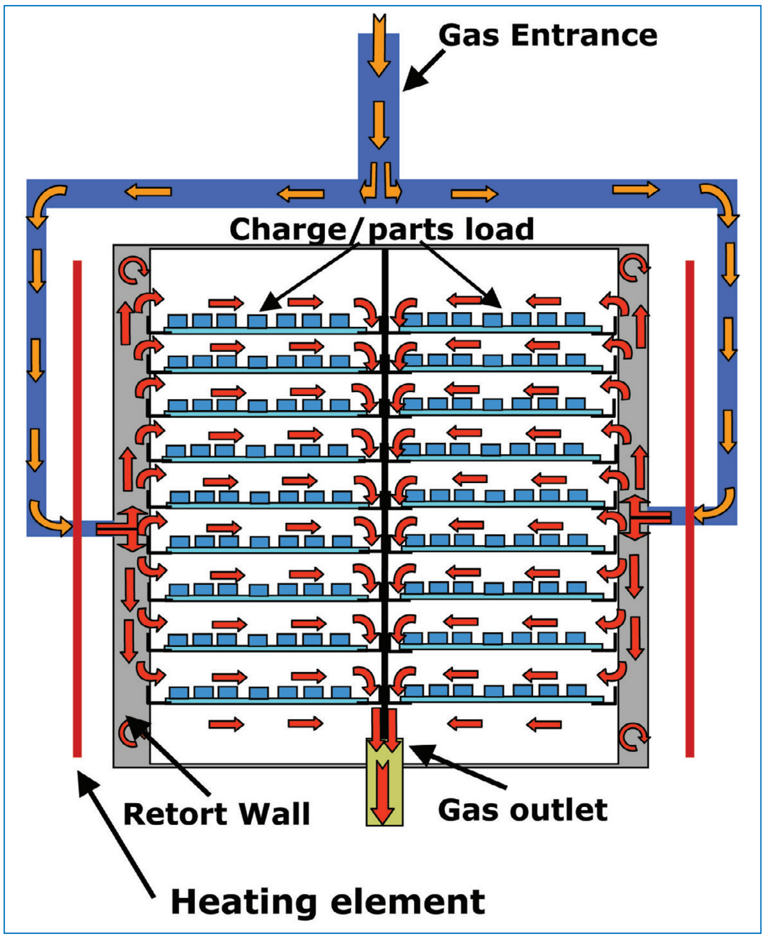


Figure 2. The process gas flows from the gas distribution holes across the shelves and parts to the centre of the furnace. It is preheated by heating elements and flows into the furnace at a higher temperature than the internal furnace temperature. The design ensures short gas flows to the centre of the furnace giving a constant clean gas flow across the parts. The centre area where gas is evacuated through the manifold vacuum ports is a few degrees colder, guiding the gas across the parts.

The double debind-sinter cycle is time consuming and expensive in terms of power used, since the parts area heated to debind temperature, cooled, then transferred to the sinter furnace, heated again to sinter temperature and cooled.

To overcome the problems of long process cycle times and breakage, a furnace with partial pressure operation in the range of 1 to 760 Torr was built to combine the thermal debind and sinter cycle in one step. This furnace design, with built-in retort and gas management system allows processing the injection moulded part under "laminar gas flow". This eliminates the contamination issues associated with the debind ovens of earlier days.

In this furnace design, the process gas flows from the distribution holes across the parts to the centre of the retort through the gas manifold with its inlet and outlet passage ways.

The gas is preheated by the heating elements, which guarantees the flow to the center of the retort.

While the physical attributes of the furnace are important in directing the gas flow, the type of flow is critical to the success of the laminar gas flow design. The three different principal gas flows are turbulent, laminar and molecular.

At an atmospheric pressure of 760 Torr, (typical for air or controlled gas ovens) the gas molecules flow at high pressure and velocity, colliding with each other. This creates uneven flow and shadow effects on the parts with consequent uneven debinding.

At a molecular flow of 1 Torr or less, (typical for vacuum ovens) the gas molecules collide with each other randomly and gas flow becomes unpredictable. The gas flow also escapes to the cold walls of the oven, creating random flow on the parts and contamination inside the furnace.

At a laminar flow of around 300 Torr, the gas molecules flow at sufficient velocity to flow smoothly and evenly over surface irregularities. This creates an even flow and no shadow effects, much as if the parts were submerged in a liquid.

What exactly is laminar gas flow, and what are the benefits?

Figure 3 shows turbulent flow, which results in greatly separated flow at the back side of the part. This uneven flow creates an uneven temperature distribution on the part resulting in different debinding and sinter results.

Figure 4 shows that by lowering the density of the gas via partial pressure, we provide a greater chance of laminar flow with less separation at the back side of the part. This can be measured by calculating the Reynolds number, indicative of turbulence, which decreases under partial pressure. And by lowering the density, we achieve a higher gas velocity. This in turn creates a thinner viscous boundary layer, which allows for greater thermal transfer.

Figure 5 shows the ideal laminar flow, which guarantees an even and continuous debinding of the part, since all gas moves in a predictable way. Additionally, laminar gas flow moves the process gas to the centre of the retort. This is where the binder contaminant is pulled through the gas manifold, ending up in an easily cleanable debind trap. The binder contaminants cannot redeposit on either the parts or the cold walls of the furnace as in atmospheric of vacuum furnaces. The advantage of a furnace equipped for partial pressure operation is the flexibility it creates. The profile parameters can be tailored specifically to the concerns of the material. Three such concerns are: the slow ramping during specific temperature phases, the variation of partial pressure, and the mix of gas to obtain surface finishes. All three

Figure 3. Low gas velocity results in a high Reynolds number (indicating turbulence) and greatly separated flow. An uneven gas or temperature distribution at the product leads to different debinding results, most common in vacuum furnaces with a sweep gas option. Only even flow round the product causes a continuous and even debinding as shown in Figure 5.

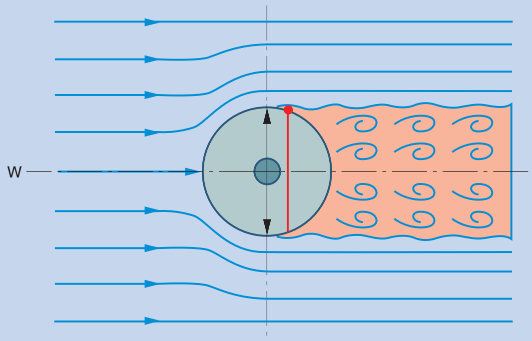


Figure 4. Lowering the density of the gas via partial pressure results in a lower Reynolds number, providing a greater chance of laminar flow with less separation. Higher gas velocity creates thinner viscous boundary layers that allow for greater thermal transfer and a lower Reynolds number

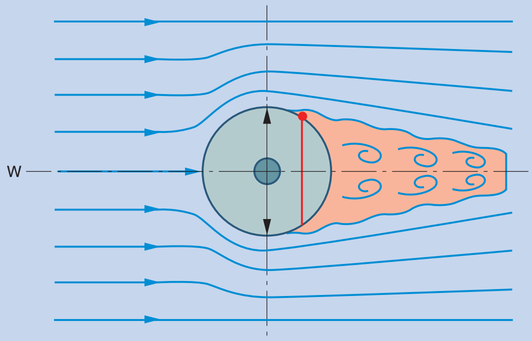
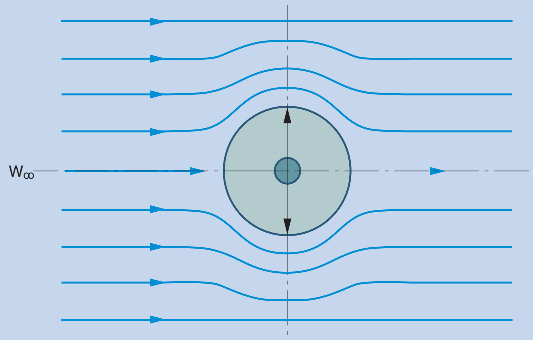


Figure 5. Lowering the Reynolds number overall creates conditions that approach ideal laminar flow, as shown in Figure 5, creating even and continuous debinding.



contribute to the great variety of materials such a furnace is capable of running. The range extends from iron through steel, stainless steel, tool steel, high-temperature alloys such as Inconel 718 and Hastelloy X, to titanium and tungsten compounds including tungsten carbide.

The heating inside this furnace is accomplished partially by radiation and partially by convection. This depends on the partial pressure and the resulting temperature uniformities. The temperature uniformity varies greatly under the conditions from vacuum to different partial pressures as well as different temperature levels and type of gas.

The ability to change the partial pressure, gas type and flow allows this furnace to process any MIM material with any binder component. Some materials require a higher partial pressure during sintering to prevent the evaporation of material components such as copper in stainless steel.

Additionally, laminar gas flow allows different sized parts to be processed in the same furnace envelope in the same process run. This is because gas flows evenly from both sides to the centre, which guarantees perfect product results every time, regardless of whether the furnace is fully loaded with identical parts or differently sized ones. There is no shadow effect under laminar gas flow.

Several case studies show the benefits of laminar gas flow. In the first case, an electronic housing was being produced in a separate debind oven. By using a laminar flow partial pressure furnace a cycle time reduction of 45 hours from 60 hours to 15 hours was achieved, saving considerable amounts in terms of consumables costs -

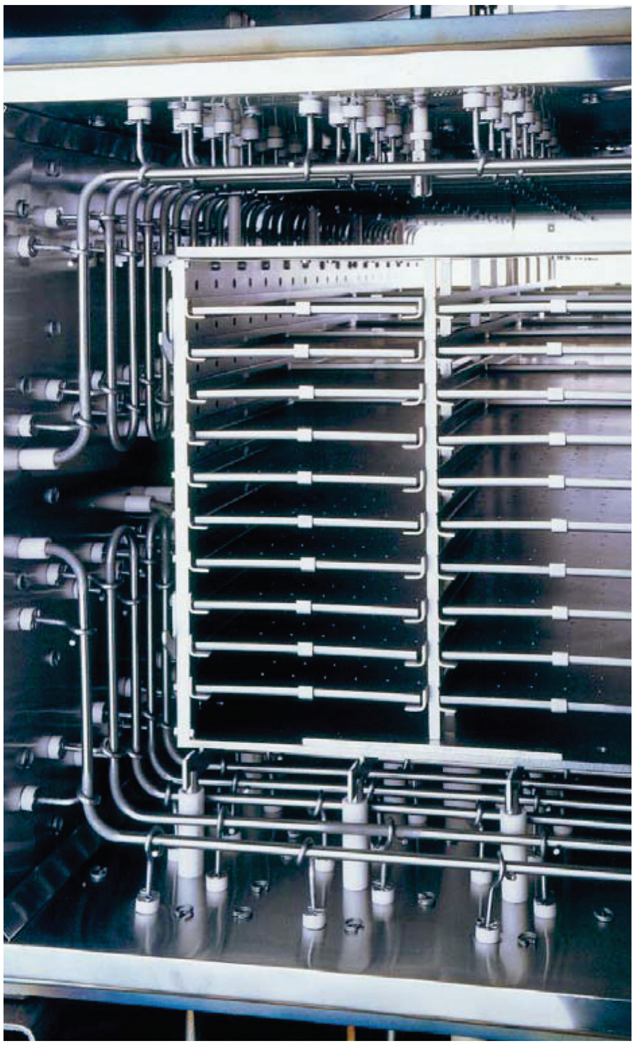


Figure 6. A typical partial pressure furnace can handle applications up to 1650°C with six individually controlled heating zones. The makers say this results in temperature uniformity better than ± 3°C.

electricity and gas consumption. At the same time, the carbon control and the dimensional characteristic of the part were greatly improved.

In the second example a ring mount was made from carbon steel made in the traditional way. It had high porosity (7.04 g/cc), a high oxygen content (0.60 per cent), poor carbon control (+/-0.02 per cent), and poor dimensional control and concentricity. When the same part was made in a partial pressure furnace under laminar gas flow conditions, that part exhibited very low porosity (7.76 g/cc), low oxygen content (0.11 per cent), acceptable carbon control (+/- 0.01 per cent) and excellent dimensional control and concentricity.

Batch furnaces with laminar gas flow capability have shown to be advantageous in all respects. It provides complete debinding. It ensures temperature uniformity during debind and sinter. It eliminates evaporation of key constituents of the part and it provides versatility and flexibility in producing the largest variety of PIM/MIM parts. And importantly, it eliminates a separate thermal debind step. All of these benefits prove that the batch furnace is able to improve all properties of the part, and to reduce cycle time and utility consumption.

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