Catamold® Feedstock for Powder Injection Molding
- Guidelines for processing CIM feedstock -

1. Introduction

Powder Injection Molding (PIM, Ceramic: CIM, Metal: MIM) is a process which offers advantages over conventional production methods for small parts with complex shapes or large production numbers. Starting from fine ceramic or metallic powders, a homogeneous feedstock is produced by mixing with a thermoplastic binder. The thermoplastic binder serves to combine in one manufacturing process the shaping capability that is well known from polymeric materials with the also well-established powder sintering technology. After the molding stage the shaped parts are liberated of the binder and the remaining powder preshape is then sintered to a high density part.

The Catamold® feedstock is based on a Polyacetal binder, a semi-crystalline thermoplastic material with good processing characteristics, high dimensional stability, high rigidity and good warm strength. This excellent property profile makes Polyacetals the preferred material in demanding applications like precision mechanics, but these advantages can be exploited in PIM equally well. However, the decisive advantage of Polyacetal as a binder for Catamold® feedstock is the ability for rapid catalytic binder removal. In the presence of a suitable catalyst Polyacetal can be depolymerised far below the melting point to yield the gaseous constituent monomer. Thus catalytic debinding allows binder removal from the molded shape by a controlled, smooth development of gas from the solid binder along the lines of a shrinking unreacted core model. A small amount of residual binder, necessary to confer a certain strength for handling to the remaining powder preshape, is then easily eliminated in the early stages of a conventional sintering cycle. The processing properties of the highly loaded Catamold® ceramic feedstock in the injection molding, debinding and sintering steps are discussed in the following chapters.

2. Injection Molding

Compared with plastics, Catamold® has a higher thermal conductivity, a higher density and a higher viscosity. These differences must be taken into account before choosing the molding machine, designing the mold and during processing.

2.1. Injection molding machine

For the production of ceramic parts by Ceramic Injection Molding using the BASF Catamold® line of products normal hydraulic or electric injection molding machines with open nozzles can be used. Electric machines, having a faster control feedback loop, may offer advantages in critical applications due to the control during
injection and hold stages. A reversal of the direction of flow due to inexact control in the
critical solidification stage may be the precursor to a planar particle stacking fault and
this will be detrimental to the integrity of the sintered part.
A low compression three zone screw (compression ratio 1 : 1.6 preferably, maximum
1 : 2) is recommended, for Catamold® TZP grades only 1 : 1.6. Choose a screw where
the shot volume matches the plasticising capacity reasonably well, otherwise the
excessively long residence times may lead to binder degradation which is witnessed by
the appearance of gas bubbles. Screw diameters of 18 - 25 mm are common.
The clamp force is determined by the size of the part to be injected, but the majority of
CIM parts are relatively small (1 - 10 mm) and 25 - 50 tons clamp force will cover the
majority.
Wear protection should be present in the form of a through hardened screw and a
hardened cylinder liner. High production numbers (several 100,000 shots) may need an
all-tungsten carbide plasticising unit.

2.2 Mold design

Before starting mold construction some thought must be given to the position of parting
line, ejector pins and gate. These are unavoidable features of a mold, they will leave a
visible remnant on the sintered part and should be positioned there where they do not
matter or where they can be easily removed.
Weld lines can be, particularly for alumina, the precursor to a locally weakened surface
in the sintered part and may extend up to 0.1 mm below the surface. If the function of
the part does not allow this sort of imperfection, the position of the gate should be
changed or the cavity needs multiple gating to shift the transition and/or reduce the size
of the defect.
Since the viscosity of Catamold® is higher than of most thermoplastic materials, the
pressure drop in the gating system should be reduced as much as possible:

- Runners as short as possible.
- Runner cross section as large as possible; 4mm is the usual compromise.
- Runner cross section round.
- Avoid sharp bends.
- Hot runners are troublesome due to inaccurate temperature control, but
  rewarding to reduce pressure loss and cycle time.

The gate should fulfill the following criteria:

- Uniform mold filling.
- As large as possible to minimise pressure drop
- Position at the thickest section.
- Direct the jet of melt along or against a wall or pin.

Design of the mold essentially follows the guidelines for thermoplastics:

- Avoid unnecessary and abrupt differences in wall thickness. Jetting problems
  and air entrapment are encouraged.
- Use stiffening ribs instead of thick walls.
- Core out thick sections.
- Avoid sharp corners. Use at least 0.3 mm radius.
- Symmetrical pressure application for long and thin parts or round sections.
- Good venting (depth 0.01 - 0.02 mm) at the end of the flow path is essential and also there where air is trapped. Supplementary ejector pins are useful to vent pockets of air.
- Contact of flow fronts far off the gate may form a weak spot (weld line). Venting is again essential.
- If more than one flow front move away from the gate, one of them usually comes to a halt, cools, hardens and causes an inhomogeneous zone.
- Carefully balance multi-cavity tools (i.e. simultaneous cavity filling), otherwise tolerance and possibly quality differences occur. Do not consider more than four cavities for high tolerance or difficult parts.

Demolding:

- A taper of 0.5 - 1° should be provided for surfaces in the demolding direction. These surfaces should be polished.
- For other surfaces a fine eroded quality is usually sufficient and improves the ventilation. Mirror quality cavity surfaces promote sticking problems and binder segregation.
- Be generous with ejector pins. Use large pins or profijectors on thin sections.

Mold temperature control is one of the most important parameters in processing of Catamold®:

- Use a thermally insulating plate between mold and clamp plate.
- A uniform temperature (+/- 2°C) must be provided. This needs to be obeyed in particular for multi-cavity tools, otherwise tolerance and quality differences will result.
- Mold surface temperatures of 140 - 145°C may be needed for thin-walled or very slender parts.
- A too cold mold causes a dull, in the extreme case white appearing surface due to premature freezing. Surface quality and mechanical properties of the sintered part deteriorate.
- Only oil temperature controllers (3 - 6 KW) are recommended. High pressure water controllers need experience and are potentially dangerous.
- Larger molds will require more independent temperature control units, one for each mold plate.

Wear protection:

- The mold inserts should be at least a through hardened tool steel, hardness at least 60 HRC.
- Large series in alumina will need tungsten carbide inserts.
- Highly sheared regions (gate, runner) may be coated with a PVD layer, e.g TiN. The disappearance of the gold colour serves as a useful warning for wear.

Inspection and Maintenance:

- As venting is often essential, regular disassembling and cleaning of the mold is a prerequisite for maintaining quality in large series.
2.3 Catamold® Feedstock

2.3.1 Packaging

The Catamold® products are packed in a strapped polyethylene inline bag inside steel drums with a rubber seal ring in the lid. The shelf life is 2 years. The granulate does not need a drying treatment when freshly opened. After removal of the required quantity of granulate the polyethylene bag and the lid should be closed again. Leaving the granulate exposed to the atmosphere for several days will enable moisture pickup and may cause moulding problems (gas bubbles). Drying will assist in regaining the original feedstock properties, but in severe cases this may not be entirely possible. Recommended drying treatment: 100°C / 2 h / dry air or 80°C / 1 h / vacuum.

2.3.2 Flow behaviour

The flow behaviour is shown in Figure 1 for the example of Catamold® TZP-A (see next page). The viscosity level is higher than for conventional thermoplastic materials. The pseudoplasticity, i.e. the drop in apparent viscosity at higher shear rates, is more pronounced than in plastics. The consequence of this is that the flow-related increase in pressure for filling through narrow cross section gates compared with large gates is relatively small. Like all highly loaded materials, the flow behaviour may become unstable at extremely high shear rates (dilatancy) and the feedstock then blocks. This happens far beyond the shear rates shown in Figure 1.

2.3.2 Recycling

Provided the Catamold® feedstock has been processed properly, recycling is possible. Common practice is to maintain a 50/50 % mixture of virgin and recycle feedstock. The number of times Catamold® can be recycled depends on the product processed, the accumulated residence time in the cylinder and the shear stress during molding. In extreme tests with 100 % recycle we found three (Catamold® TZP-A) to more than five passes (Catamold® AO-F), starting with virgin feedstock, were possible without a significant loss in moldability and quality. Regrinding should be done with tungsten carbide-equipped jaw or cone crushers. High speed grinders should be avoided.
2.4 Injection molding operation

The molding quality is, when the mold design has been done properly, determined by the following injection molding parameters:

- Screw feeding speed
- Temperature (cylinder and mold)
- Injection speed
- Time (hold pressure, cooling)
- Pressure (injection, hold, back)

Plasticising:
Catamold® is a homogeneous, granulated material which does not need further homogenisation. It should be melted under the gentlest conditions so that unnecessary overheating and shearing is avoided. For this reason a low compression screw (1 : 1.6) and a low screw speed (20 - 50 RPM or 3 - 5 m/min circumferential speed) are recommended. The back pressure is set very low at 5 - 20 bars.
To avoid shear heating the temperature profile of the barrel is flat at 175°C. A lower temperature (172°C) is recommended for small shot volumes and longer residence times.

Injection speed:
The injection speed should be set such that mold filling is complete within 0.3 to 0.6 second. Only for larger shots (more than 30 g) a mold filling time of near 1 second can
be tolerated. In most cases, a constant injection rate in the range 10 - 30 ml/s is adequate. Small shot volumes are better set at 5 - 10 ml/s. If jetting can not be avoided, injection should commence at a low rate until laminar flow has developed. The rate can then be increased. The volume switch points must be determined in a mold filling study.

Injection pressure:
The pressure should be set at a limiting value sufficiently large to allow the preset injection speed to be achieved and maintained. Figure 2 presents a typical pressure

![Pressure trace during injection molding.](image)

**Figure 2:** Pressure trace during injection molding.

signal from a sensor positioned near the gate in the cavity. The pressure increases initially slowly as the cavity is filled, then steeply after volumetric filling is achieved and the melt is compressed. Normal injection pressure values are 800 - 1500 bars. After volumetric filling the injection stage is finish switch to hold pressure is initiated by a distance, time or pressure signal.

Hold pressure:
The hold pressure phase follows completion of the injection phase, compensates volume shrinkage during cooling of the melt in the mold and ends when the gate has sealed. The gate sealing point can be determined by measuring the molding’s weight at
a given hold pressure as a function of the hold time. The hold time should be limited to the sealing time, because after sealing only the sprue is packed and may stick. The hold pressure level must be chosen at such a level that the residual pressure inside the molded part after completion of the cooling cycle is near atmospheric values to allow trouble-free demolding (see PVT - diagram, below).

Cooling:
After completion of the hold stage the part is allowed to continue cooling to complete solidification and gain the strength for demolding. A rough guideline is: Cooling time (in seconds) equals wall thickness squared (in mm).

PVT - diagram:
The whole molding cycle with compression and cooling in the mold can also be represented in a PVT - diagram (Figure 3), which shows the change in specific volume of the feedstock as a function of temperature and pressure. The material is injected at a processing temperature of 175°C and compacted to the hold pressure (mold internal pressure about 600 - 800 bars) with no significant cooling (A ➔ B).

![PVT Chart](image)

**Figure 3:** PVT - chart for Catamold® TZP-A.

After the hold pressure has been reached the material flows at virtually constant pressure parallel to the isobars and passes through the crystallisation range (B ➔ C). During crystallisation the specific volume drops constant molten material continues to flow into the cavity to compensate for the shrinkage. At the end of the crystallisation range in point C the gate solidifies and the cavity is sealed. The material now continues to cool at constant volume and a pressure reduction takes place (C ➔ D). When ambient pressure is reached in point D the part is under no pressure in the cavity. This is the ideal time for demolding.
If the hold pressure were set at a higher value, the part would still be under pressure when the mold temperature has been reached and demolding and relaxation problems would be the consequence. The pressure and mold temperature therefore can not be varied independently.

If the molding contains thick regions which solidify significantly later than the gate, it is not possible to supply molten material to compensate the volume shrinkage of the solidifying region. Since the outer skin of the molding rapidly forms a stable frame on solidification, the molten material in the thick region can only, after passing through the atmospheric pressure, express the continuing shrinkage process into voids. Thus it is important to position the gate near the thickest section.

After demolding the green part continues to shrink and cool to room temperature (D/E), and achieves the normal green density of 3.49 g/ml (specific volume 0.2865 ml/g). Although the associated shrinkage is not insignificant (about 1.4 % by volume, i.e. about 0.5 % linear), it is not an important parameter for the manufacturing process and does not need to be taken into account. The green molding is only a transitory state in the part manufacturing process; the largest part of this thermal contraction is negated again in the now following debinding treatment at 110°C. The shrinkage relevant for manufacturing is defined by the dimensions of the cold mold as it is produced and measured in the tool workshop related to the dimensions of the cold sintered part as it is measured in the final control.

3. **Debinding**

3.1 **Debinding principle**

Catamold® is totally unique in its ability for catalytic gas phase decomposition of the binder. This ability is innate to the chemical structure of Polymetal. The Polymetal chain is characterised by recurring carbon-oxygen bonds as depicted in Figure 4. The oxygen atoms in the polymer chain are susceptible to acidic attack, causing the macromolecule to split off successively formaldehyde units when it is exposed to a suitable acidic catalyst. The catalyst used for the debinding process is gaseous nitric acid (> 98.5 %).
Figure 4: Chemistry of debinding.

The reason why this reaction is so eminently suited for PIM are the conditions under which this reaction can take place: Debinding proceeds at a high speed at 110°C, which is far below the melting range of Polyacetal, 150 - 170°C (this is not identical with the solidification range of Figure 3), so the polymer is directly converted from a solid into a gas. The binder/gas interface proceeds inward at a linear speed of 0.5 - 2 mm/h, depending on the Catamold® grade.

The small formaldehyde gas molecules (boiling point – 21°C) are able to escape easily and without disrupting the powder particle packing structure through the already porous outer zones of the part (Figure 5). At the same time the binder still is fully rigid, lending the parts a continuing stiffness during debinding, avoiding any plastic deformation and resulting in better tolerances.

After completion of Polyacetal removal there is a residual amount (usually around 10 weight % of the binder content) of an acid resistant binder component which confers a certain strength for handling to the preshaped powder. This organic fraction is expelled in the subsequent sintering process.
3.2 **Debinding oven**

Figure 6 shows how the debinding process has been implemented in practice. The parts to be debinded are placed on support plates on the oven grids. The oven is equipped with a fan to ensure thorough mixing.
The normal settings for a 50 liter gross volume debinding oven are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen throughput</td>
<td>500 l/h</td>
</tr>
<tr>
<td>Temperature</td>
<td>110°C</td>
</tr>
<tr>
<td>Nitric acid (&gt;98.5 %)</td>
<td>30 ml/h</td>
</tr>
</tbody>
</table>

In the 1 h purge cycle before commencing debinding the oven receives an inert atmosphere, at the same time allowing the green parts and the oven to warm up to 110°C.

A too long debinding time does not harm the parts, while too short debinding produces scrap. It is therefore recommended to start generous, decrease the debinding time in one hour steps until the weight loss starts to decrease and return to the previous debinding time.

The debinding time for a fully loaded oven may increase up to 50 % compared with sample runs, especially with small parts, so these safety precautions should be used again in scale-up.

Larger batch debinding ovens up to 430 liter volume are available from several oven manufacturers. The debinding process also allows the use of continuous debinding ovens and this is common practice in Metal Injection Molding using Catamold®.

The exiting process gases are usually treated in a two stage burner operated with natural gas or propane/butane. The first burner stage operating under oxygen deficient conditions to reduce the nitrous oxides using the strongly reducing properties of formaldehyde. The second stage involves complete combustion at high temperatures.
with additional air to eliminate formaldehyde. The stack gas is in conformity with existing legislations.

Support of the parts:
The best compromise of cost and suitability is offered by flat, dense, smooth, high purity alumina ceramic plates as support. Dense, flat supports may, however, interfere with the debinding process (uneven cooling of the part during the endothermal debinding process leading to thermal stress and cracks), especially when thicker parts (more than 3 - 4 mm) are positioned on a flat section; these plates should then be used with some caution. Dusting the setter plate with coarse alumina powder may yield good results. Rough ceramic plates are more satisfactory, but the parts may stick by physical interlocking during sintering. Thicker parts are best placed on a woven steel wire mesh or on a ceramic foam to allow the catalyst access from all sides. The distance between the parts on one support and between neighbouring support plates on the same shelf in the debinding oven should be sufficiently large (0.5 cm between parts, 2 cm between plates) that an atmosphere exchange can still take place.

Debinding temperature:
The lower practical limit is 100°C to keep a safe distance from the dewpoint of nitric acid, the upper limit is in principle set by the softening point of the binder (150 - 170°C). In practice the upper temperature is 135°C: The higher the temperature, the higher the speed of debinding, but also the higher the risk of thermal stresses and cracks within the part due to excessive dynamic cooling during the endothermal debinding reaction (See Debinding rate). These stress-related cracks follow the contour of the surface and are not immediately visible, but are revealed upon breaking for inspection of completion of debinding. In extreme cases it may be necessary to employ 100°C and 20 ml/h acid flow rate.

When debinding thicker parts (> 4 mm), the debinding oven should, after completion of the purge cycle, be allowed to cool to 70°C before opening the oven door. The inner section of the part contains comparatively more residual organic than the outer shell and this may cause, depending on the completeness of b removal, a different thermal contraction behaviour and consequently initiate cracking.

Nitric acid:
In principle the debinding speed can be increased with the acid flow, but beyond 40 ml/h (50 g/h) at 500 l/h nitrogen flow rate the concentration of oxidising gases plus the formaldehyde from debinding can, in extreme cases, lead to conditions of spontaneous combustion.

Our recommendations and specifications are based upon experience with >98.5 % nitric acid. The debinding process functions also with less concentrated acid, but the use of less concentrated acid is at the producer's responsibility.

Debinding rate:
Typical speeds for debinding are 0.5 to 1 mm/h under the standard conditions. A too high debinding rate leads to rapid cooling of the part during the debinding process. Since the thermal expansion coefficients of the binder containing section and the binder free section differ by an order of magnitude, dynamic cooling during debinding will, above a threshold value for the temperature difference, lead to such an extent of thermal contraction of the binder containing core away from the debinded shell that loss of particle contact occurs and a planar fault develops. Thick and/or long
shapes are more vulnerable because the absolute values of core contraction scale in the part’s dimensions.

Process control:
It is useful to debind one or more control parts which are weighed and broken for inspection of completion of debinding. A core which has not been debound is immediately apparent in the fracture mirror and displays a different colour.

4. Sintering

Sintering involves thermally activated transport of material and strives to eliminate surface energy. The growth of particle contact points and the reduction of the pore volume result, in macroscopic terms, in shrinkage of the parts. At the end of sintering the part is virtually pore free.
In programming the sintering furnace it must not be forgotten that the molding still contains a small residual amount of binder.

General aspects:
The Catamold® oxide ceramic products are sintered in air. The sintering furnaces are normally electrically heated with fibre board insulation. Electric furnaces are equipped with MoSi2 heating elements and these should be rated for a maximum temperature of 1800°C, even if TZP-zirconia is produced with a sintering temperature of 1450 -1500°C. The reason is a longer life of the elements and much less evaporation of Mo and Si, which leads to a yellow surface discolouring in TZP-zirconia.
Gas-fired batch furnaces are not too well suited, because they do not offer sufficient temperature uniformity in the lower temperature range (200 - 500°C) where the residual binder is pyrolysed. Modern tunnel kilns offer adequate I.

Pyrolysis:
In the first stages of the sintering cycle, between 20 residual binder, which lends the debinded parts the strength for handling, is burnt off. To do this in a controlled way the heating rate needs to be limited to 1°C/min up to 270°C with a 1 h dwell at 270°C to allow the furnace load to reach thermal equilibrium and then to continue with 2°C/min up to 600°C. At this stage all organic material has left the molding. Electric furnaces must be equipped with a programmer allowing the low heating rates in this temperature range to be met.
Thin parts (less than 3 mm wall thickness) may be heated at a higher rate. Continuous pyrolysis heating rates as high as 5°C/min have been used without damage to the parts, but this must be optimised for a given part and a given furnace loading.
Too high pyrolysis heating rates cause cracking and carbon formation.
During pyrolysis there is a continuous liberation of combustion products and the furnace should therefore be equipped with an outlet. It is recommended to use a mild purge of air during pyrolysis, especially for the fine powdered Catamold® TZP products, since the adsorbed nitric acid from debinding will corrode the heating elements. The combustion products can be expelled in pilot scale plants (60 l furnace), but should be treated in a burner in full scale production.

Sintering:
A typical sintering curve is shown in Figure 7. In order to get the best dimensional tolerance the maximum density and the maximum shrinkage must be achieved. Our
recommendation for the final sintering temperature ensures the sintered parts have attained the final density. If the sintering process is terminated before final density has been achieved, slight differences in temperature uniformity cause a considerable scatter in shrinkage values and density. Open porosity and poor mechanical properties may be the consequence.

On the other hand, overfiring does nothing to enhance the mechanical properties and may even destroy the microstructure. The recommended final sintering temperature should not be overshot by more than 30°C. Especially in larger furnaces it must be assured that the whole sintering load has achieved thermal equilibrium. Since the thermal mass of the furnace contents may be considerable, it may be necessary to increase the dwell time at the final sintering temperature from the recommended 1 h or, alternatively, to decrease the heating rate 100°C below the final sintering temperature.

An independent way to check and calibrate the final sintering temperature and also the temperature distribution inside the furnace room is offered by shrinkage rings and the use of at least one in every sintering run is strongly recommended. These rings are calibrated for 1 h dwell time. All our recommendations are based upon PTCR shrinkage rings from DMC².

![Temperature profile](image)

**Figure 7:** Typical temperature profile for sintering Catamold TZP-A.

Shrinkage process:
Exposure to heat produces a shrinkage behaviour which is specific for the Catamold grade. The sintering process for TZP-zirconia starts at about 900°C, whilst alumina starts to sinter at 1100°C. Up to 800°C and 1000°C, respectively, i.e. below the initiation of densification, the heating rate of the furnace after completion of the pyrolysis may be increased to 5°C/min, but then needs to slow down to 2°C/min. The highest shrinkage rate for TZP-zirconia is at 1200 - 1300°C and for alumina 1300 - 1400°C. In critical cases (long, thin or large, heavy shapes) the heating rate may need to be further reduced in the shrinkage regime. Too high heating rates cause warping and cracking due to temperature gradients and, related to that, differential sintering.

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Support during sintering:
The setter plates should be made of pure alumina (>99.5%) or mullite. They should not contain free silica, because this promotes sticking with alumina and affects the colour (yellowing) of TZP-zirconia.
To allow free sliding of the shrinking part during sintering dense, smooth alumina plates are preferred. When the contact area of the parts with the support is large, rougher plates may function better (see Debinding). Dusting the setter plates with coarse alumina powder may assist in allowing free-shrinking parts.
Thin-walled parts quickly tend to deformation and warping. Dusting the setter plate will assist again, or the use of a support with a low thermal mass (ceramic foam, ceramic fibre board or silicon carbide-based kiln furniture) may be tried. A closed ceramic saggar is the last option.

Cooling:
It is recommended to use a controlled cooling rate of 3 - 5°C/min until 600°C after completion of the dwell at the final sintering temperature. This avoids thermal shock damage to sintered parts and increases the life of the setter plates.
At 600°C the furnace is switched off and the natural cooling rate is followed. This may take rather long, especially with brick insulation, and only fibre board insulation is recommended. Some furnace manufacturers offer an option for opening a flap in the cooling section of the sintering program and this is beneficial. Low thermal mass kiln furniture further reduces the cooling time required.
The furnace door should not be opened before 200°C is , otherwise the passivating silica surface layer on the heating elements may spall off and cause glassy spots on the parts. It also leads to excessive wear of the heating elements.

5. **Tolerances**

Good tolerances and/or shape capability are normally the driving force to choose for Ceramic Injection Molding, since the conventional dry pressing of powders offers only a limited ability for complex shapes and, more important maintains a tolerance of merely around 1 % on final dimensions. Ceramics are hard and costly to machine, so every tenth of a percent means money saved; even simple shapes may be more economic to produce by CIM, in spite of the obvious relative material cost disadvantage.
If the molded part has one tight tolerance and the others are less severe (around 1 %), +/- 0.3 % on the final sintered size can be well kept; in a very stable production situation even +/- 0.2 % can be held over years.
Should the part have two tight tolerances a level of +/- 0.4 - 0.5 % can be confidently kept for both.
In general it helps to position the gate close to the tightly tolerated feature.

If tight tolerances are required it is recommended to use an iterative approach in the cavity dimensions: First make a dummy mold insert, not necessarily hardened, the cavity intentionally too small and not necessarily displaying all features of the final part, but using the intended runner and gate geometry. After determination of the production parameters for molding, a pilot series is produced and measured precisely after sintering. This data is then used to calibrate the cavity in the production mold to the final dimensions taking into account the likely differences in form factor near or far from the gate as resulting from differences in green density.
A second cause for deviations is non-isotropic shrinkage. Non-isotropic shrinkage results from particle ordering and particle orientation: The shrinkage parallel or perpendicular to the direction of flow during molding is never exactly the same, because the particles arrange in hexagonal strings in order to allow flow. Particle orientation aggravates the small difference in packing density. The extent of anisotropy is thus small (0.1 - 0.2 %) for approximately spherical powders, but becomes very significant for platey powders like alumina (up to 2 %). Particle orientation is also the cause for the occurrence of warping phenomena in asymmetrically gated alumina parts.

The above described iterative approach for mold making is recommended generally, because the Catamold® specifications for the form factor are based upon our Quality Control mold and our Quality Control injection molding parameters. Since the effective pressure in the cavity is likely to be different for customer parts, it would be more or less a coincidence to find exactly the BASF Quality Control form factor for a particular blend of Catamold®. Similarly it is potentially dangerous to use a form factor found on a first production mold for a second, different part. It should also not be forgotten, that the Catamold® Specifications allow a certain band width for the form factor and the Catamold blend used for the pilot series may not be in the middle of the band width.

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