Karlsruhe Institute of Technology

Institute for Applied Materials

Adaption of metal injection molding to quinary high entropy alloys

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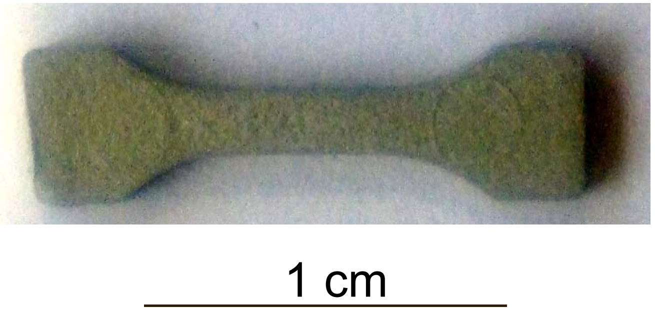

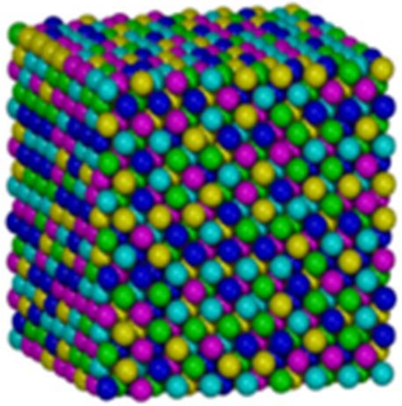

Motivation

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)

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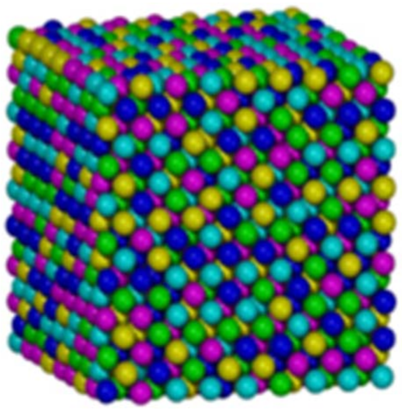
- High configurational entropy
- Lattice distortion
- Sluggish diffusion
- Cocktail effect

possibility of new exceptional properties

- **CoCrFeMnNi[1]**
  - Single phase with fcc crystal structure
  - High strength & ductility
  - Application as structural material



CoCrFeMnNi[2]

[1]Cantor et al., Mater. Sci. Eng., A 375 (2004)
[2]Wang et al., MDPI, Entropy 15 (2013)

Powder injection molding (PIM)

- Big volume of parts & short time

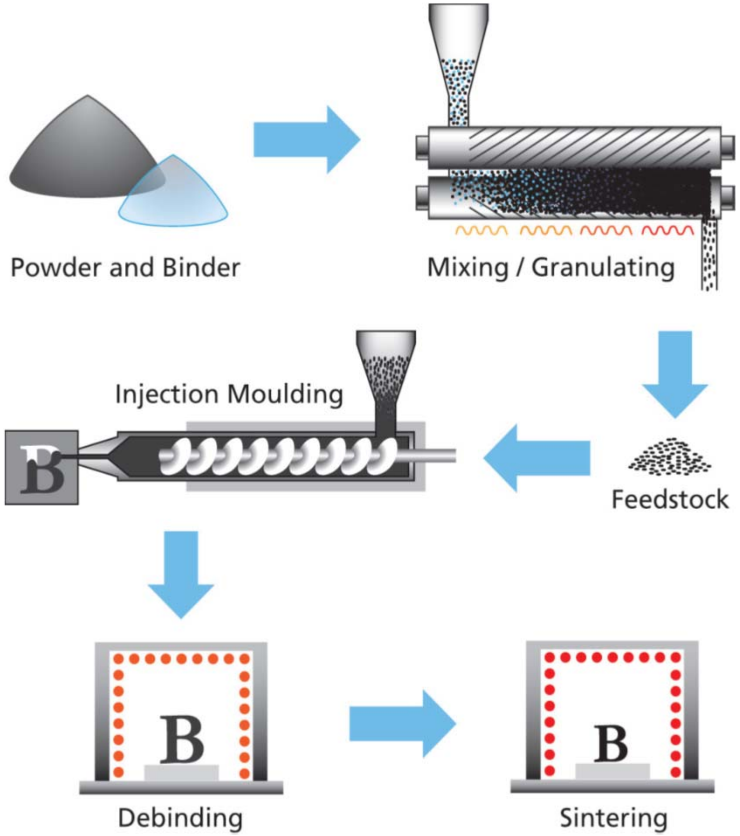
  = ***cost-efficient***

- Complex geometry & near-net shape

  = ***reliable***

- Less waste & energy consumption

  = ***environmentally friendly***



PIM process[1]

[1]*European Powder Metallurgy Association (2013)*

Content

Arc melting

↓

Gas atomization

↓

PIM

↓

Mechanical testing

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)

Arc melter AM/0.5[1]

At%	Co	Cr	Fe	Mn	Ni
ICP-OES[2]	20.4	19.7	20.3	19.2	20.4

[1]Edmund Bühler GmbH
[2]Courtesy of Dr. T. Bergfeldt, KIT

Gas atomization

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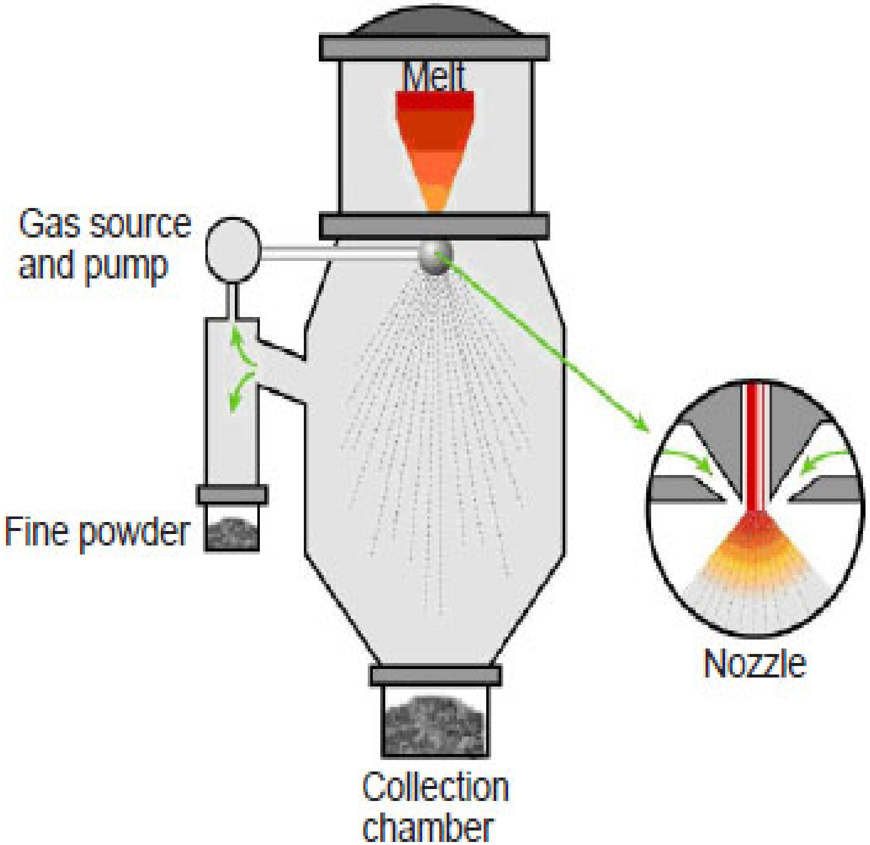


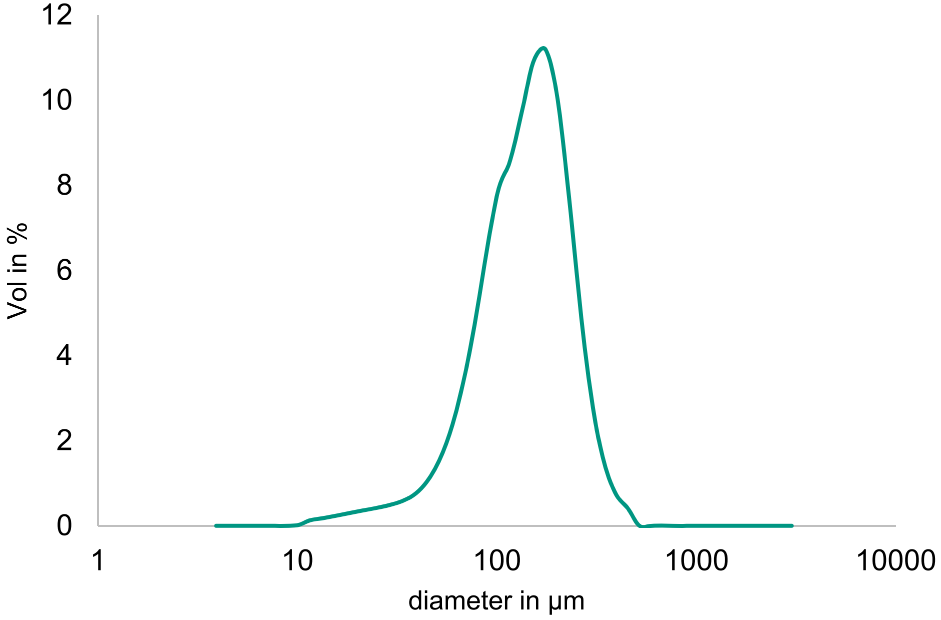
Gas atomization principle[1]

CoCrFeMnNi rods in a crucible of a vacuum induction furnace

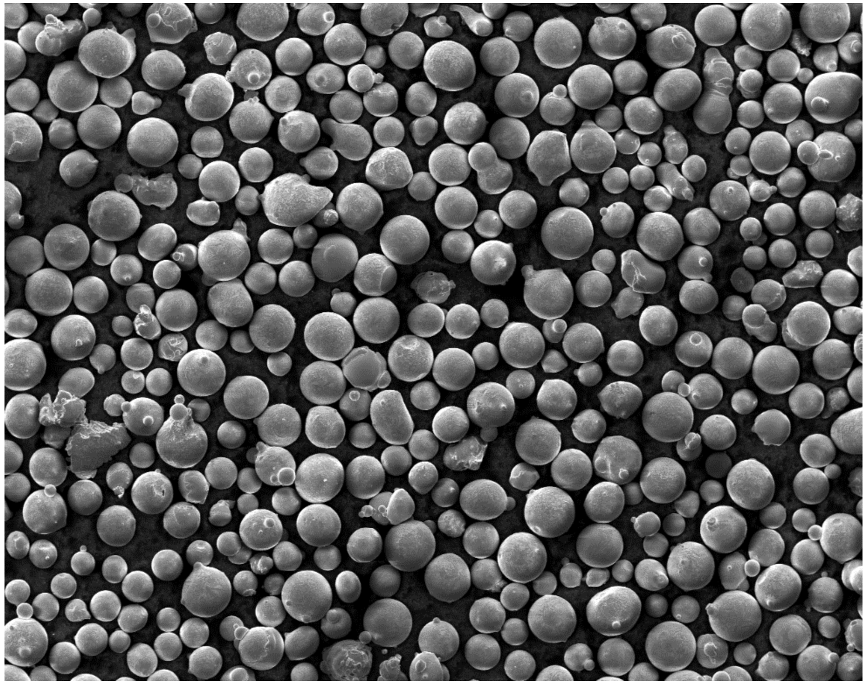
[1]*Courtesy of PW Technology*

Gas atomization

Particle size distribution of the big receiver



CoCrFeMnNi powder

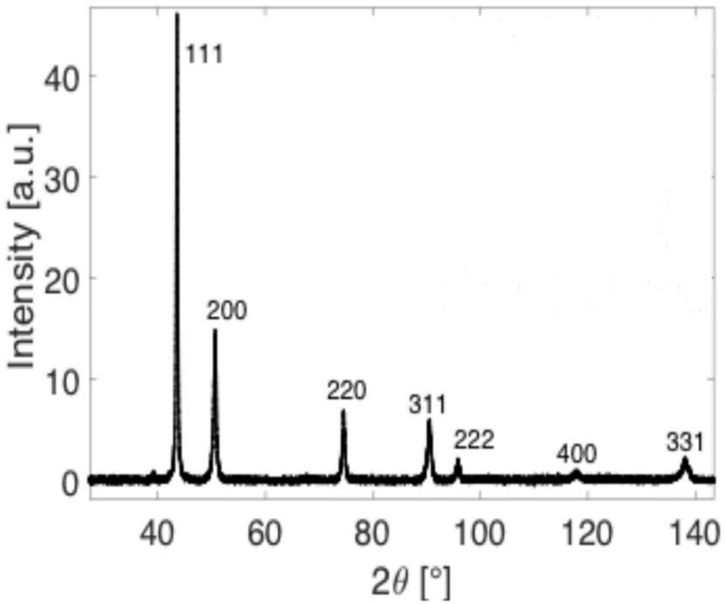


500 µm

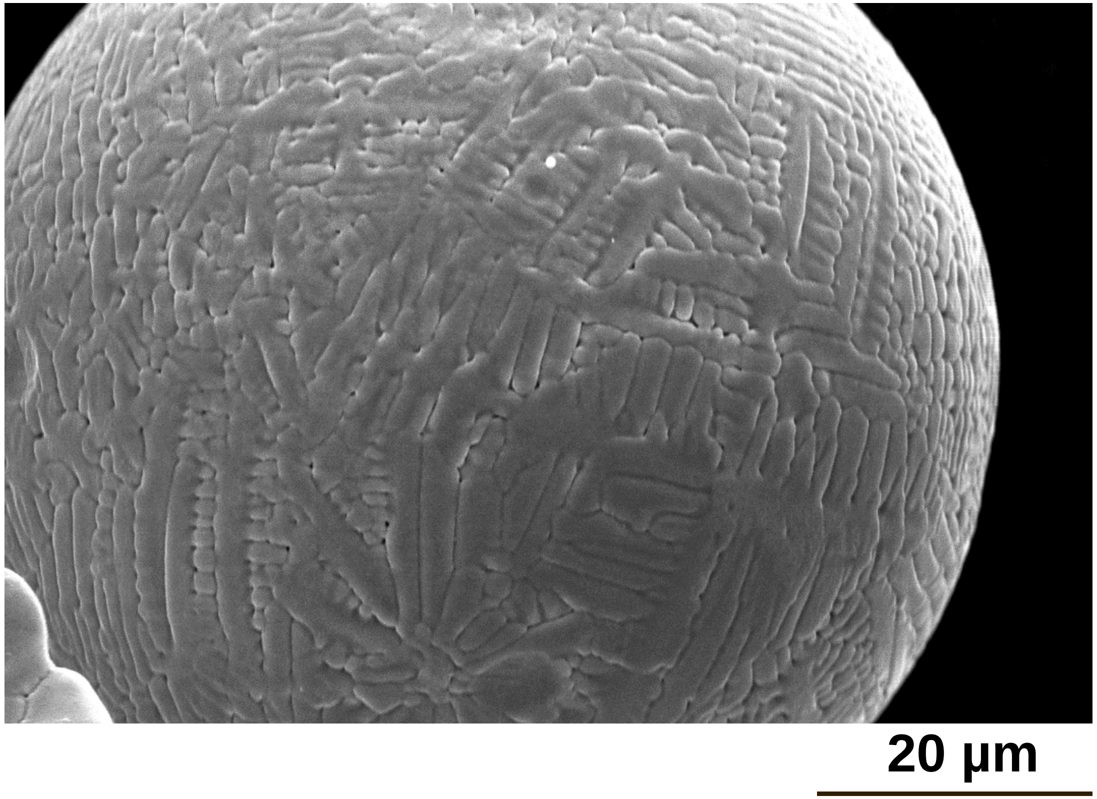
118 µm (~ **90 vol%**)

Sieving < 80, <50, <32 µm

Gas atomization



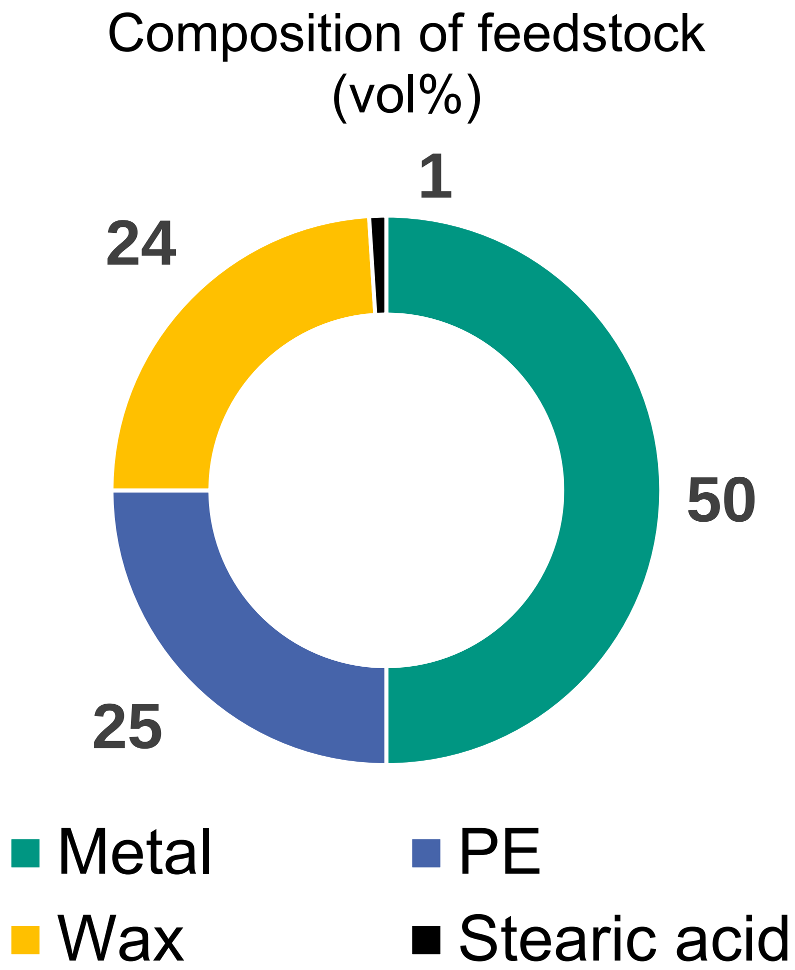
CoCrFeMnNi powder



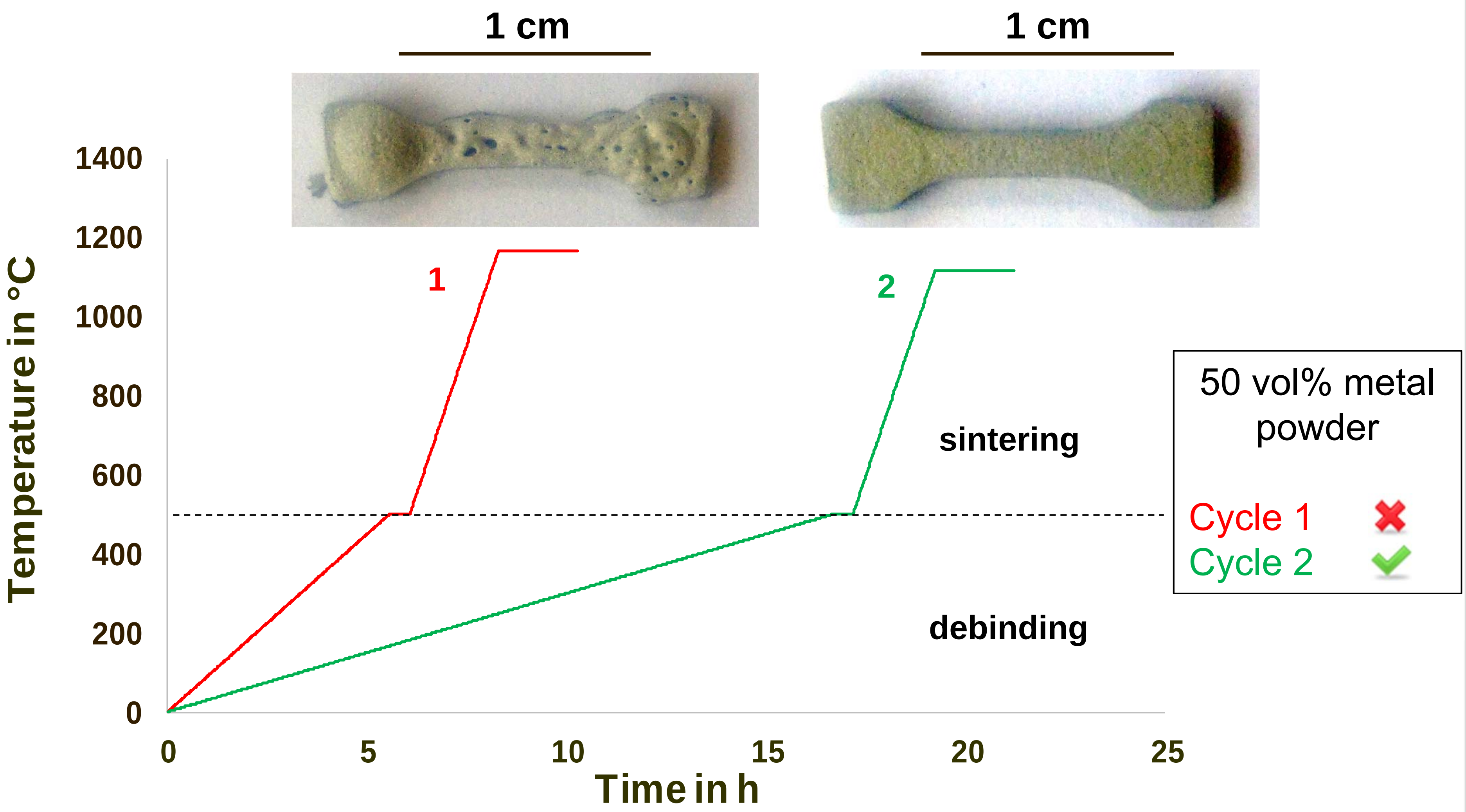
- Single fcc phase
- Spherical particles
- Dendritic microstructure

Feedstock development

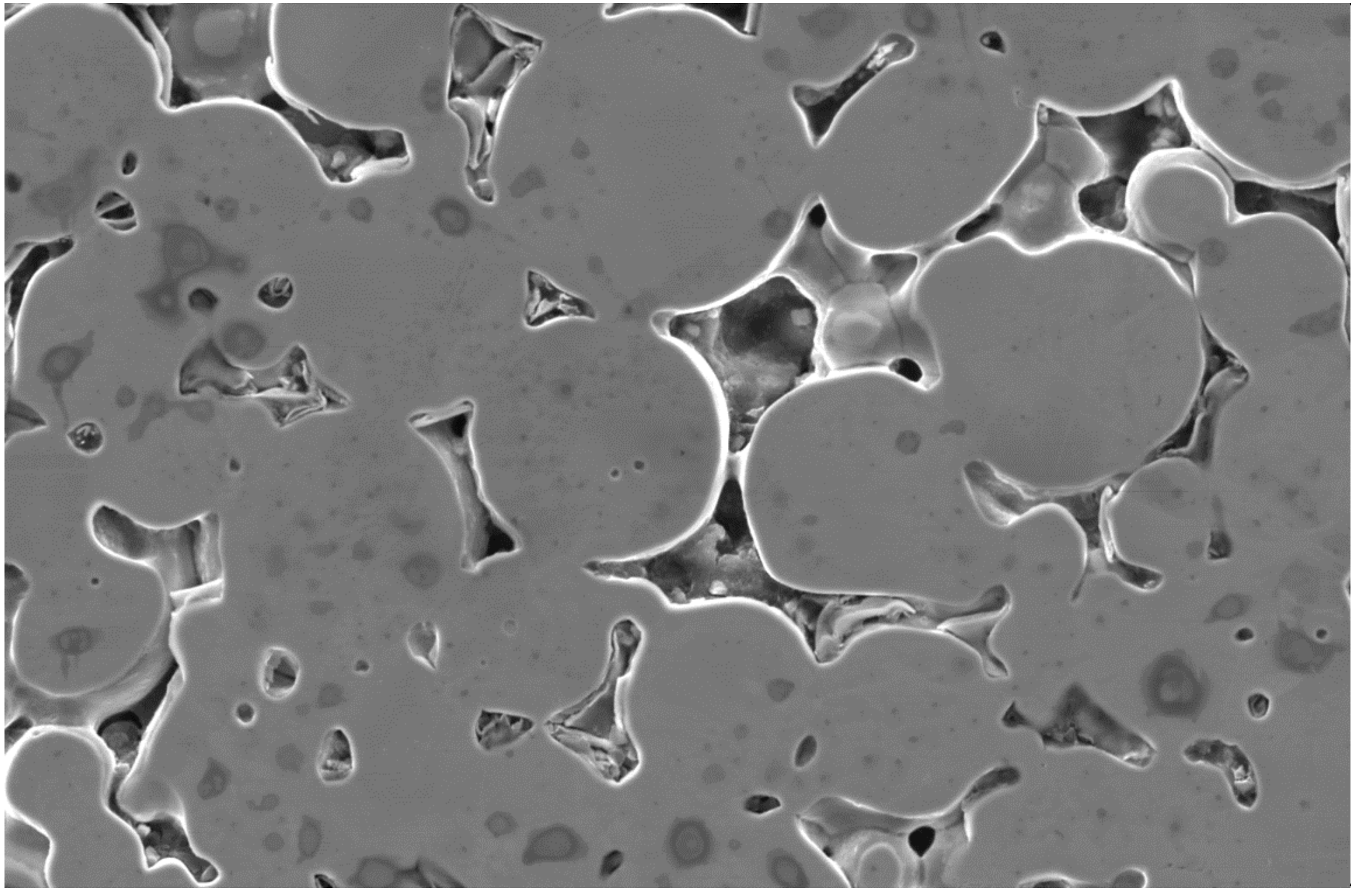
- CoCrFeMnNi metal powder: $50 < x < 80$ µm
- Trials with different amounts of metal powder
  - 63 vol% ✗
  - **50 vol%** ✓

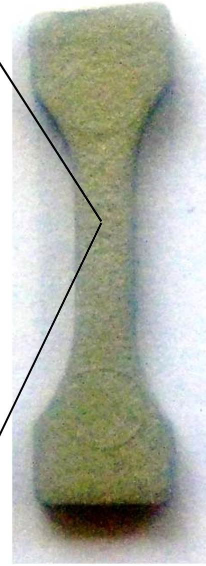


Debinding and sintering



Microstructure of PIM sample

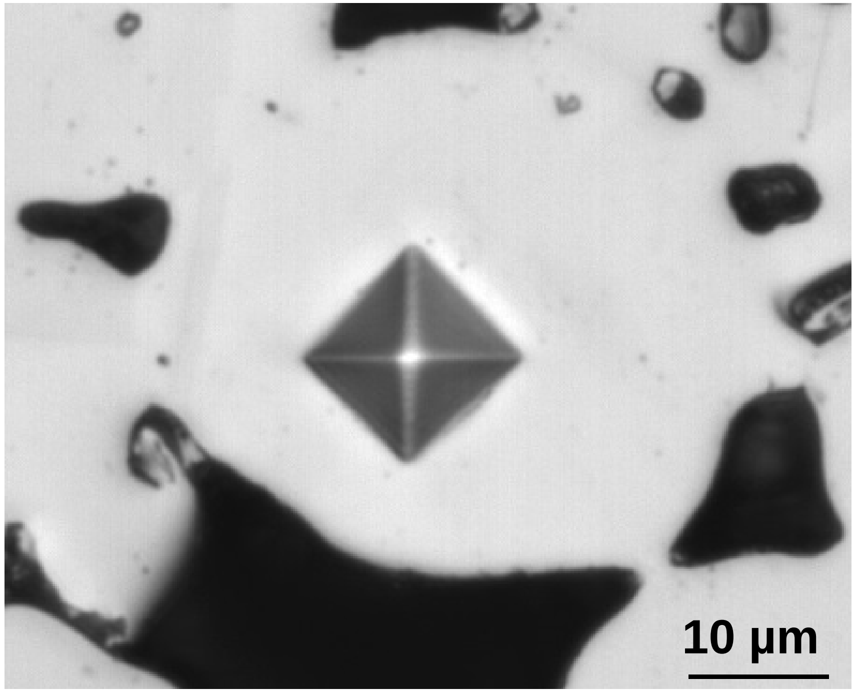




50 µm

Close porosity ≈ 5%
Open porosity > 30%

Mechanical tests



	PIM	MA[1]	Cast[2]
Hardness (HV)	**140**	**145**	**160**
Standard deviation (HV)	20	3	15
Load (g)	10	50	10

- No cracks observed
- Ductile deformation

[1]*Irving et al., JOM vol 35, No 12 (2013)*
[2]*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

pim-international.com