Near-net-shape fabrication of porous NiTi: Use as implant materials and energy-absorbers

M. Köhl[1], T. Habijan[2], M. Bram[1], H.P. Buchkremer[1], M. Köller[2], D. Stöver[1]

[1] Forschungszentrum Jülich GmbH
IEF-1: Institute of Energy Research

[2] Universitätsklinikum Bergmannsheil Bochum
Chirurgische Forschung

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Outline

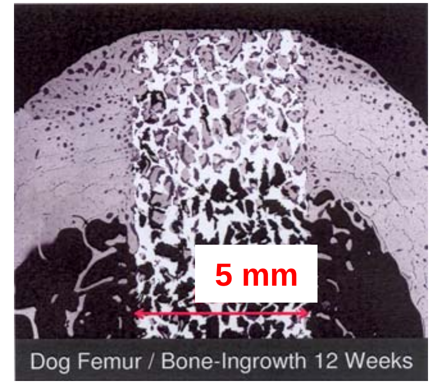
- Demands on Implant Materials
- Production of Net-shaped Highly Porous NiTi
- Characterization of Porous NiTi
- Cell Culture Experiments
- Applications of Porous NiTi

Demands on Implant Materials

- **Osseointegration**

→ Structural and functional connection between natural bone and implant:

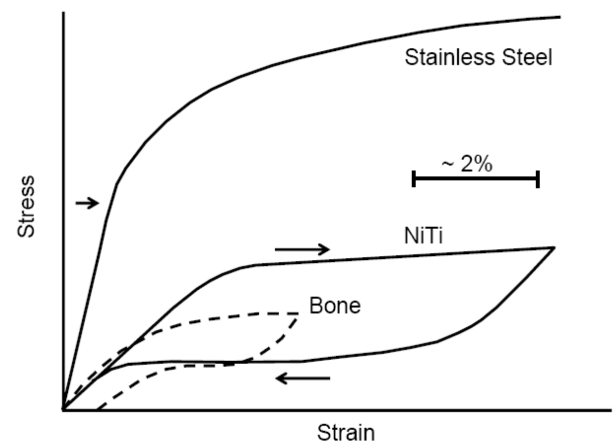
- Pore size of 100 – 500 µm
- Interconnecting porosity
- Bone-like stiffness
- Sufficient strength



T. Steffen et al., 51st Annual Meeting of the Orthopaedic Research Society, Washington DC, **30**, p.1396 (2005).

- **NiTi as an implant material**

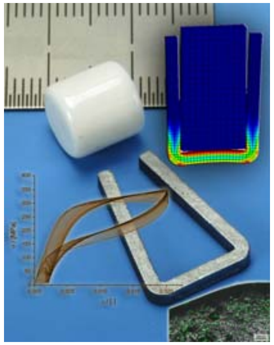
- Unique Shape Memory Properties
- Bone-like stiffness
- Sufficient strength
- Good corrosion resistance and biocompatibility



S.A. Shabalovskaya, Bio-Medical Materials and Engineering **12**, pp. 69–109 (2002)

Combination of Different Methods

- **Metal Injection Molding (MIM) of NiTi at FZJ:**
  - Production of complex shapes
  - Mass production possible
  - Powder metallurgical results comparable to melt metallurgy



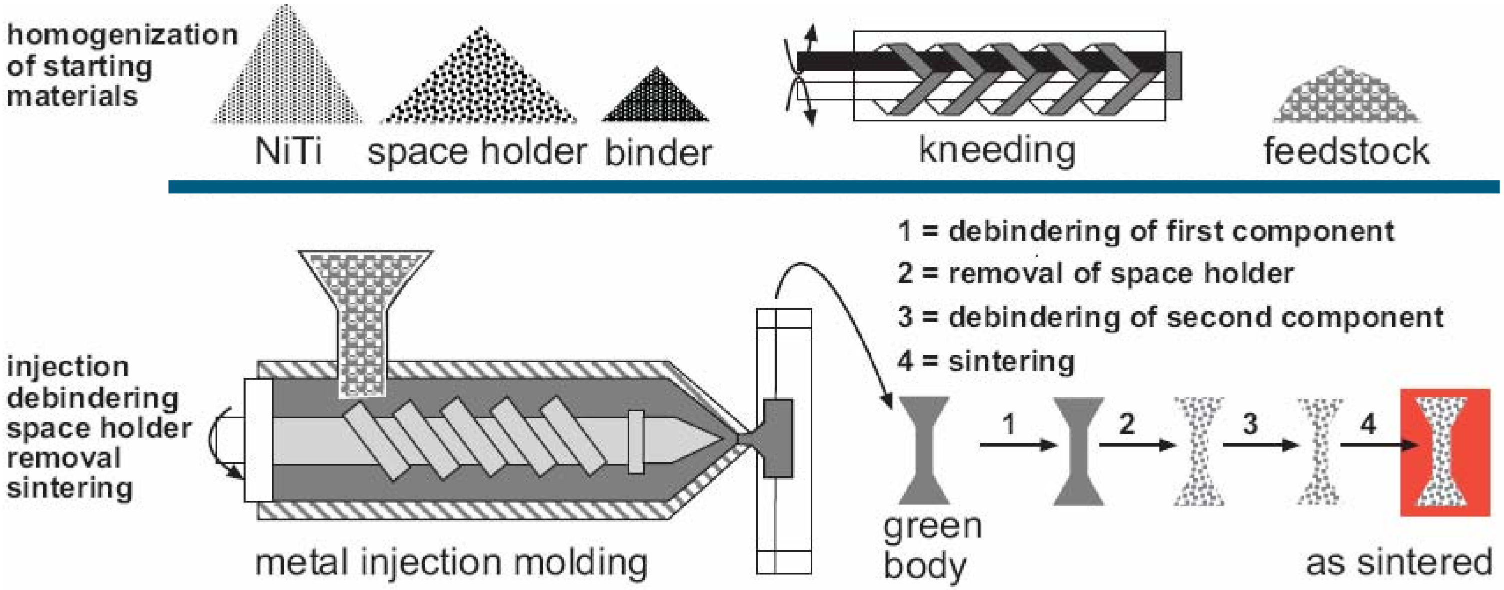
L. Krone et al., Advanced Engineering Materials, **7**, pp. 613–619 (2005)

- **Space Holder Method at FZJ for Titanium:**
  - Established method
  - Applications for dental implants and intervertebral disc replacement

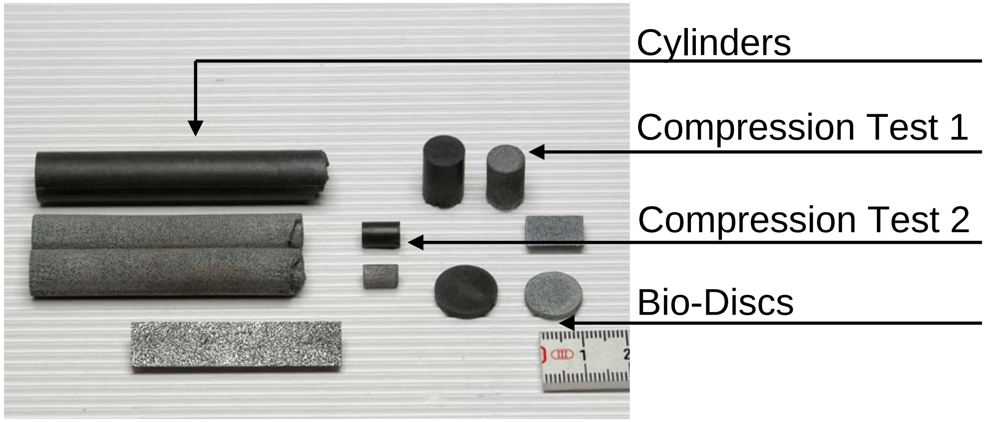
Laptev et al., Powder Metallurgy, **47**, pp. 85-92 (2004)

SYNTHES®

Processing

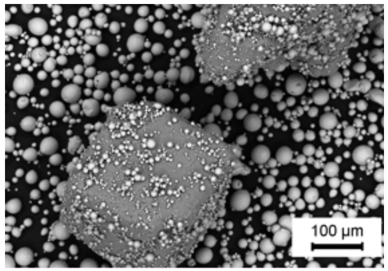


homogenization of starting materials
NiTi
space holder
binder
kneeding
feedstock
1 = debindering of first component
2 = removal of space holder
3 = debindering of second component
4 = sintering
injection
debindering
space holder
removal
sintering
metal injection molding
green body
1
2
3
4
as sintered

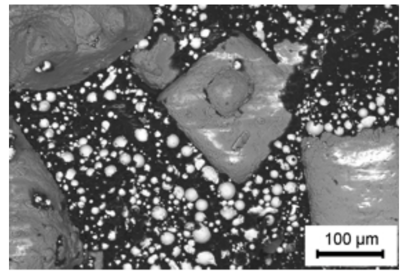


Cylinders
Compression Test 1
Compression Test 2
Bio-Discs

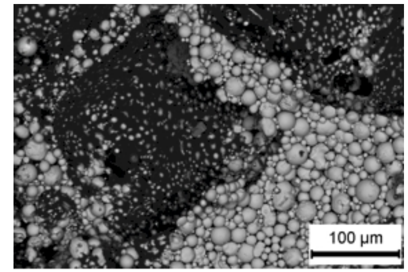
Development of Microstructure



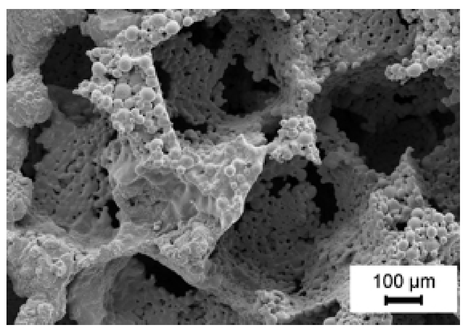
starting powders NaCl+NiTi



Green body



after space holder removal



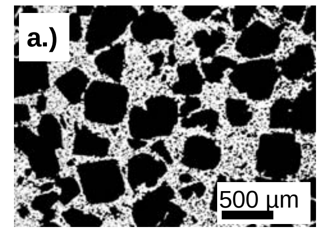
as-sintered

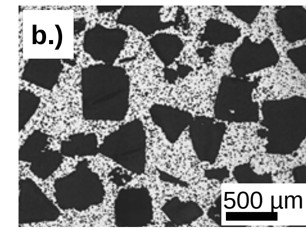
Microstructure achieved as-sintered
comparable to trabecular bone.

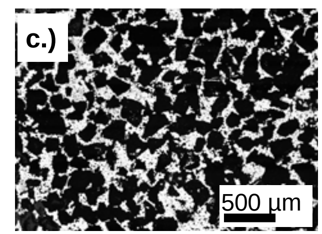
Characterization of Porous NiTi

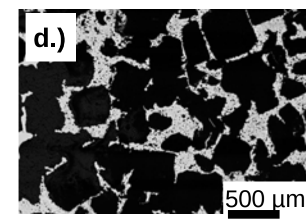
Microstructures

Sample	NaCl	NiTi	Ni [at.%]
a.)	50 vol.% 355-500 µm	50 vol.% 25-45 µm	50.6
b.)	50 vol.% 355-500 µm	50 vol.% 25-45 µm	49.7
c.)	70 vol.% 125-250 µm	30 vol.% 25-45 µm	49.7
d.)	70 vol.% 355-500 µm	30 vol.% 25-45 µm	49.7









50.6 at.% Ni → Pseudoelasticity
49.7 at.% Ni → 1-Way-Effect

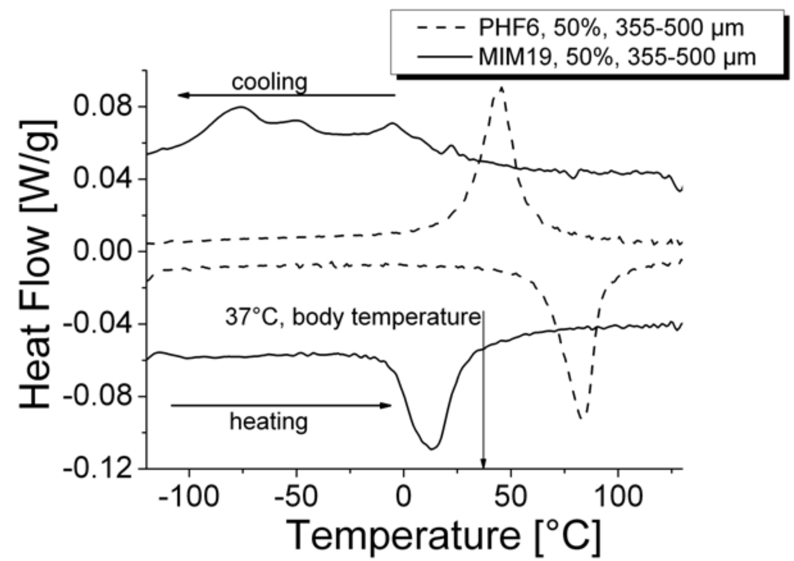
Different Porosities 50-70 vol.%

Different Pore Sizes 125-500 µm

Characterization of Porous NiTi

Chemistry / DSC – sintered bodies

	Impurity content [wt.%]	
	Carbon	Oxygen
NiTi-Powder 50.6 at.% Ni	0.04	0.05
50%, 355-500	0.04	0.14
NiTi-Powder 49.7 at.% Ni	0.03	0.06
50%, 355-500	0.08	0.17
70%, 125-250	0.07	0.21
70%, 355-500	0.06	0.15

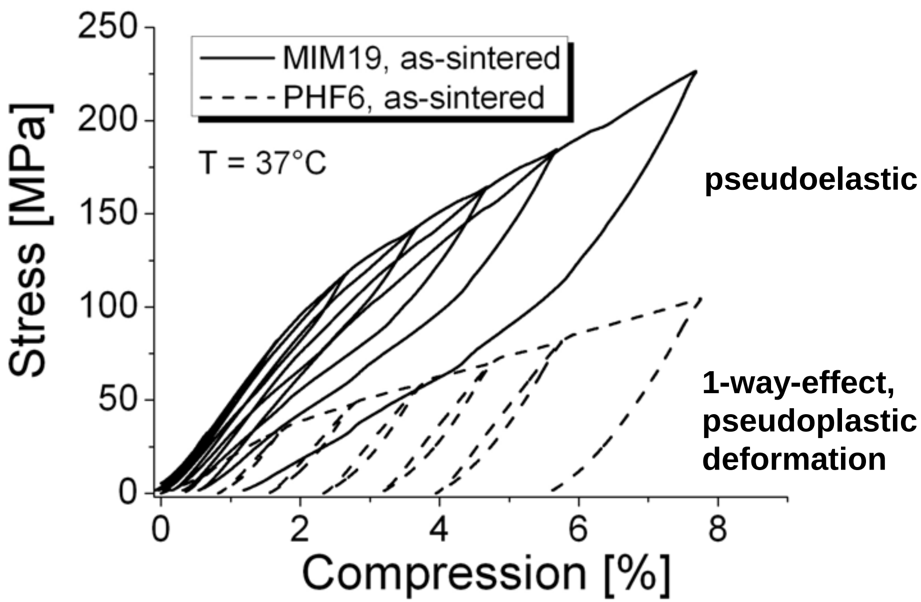


- Acceptable impurity contents
- Different transformation behaviors of sintered samples

→ at body temperature of 37°C austenitic (pseudoelasticity) for Ni-rich NiTi, martensitic (1-way-effect) for Ni-poor NiTi

Characterization of Porous NiTi

Mechanical Properties
Influence of Ni content - Porosity: 50%, Pore Size: 355-500 µm



<u>MIM19 (50.6 at.%):</u>

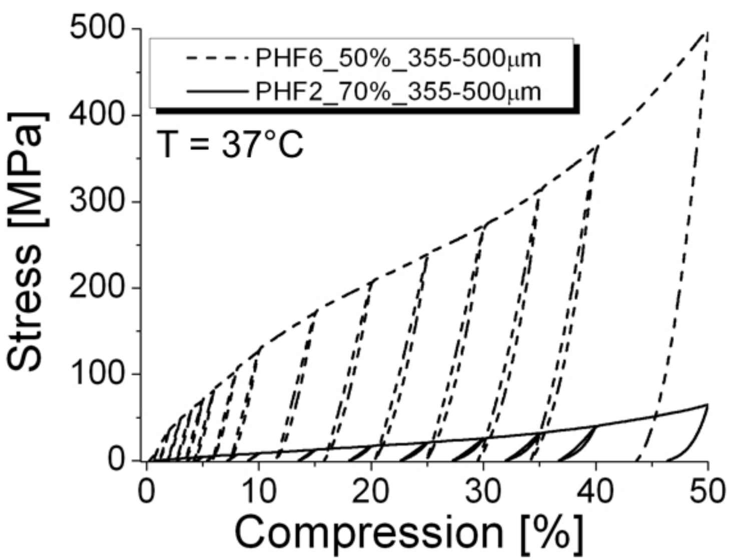
- Ni-rich starting powder
- Pseudoelastic properties
  > 6% reversible deformation
- higher compression strength at low deformations compared to...

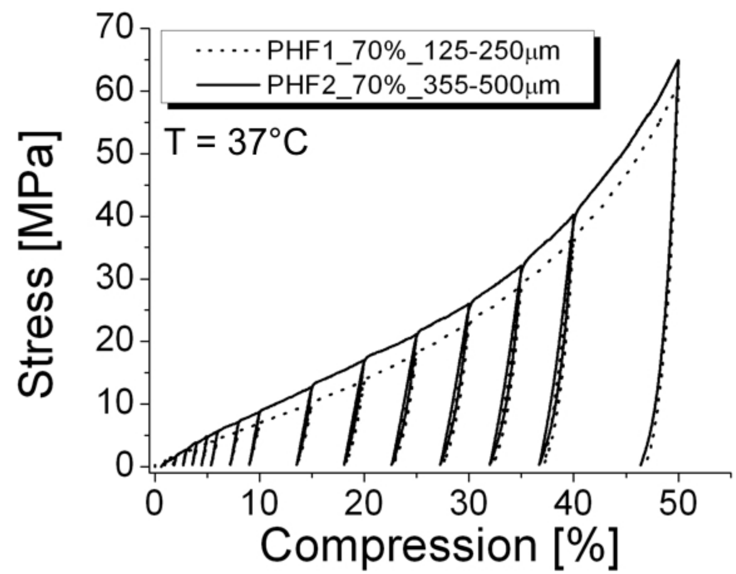
<u>PHF6 (49.7 at.%):</u>

- Ti-rich starting powder
- martensitic, shape-memory properties (1-way-effect by heating)
- no pseudoelasticity

Characterization of Porous NiTi

Mechanical Properties
Influence of total porosity and pore size – same Ni-content (49.7 at.%)

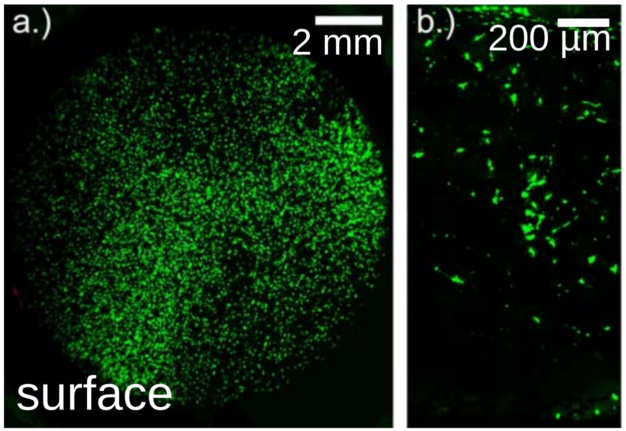




Porosity [%]	E [GPa]	σ_{d50} [MPa]
50	5.2	> 500
70	0.9	> 65

Cell Culture Experiments

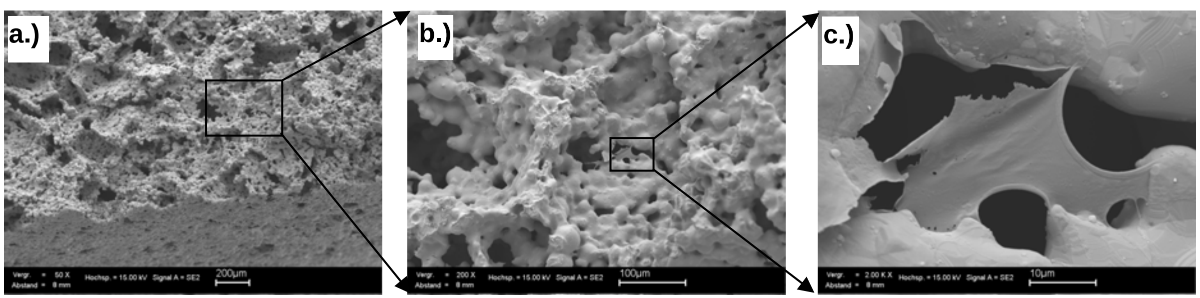
Adhesion and proliferation of hMSCs on MIM19 samples



fracture surface

After 8 days, living cells as well on the seeded surfaces as in the pore structure.

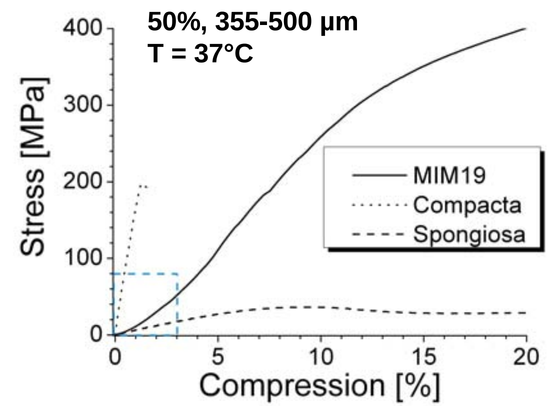
Fluorescence microscopy shows living, calcein-AM stained cells (green).

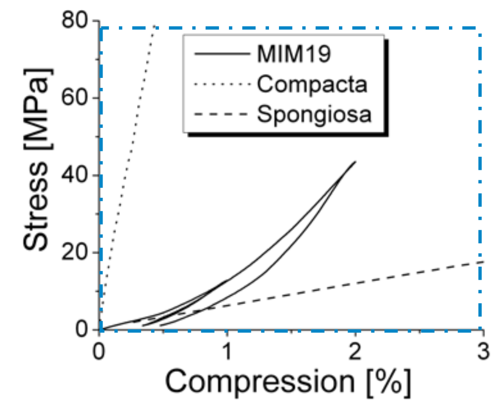


SEM images demonstrate the growth of the hMSCs in the porous structure.

Application for long term implants

- Low impurity contents lead to very good mechanical properties of porous NiTi
- Ni-rich samples show pseudoelasticity > 6%
  → elastic limit of bone ~ 2%
- Sufficent stability during handling and for long term applications
- For low compressions, Ni-rich NiTi follows the mechanical properties of spongiosa
  → Reduced risk of stress shielding

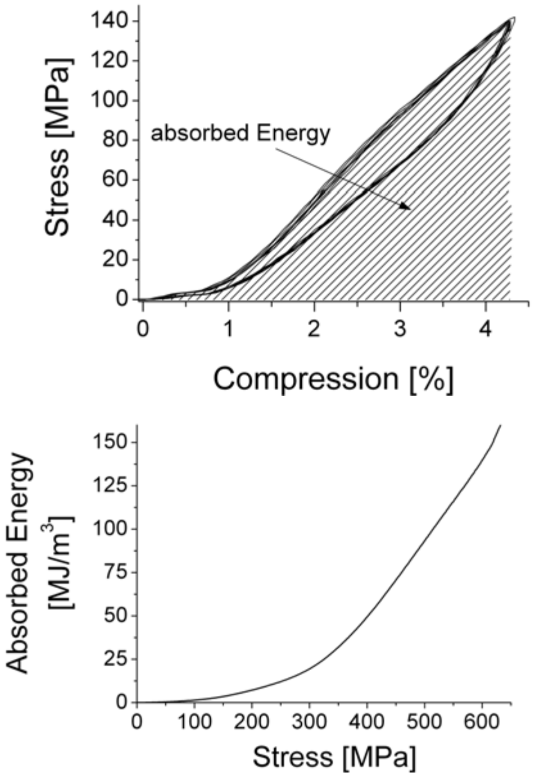




L. J. Gibson and M. FG. Ashby,
Cellular Solids, Cambridge University Press (1997)

Energy Absorbers

- Pseudoelasticity properties > 6%
- $E_{abs.}$ > 7 MJ/m^3 → Reversible
- $E_{abs.}$ > 150 MJ/m^3 → Maximum
- Porosity in combination with shape memory properties lead to high damping capacity
- Combination of space holder method with MIM process
  → defined damping properties, near net-shape fabrication



50% porosity, 355-500 µm RT

50% porosity, 355-500 µm RT

Acknowledgements

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Thank you for your attention.