Micro Parts Manufacturing by Powder Metallurgy (Micro-PM)

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Content

1. Introduction
2. Goals
3. Screen Printing
4. Sintering
5. Calibration
6. Future Work
7. Summary / Outlook
1. Introduction

| Powder Metallurgy: | Mass production of complex shaped parts with highest accuracy (IT 7) |
| Process:          | Powder $\rightarrow$ Mixing etc. $\rightarrow$ Compaction $\rightarrow$ Sintering $\rightarrow$ Calibration (IT 7) |
| Compaction:       | Multi-level dies for density = const. Powder: $>100$ $\mu$m (flowability) |
| Limits:           | Parts $>2$-$5$ mm (particle size / tools) flowability of fine powders: poor |
2. Goals

- Production of multi-level parts < 2mm with highest accuracy

Concept:

- Multi-level green parts by screen printing
- Sintering to high density
- Calibration in simple tool
Calibration

- **press/sinter**
  - Small parts (< 2 mm) limited
    - Rough particles (160 μm) do not flow into small dies
    - Even green density necessary -> small complicated pressing tools are expensive

- **MIM**
  - Small parts (< 2 mm) are possible
    - Pressing tools are expensive

- **3D screen printing**
  - Small parts (< 2 mm) are possible
    - Tools (screens) are inexpensive
    - Mass production capable
    - No complicated pressing tools for powder compaction necessary
3D screen printing – process scheme

design → screen/stencil → printing → „green part“ → sintering

suspension
3D screen printing – possibilities

- Fine details
- Complex structures
- Cavities
- Material combinations
- Mass production
3D screen printing – surface quality artifacts

Mesh imprint
screen mesh is visible if paste viscosity is not correctly adjusted.

Grooves
junction points at screen can cause grooves at the surface of printed parts.

Particle roughness
The spherical shape of the sintered particles causes surface roughness with \( R_a \sim 5 \, \mu m \).
Methods und Materials

- 316L – powder PF-10F (5-10 µm)
- Sintering temperature → nearly full density
- Calibration pressure: ~1000 MPa
- Lubricant: M25
- Calibration speed: 0,1 mm/min
Green parts
Calibration Tool
Cylinders
Cylinder – sintered

<table>
<thead>
<tr>
<th>$R_a$ (µm)</th>
<th>$R_z$ (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,0</td>
<td>15,6</td>
</tr>
</tbody>
</table>

O.k.  high!
Row XXV – „big gap“ – single sided pressing

Single sided pressing still clear „cratches“
Pressure 800 MPa

Porosität 5,2%

<table>
<thead>
<tr>
<th>$R_a$ (µm)</th>
<th>$R_z$ (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,5</td>
<td>6,9</td>
</tr>
</tbody>
</table>

better!
Row XXVIII – „small gap“ – single sided pressing

<table>
<thead>
<tr>
<th></th>
<th>$R_a$ (µm)</th>
<th>$R_z$ (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glossy</td>
<td>0,5</td>
<td>2,8</td>
</tr>
<tr>
<td>rough</td>
<td>2,5</td>
<td>13,6</td>
</tr>
</tbody>
</table>

Gloss only upper part (die friction)
Pressure 1000 MPa
Row XXVIII – “small gap” – **double sided pressing**

Double sided pressing, glossy surface !!

1000 MPa

<table>
<thead>
<tr>
<th>$R_a$ (µm)</th>
<th>$R_z$ (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>3.8</td>
</tr>
</tbody>
</table>
Row XXVIII – „small gap“ – double sides pressing 1200 MPa

Cold welding with the tool!!

Pressure 1200 Mpa
→ To high !!!

<table>
<thead>
<tr>
<th>$R_a$ (µm)</th>
<th>$R_z$ (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,7</td>
<td>3,8</td>
</tr>
</tbody>
</table>
Row XXVIII – „small gap“ – Asp.-ratio: 1:1 – single sided pressing – 800 MPa

Porosität 5,9%

<table>
<thead>
<tr>
<th>$R_a$ (µm)</th>
<th>$R_z$ (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,4</td>
<td>2,2</td>
</tr>
</tbody>
</table>
Row XXVIII – „small gap“ – Asp.-ratio 1:1 – single sided pressing – 1000 MPa

Asp.-ratio 1:1, Pressure: 1000 MPa

Porosity 5.7%

<table>
<thead>
<tr>
<th>$R_a$ (µm)</th>
<th>$R_z$ (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Dimensions

<table>
<thead>
<tr>
<th></th>
<th>Tooth ground</th>
<th>Tooth tip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ø Diameter (n=3)</td>
<td>1,15 mm</td>
<td>1,83 mm</td>
</tr>
<tr>
<td>Height (Asp-ratio 1:2)</td>
<td>3,54 mm</td>
<td></td>
</tr>
</tbody>
</table>
Row XXIII (big gap) before pressing
Row XXIII (big gap) (sintered)

Top: Some rounding of edges during sintering

Bottom: Sharp edges due to constrained sintering on the substrate
Row XXIII before pressing (with die)

Die entry

Gap

Ø Die = 1,94 mm
Ø Gear = 1,83 mm
Gap = 0,055 mm
Row XXII (big gap) after pressing (1000 MPa)

Only partial smoothening due to big gap
Roughness Row XXIII (big gap) → Aspect ratio: 1:2

Tooth tip
Tooth flank
Tooth ground

<table>
<thead>
<tr>
<th></th>
<th>sintered</th>
<th></th>
<th>pressed</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tooth ground</td>
<td>Tooth tip</td>
<td>Tooth flank</td>
<td></td>
</tr>
<tr>
<td>$R_a$ (µm)</td>
<td>4,5</td>
<td>3,6</td>
<td>4,9</td>
<td></td>
</tr>
<tr>
<td>$R_z$ (µm)</td>
<td>22,6</td>
<td>20,5</td>
<td>26,8</td>
<td></td>
</tr>
</tbody>
</table>

Result: („big gap“)
Calibration at Tool tip: good. Tooth ground and flanke: NO calibration.
Row XXVIII (small gap): Aspect ratio 1:2

<table>
<thead>
<tr>
<th></th>
<th>Tooth ground</th>
<th>Tooth tip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ø Diameter (n=3)</td>
<td>1.21 mm</td>
<td>1.94 mm</td>
</tr>
<tr>
<td>Hight (n=3)</td>
<td>3.55 mm</td>
<td></td>
</tr>
</tbody>
</table>

**Exact fit in the die!!**
Row XXVIII (small gap): after pressing 1000 MPa

Tooth tip: smoothended

Tooth ground: smoothended
Roughness Row XXVIII (small gap) → Aspect ratio: 1:2

![Image of tooth with annotations]

<table>
<thead>
<tr>
<th></th>
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<th>Tooth ground</th>
<th>Tooth flank</th>
</tr>
</thead>
<tbody>
<tr>
<td>sintered</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>4,5</td>
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<tr>
<td>$R_z$ (µm)</td>
<td>22,6</td>
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<td>26,8</td>
</tr>
<tr>
<td>pressed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_a$ (µm)</td>
<td>0,7</td>
<td>1,0</td>
<td>5,5</td>
</tr>
<tr>
<td>$R_z$ (µm)</td>
<td>3,7</td>
<td>5,7</td>
<td>25,6</td>
</tr>
</tbody>
</table>

Result: („small gap“)
Calibration at Tool tip: GOOD. Tooth ground: GOOD. Flanke: POOR
Row XXVIII (small gap) → Aspect ratio: 1:1
Stress-strain curve for the calibration of gear-wheels

„Big gap“  „Small gap“

Wall friction

Yield strength
Ejection Forces

Clearance = Gap (between tool and part)
Future work (To-do list)

• Influence of sintered density
• Aspect ratio
• Smaller dimensions (<< 2 mm)
• Other materials (steels, Pt, Au,…, Ti)
• Complex shapes (multi-level parts, holes)
• Micro-tools and calibration presses
• Automation
Summary /Outlook

• Mass production (10,000 – x Mio. parts/year) of complex shaped small parts by 3D-printing and calibration is possible
• High accuracy (~ 1-5 µm)
• Low cost processes
• Development from Lab-scale to production
• Possible applications: microparts in medical, electronic, microsystems applications
• Alternative to cost-intensive machining for ductile materials
Thank you for your attention!