Powder Piloting Service
Service for Powder Injection Molding

Material Solutions…
...from powder to product
Development steps from powder to product

1. Raw material selection
   - Selection of raw material composition meeting demands of component operation conditions

2. PIM feedstock design and manufacturing
   - Selection of binder system and suitable raw material particle size range
     - Mixing of binder components and raw material powder in a compounding and pelletizing of compounded feedstock material

3. Injection molding of a feedstock material
   - Design of an injection molding tool (including runners, gating etc.) with a help of MoldFlow analysis/simulation.
   - Design of experiment (DoE) for injection molding parameter mapping
   - DoE based processing parameter optimization

4. Debinding of molded components
   - Binder removal from the green parts (molded components) can be done with a combined solvent and thermal process, only thermally or in catalytic debinding process.

5. Sintering
   - Densification process of a highly porous brown part (debound) in high temperature close to melting point.
   - Optimization of a temperature cycle to meet a correct shrinkage value
   - Metal parts are typically sintered in protective and/or reductive gas atmosphere or in vacuum. Oxide ceramics can be sintered in air atmosphere.

6. Post treatments
   - Sintered parts may need some surface treatments e.g. mechanical or coatings
Development steps from powder to product
STEP 1. Raw material selection

- Demands and restrictions from operation conditions
  - Strength, corrosion, operation temperature etc.
- Demands and restrictions of PIM process
  - Thermodynamics, prediction of phase structures
  - Powder properties, particle size distribution
  - Size and geometry of components
  - Availability of suitable raw material powders
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STEP 2. PIM feedstock design and manufacturing

- Design of feedstock material includes selection of binder system and amount of raw material powder loading. Target is to have a feedstock which has suitable rheological properties for injection molding and ensures effective binder removal.

- Z blade and planetary mixers are examples of batch type of mixers. When a large amount of work is needed to secure feedstock homogeneity, twin-screw extruders can be used for the final feedstock preparation.

- Characterization of properties e.g. melt flow indexes, feedstock viscosity and homogeneity with capillary rheometer is important to ensure good molding quality. DSC and TG measurements are useful for design of thermal debinding process.

<table>
<thead>
<tr>
<th>Binder</th>
<th>Main Ingredients</th>
<th>Polymer Backbone</th>
<th>Additives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermoplastic Binders</td>
<td>paraffin / microcrystalline / carnauba / beeswax / vegetable / peanut oil / acetanilide / antipyrine / naphthalene / PEG</td>
<td>PE, PP, PS, PA PE-VA, PE-A, PP-A, PMBA-E-VA</td>
<td>stearic / oleic acid and esters thereof, phthalic acid esters</td>
</tr>
<tr>
<td>Polycetal Binder</td>
<td>Polyoxyethylene</td>
<td></td>
<td>proprietary</td>
</tr>
<tr>
<td>Gelatin Binders</td>
<td>Water</td>
<td>Methyl cellulose / agar</td>
<td>glycerine / boric acid</td>
</tr>
</tbody>
</table>
Development steps from powder to product

STEP 3: Injection molding of a feedstock material

Mold Flow analysis to simulate filling of tool cavities and optimization of runners and gates.

Experimental designs
Using D-optimal design of experiments.
Fitting a numerical model and calculating the optimal parameters.

The machines normally used for MIM are substantially the same as those in use in the plastics industry. Only screw geometry and better wear resistance of moulding machines as well as special control of the injection and ejection process are different.

<table>
<thead>
<tr>
<th>#</th>
<th>Factor</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pack Time (s)</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Material Blend (%)</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>Barrel Temperature (°C)</td>
<td>195</td>
<td>205</td>
</tr>
<tr>
<td>4</td>
<td>Cavity Temperature (°C)</td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>5</td>
<td>Injection Velocity (mm/s)</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>6</td>
<td>Pack Pressure (MPa)</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>7</td>
<td>Shot Size (mm)</td>
<td>20.75</td>
<td>20.75</td>
</tr>
<tr>
<td>8</td>
<td>Back Pressure (MPa)</td>
<td>20</td>
<td>26</td>
</tr>
<tr>
<td>9</td>
<td>Cooling Time (s)</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>Screw Speed (RPM)</td>
<td>100</td>
<td>150</td>
</tr>
</tbody>
</table>

Important process factors

D-optimal matrix
STEP 4: Debinding of molded components

Binder removal from the green parts (moulded parts) is an important process step which has a direct effect on quality of sintered parts. Common binder systems and their debinding methods are shown in the following table. Debinding process has usually two steps and it starts with solvent debinding (e.g. organic solvent or water) in order to decompose primary binder and to create open porosity in part to ensure fluent removal of secondary binder during thermal debinding.

Common binder systems of PIM

<table>
<thead>
<tr>
<th>Binder</th>
<th>Debinding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wax / polymer</td>
<td>thermal or solvent + thermal water (or solvent) + thermal drying</td>
</tr>
<tr>
<td>PEG / polymer</td>
<td>catalytic</td>
</tr>
<tr>
<td>Water / agar</td>
<td>super critical CO₂</td>
</tr>
<tr>
<td>Polyacetal + additives</td>
<td></td>
</tr>
<tr>
<td>several types</td>
<td></td>
</tr>
</tbody>
</table>

Catalytic debinding e.g. Catamold® feedstocks of BASF.
STEP 5: Sintering

Sintering is carried out in controlled atmosphere to prevent e.g. oxidation of metallic raw materials. Oxide ceramics are normally sintered in air. Sintering temperature must be very carefully controlled and should be below the melting point of raw material in order to secure shape of the parts and prevent slumping. Final part has a density usually greater than 95%.

Smaller powder particles undergo the onset of densification at lower temperatures than large ones and are therefore preferred. They typically ensure also better density in shorter time.

An important thing to understand is the fact that final quality of sintered parts starts from homogeneity of the compounded feedstock material and quality of moulded parts. If they are not OK, then sintering result will be poor.

Green and final sintered parts. Shrinkage is typically 18-24% depending on feedstock composition. Courtesy of ETA SA.

Fig. 1 Scanning electron micrographs of particle bonding during sintering. These 32 μm nickel spheres were loose prior to heating to 1030°C for 1 h in vacuum.
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**Step 6: Post treatments**

PIM parts are near net-shape components which usually don’t need extra machining etc.

Typical treatments after sintering are:
- Case hardening
- Mechanical post treatments like deburring and polishing
- Coating processes like electroplating or PVD thin coatings, either functional or decorative.

Tumbler polished zirconia. 
*Courtesy Oechsler AG.*

Metal Injection Molded, polished and anodized knee implant parts made from Ti6Al4V. 
(Courtesy Maetta Sciences Inc., Canada)

FN08 low alloy steel - 14 gr.
Hardened condition. 
(Courtesy Basf GmbH)
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