Adaption of metal injection molding to quinary high entropy alloys

A. Grimonprez¹, Y. Chen¹, A. Kauffmann¹, V. Piotter¹, J. Wagner², M. Heilmaier¹

¹Karlsruhe Institute of Technology, ²University of Stuttgart
Motivation

*Is it possible to produce High Entropy Alloy parts with Powder Injection Molding?*

- Casting of HEA leads to heterogeneities (e.g. microstructure)
- Obtain parts with high homogeneity & density thus good mechanical properties
- Compare with:
  - Casting methods
  - Other PM processes
High-entropy alloys (HEA)

- High configurational entropy
- Lattice distorsion
- Sluggish diffusion
- Cocktail effect

possibility
of new
exceptional
properties

- CoCrFeMnNi¹
  - Single phase with fcc crystal structure
  - High strength & ductility
  - Application as structural material

²Wang et al., MDPI, Entropy 15 (2013)
Powder injection molding (PIM)

- Big volume of parts & short time = cost-efficient
- Complex geometry & near-net shape = reliable
- Less waste & energy consumption = environmentally friendly

1European Powder Metallurgy Association (2013)
Arc melting

- 8 buttons produced
- Each button remelted and flipped 5 times for homogeneity and drop cast as a rod
- Need to compensate for Mn evaporation to get the nominal composition (20 at% of each element)

<table>
<thead>
<tr>
<th>At%</th>
<th>Co</th>
<th>Cr</th>
<th>Fe</th>
<th>Mn</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICP-OES²</td>
<td>20.4</td>
<td>19.7</td>
<td>20.3</td>
<td>19.2</td>
<td>20.4</td>
</tr>
</tbody>
</table>

¹Edmund Bühler GmbH
²Courtesy of Dr. T. Bergfeldt, KIT
Gas atomization principle¹

¹Courtesy of PW Technology

CoCrFeMnNi rods in a crucible of a vacuum induction furnace
Gas atomization

Particle size distribution of the big receiver

CoCrFeMnNi powder

118 µm (~ 90 vol%)

Sieving < 80, <50, <32 µm

500 µm
Gas atomization

- Single fcc phase
- Spherical particles
- Dendritic microstructure

CoCrFeMnNi powder

20 µm
Feedstock development

- CoCrFeMnNi metal powder: $50 < x < 80 \mu m$

- Trials with different amounts of metal powder
  - 63 vol%  
  - 50 vol%  

Composition of feedstock (vol%)

- Metal: 50 vol%
- PE: 25 vol%
- Wax: 24 vol%
- Stearic acid: 1 vol%
Debinding and sintering

Temperature in °C

0 200 400 600 800 1000 1200 1400

Time in h

0 5 10 15 20 25

1 cm

1 cm

1

2

sintering
debinding

50 vol% metal powder

Cycle 1

Cycle 2

A. Grimonprez - Adaption of metal injection molding to quinary high entropy alloys
Microstructure of PIM sample

Close porosity ≈ 5%
Open porosity > 30%

50 µm
### Mechanical tests

<table>
<thead>
<tr>
<th></th>
<th>PIM</th>
<th>MA&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Cast&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness (HV)</td>
<td>140</td>
<td>145</td>
<td>160</td>
</tr>
<tr>
<td>Standard deviation (HV)</td>
<td>20</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>Load (g)</td>
<td>10</td>
<td>50</td>
<td>10</td>
</tr>
</tbody>
</table>

- No cracks observed
- Ductile deformation

<sup>1</sup> Irving et al., JOM vol 35, No 12 (2013)
<sup>2</sup> Schuh et al., Acta Mater. 96 (2015)
Conclusion

- It is possible to produce parts made out of HEA with PIM
- Powder particles have good homogeneity
- Residual porosity by PIM
- Low hardness & ductile behavior
Outlooks

- **Gas atomization**
  Increase the yield of small particles by adjusting the parameters (e.g. atmosphere)

- **Feedstock production**
  Find the right ratio metal/binder
  Find an appropriate debinding procedure

- **Mechanical tests**
  Tensile and compression tests (room and high T)
Thank you for your attention

A. Grimonprez - Adaption of metal injection molding to quinary high entropy alloys