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High Entropy Shape Memory Alloys- Mechanical Properties and Functional Degradation Mechanisms

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Project

- Finished study of mechanical engineering at Leibniz University Hannover in August 2017
- Research assistant at IW, Garbsen since October 2017
- Working in the field “materials engineering”

Project:	Microstructure-Functional Behavior-Relationships in High Entropy Shape Memory Alloys
Duration of project:	3 years
Applicants:	G. Eggeler (University Bochum) H. J. Maier (IW Hannover)
Funding Institution:	DFG
Project Partner:	M.Sc. David Piorunek

High Entropy Alloy with Shape Memory Effect (HESMA)

Desired properties:

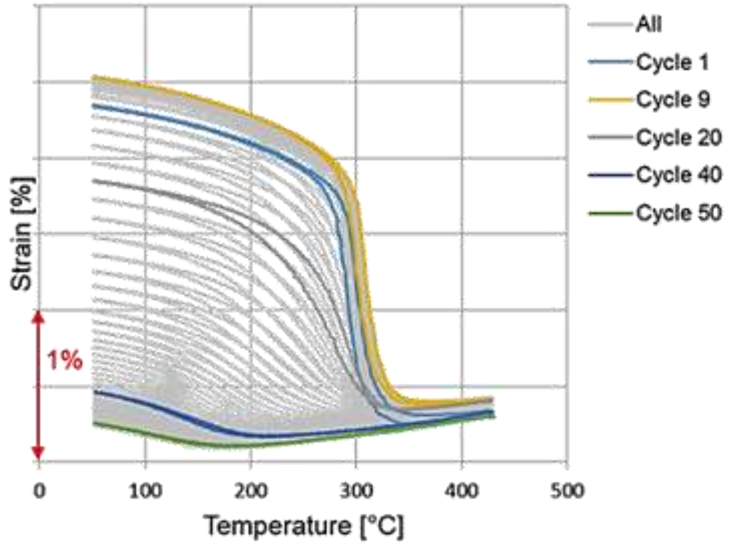
- Sluggish diffusion
- Reversible martensitic transformation
- Twinning
- „Perfect” shape recovery
- High strength
- **No fatigue?**

→ **Promising material** for elevated temperature applications

Functional properties of HESMA

TiZrHfCoNiCu HESMA

- Wide temperature range (200 - 900 K)
- Stable shape recovery strain up to 3 %
- Work output of 5 - 10 J/cm^3
- Yield strength up to 1200 MPa
- Atomic size difference (up to 11 %)
- Diffusion processes resistance



SEM in-situ thermo-mechanical cycling experiments of $Ti_{70}Ta_{30}$

(Niendorf et al., Mater. Sci. Eng. A 620 2015)

How about HESMA?

Challenges

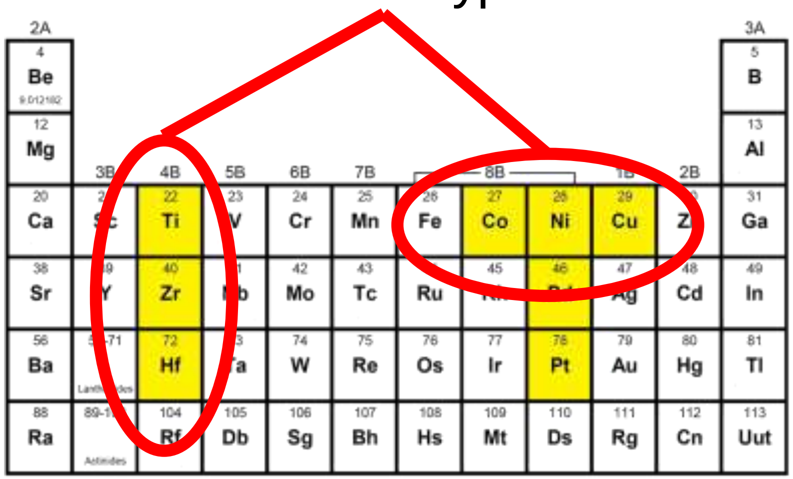
- **Functional and structural fatigue**
  - SME function loose intensity with repeated loading
  - Resulting in a gradual **degradation** of **functional properties**
  - **Life limiting** for functional applications under cyclic conditions
  - Main obstacle for a breakthrough of shape memory technology

- **Difficult to deform** due to **brittleness**

Idea

- **Complex composition** to reach structural stability
- Compositions close to **equiatomic group** of elements

B2 intermetallics of the two different types



- MT does not always take place
- Negative value of enthalpy/entropy mixing
- High-temperature phase with MT

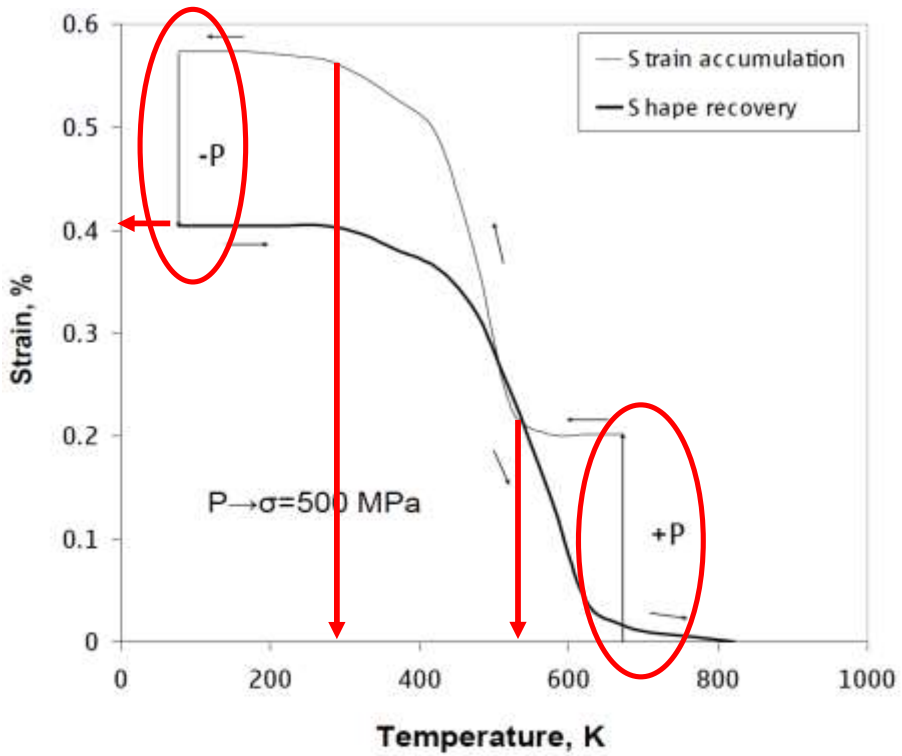
- Interatomic interaction control
- Pair enthalpy of mixing
- Equiatomic group of elements
- Valence electron concentration

Alloy Selection

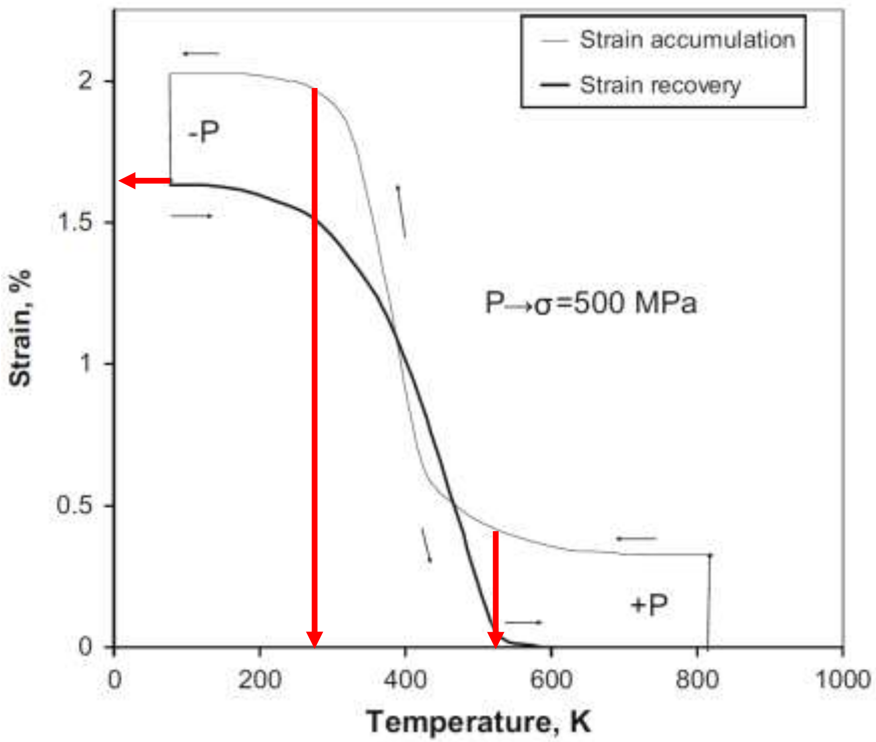
50%			50%		
Ti at.%	Zr at.%	Hf at.%	Co at.%	Ni at.%	Cu at.%
16.667	16.667	16.667	-	25	25
16.667	16.667	16.667	X	Y	Z

Ti, at. %	Zr, at. %	Hf, at. %	Co, at. %	Ni, at. %	Cu, at. %	ΔS_{mix}, J/(mol K)	H_{Meyer}, GPa	E, GPa
16.6667	16.6667	16.6667	16.6667	16.6667	16.6667	14.897	11.19	77.8
16.6667	16.6667	16.6667	25	25	-	13.211	14.97	92.3
16.6667	16.6667	16.6667	-	25	25	13.211	13.84	82.9
16.6667	16.6667	16.6667	25	-	25	13.211	20.81	110.1
50	-	-	-	50	-	5.763	6.05	46.6

TiZrHfNiCu and TiZrHfCoNiCu HEA already showed a SMA effect



shape memory behavior measured in 3 point bending for $\mathbf{Ti_{16.667}Zr_{16.667}Hf_{16.667}Ni_{25}Cu_{25}}$ HEA
(G.S. Firstov et al., Proc. Icomat-2014)



shape memory behavior measured in 3 point bending for $\mathbf{Ti_{16.667}Zr_{16.667}Hf_{16.667}Co_{10}Ni_{25}Cu_{15}}$ HEA
(G.S. Firstov et al., Sha. Mem. and Superelas. 2015)

Research Work Packages

- **Ruhr-University Bochum**
  - Development and production of high purity ingots ➡ repeatable melting process and alloy production/heat treatment
  - Phase stability and martensitic transformation
  - Thermo-mechanical processing

- **University Hannover**
  - Material characterization and reaction in different temperature regimes
  - Thermo-mechanical fatigue testing by heating/cooling
  - Investigation of fatigue behavior, crack nucleation and propagation
  - In-situ characterization of functional fatigue

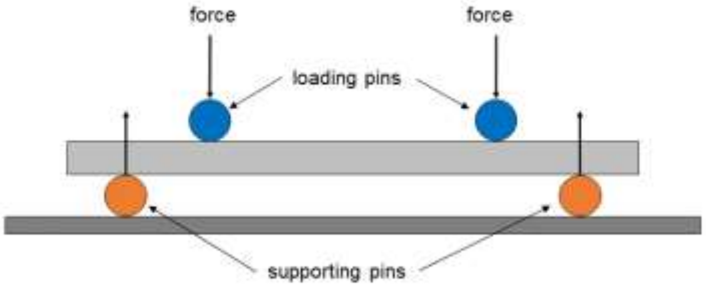
Tensile and compression tests

- Material **characterization**
- Thermo-mechanical fatigue tests

MTS Acumen™ Electrodynamic Test Systems 100 Hz, ± 3kN

Bending experiments

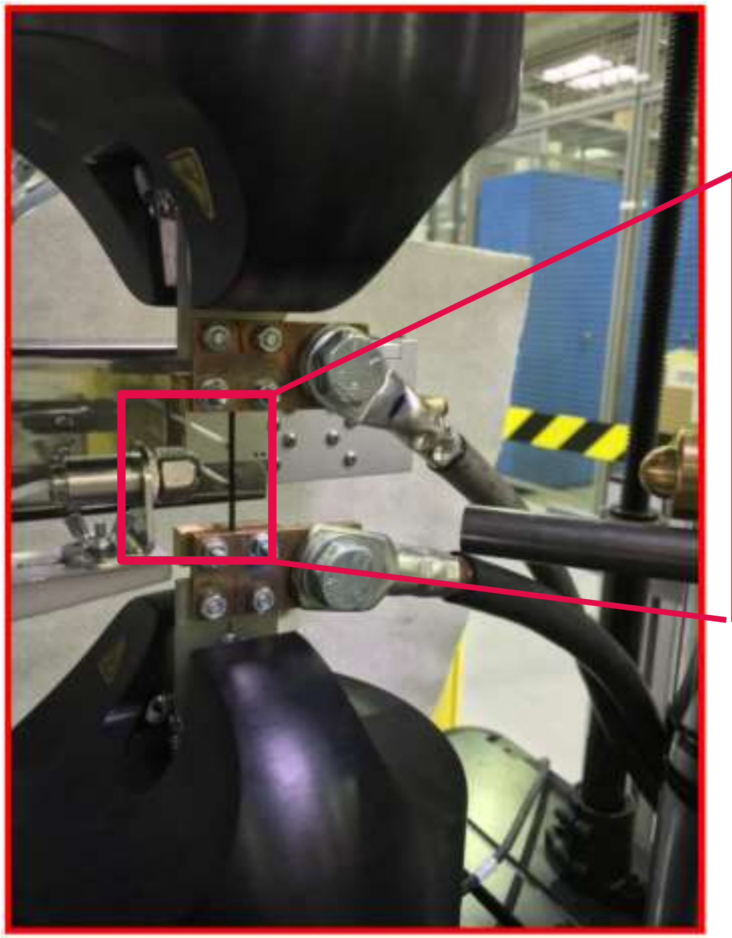
- Tempered 3 and 4-point bending tests by heating and cooling



Test Set-Up for 4-Point Bending

Heating of samples

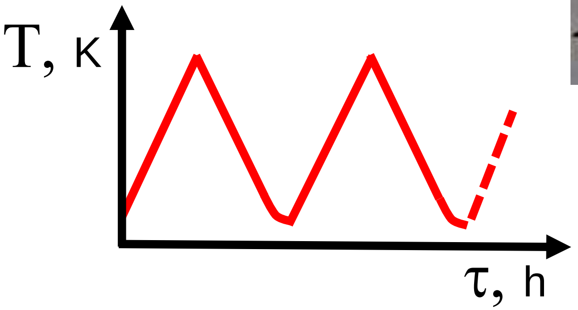
Conductive heating of tensile sample



$\Delta \quad = \pm 3$ K

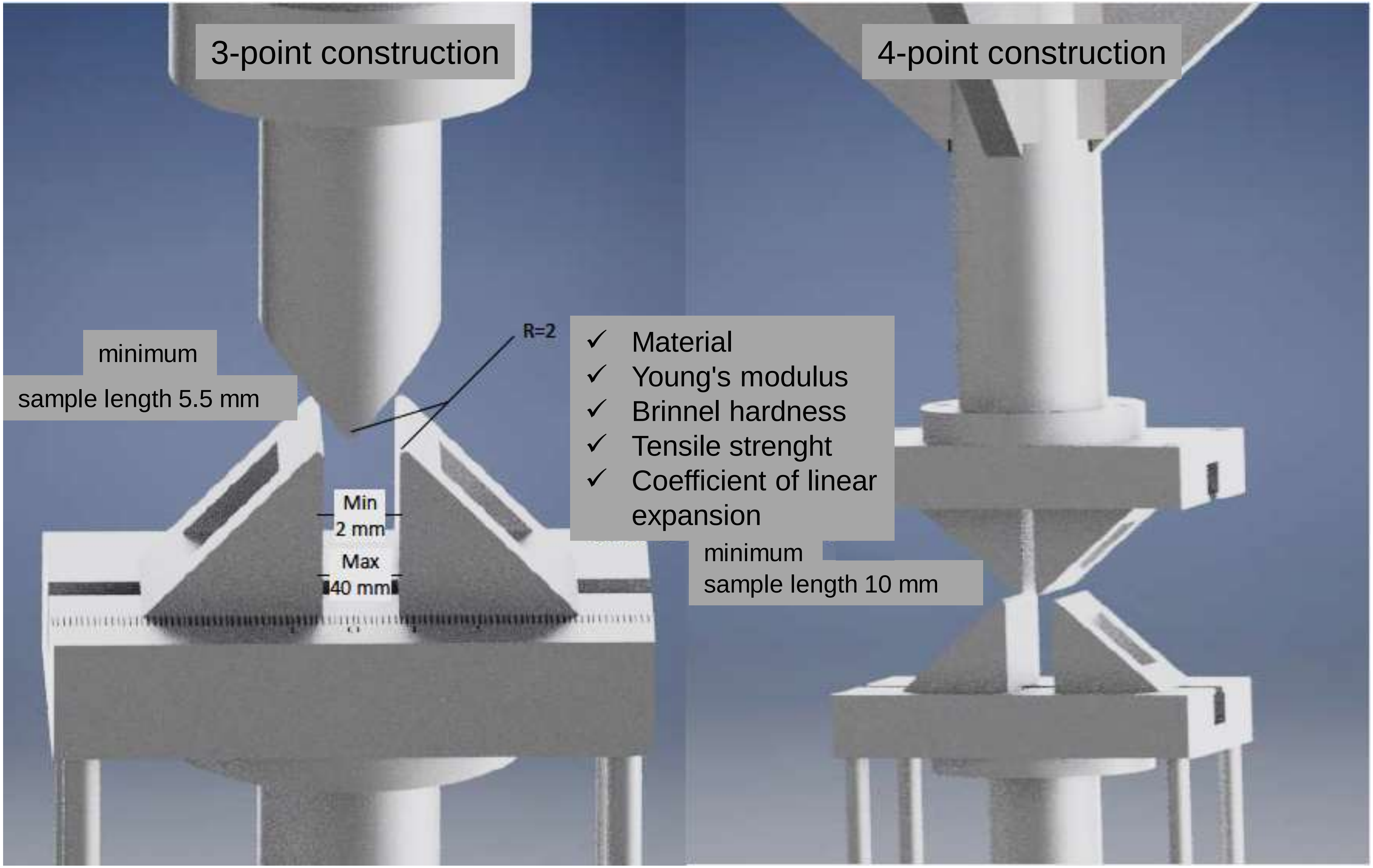
$T \leq 1173$ K

$T_{field} = \text{const.}$



Tensile and compressive samples

Test Set-Up for 3- and 4-point bending experiments



- ✓ Material
- ✓ Young's modulus
- ✓ Brinnel hardness
- ✓ Tensile strenght
- ✓ Coefficient of linear expansion

Analytical techniques

- In-situ SEM

Identification of functional degradation mechanisms:
thermo-mechanical fatigue testing by in-situ heating/cooling

Summary

- Successful production of alloys with martensitic transformation
- Extensive mechanical characterization
  - monotonic
  - cyclic
- Currently small samples but upscaling possible
- First data expected end of march