Karlsruhe Institute of Technology

Institute for Applied Materials

Elasto-viscoplastic deformation behavior of oxide dispersion strengthened steels

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Institute for Applied Materials (IAM)

Outline

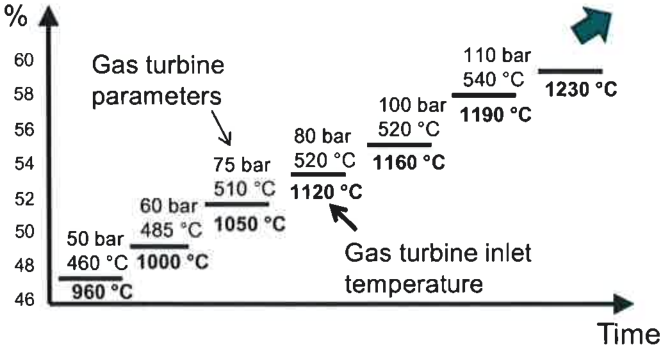
- Introduction
- Material: ODS T91

- Cyclic deformation behavior
- Microstructural evolution after cyclic loading
- Influence of hold time

- Summary
- Outlook

Introduction

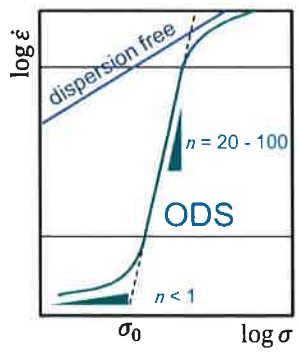
- **Higher efficiency of power conversion systems**



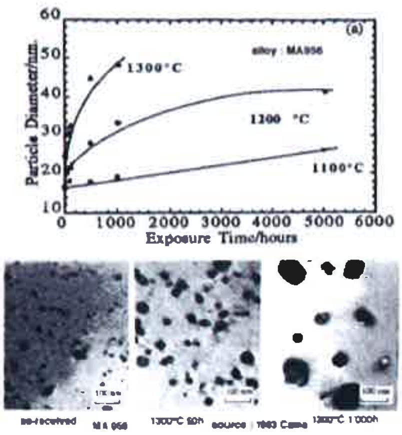
- **Expansion of renewable energy**
  - Frequent & sharp load changes
  - Increased thermo-mechanical fatigue loads
  - Higher temperature and pressure

⇨ **O**xide **D**ispersion **S**trengthened steel

Introduction

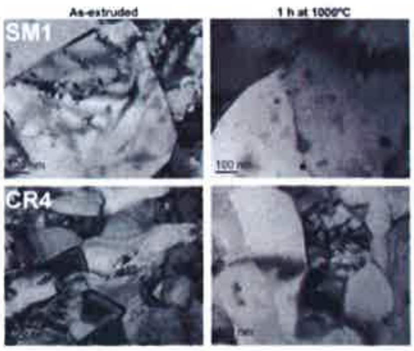


Arzt & Grahle, Acta Metal., 1998



Cama et al., Inst. of phys. conf. series, 1993

Material: 14YWT



Miller et al.,J. Nucl. Mater,2006

- Excellent mechanical & corrosion properties at high temperatures
- A lot of research in the fields of fabrication & processing, mechanical properties, microstructural stability

But: No description/ simulation of elasto-viscoplastic deformation behavior

Introduction

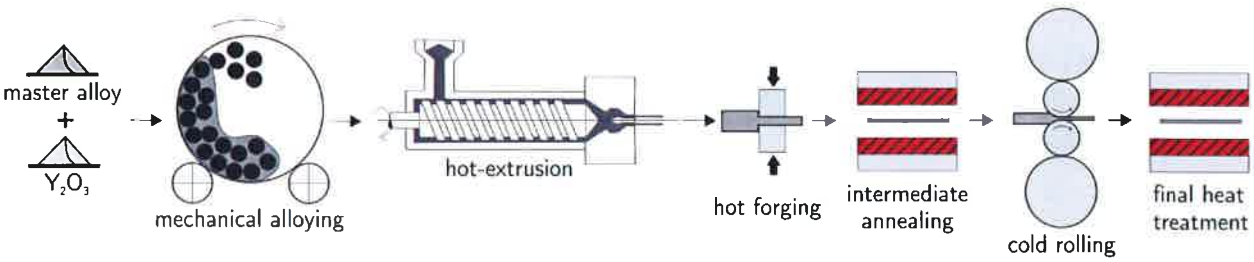
Objective:

"Development of suitable inelastic constitutive model which can describe the elasto-viscoplastic deformation behavior of ODS steels"

Important:

- Fundamental understanding of high temperature deformation behavior under:
  - Tensile loadings
  - Creep/ relaxation loadings
  - Cyclic loadings

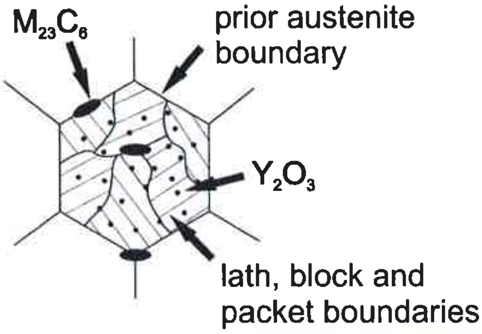
Material: ODS T91

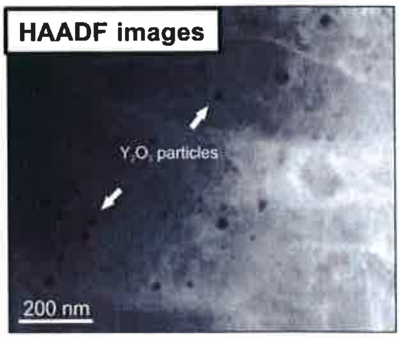


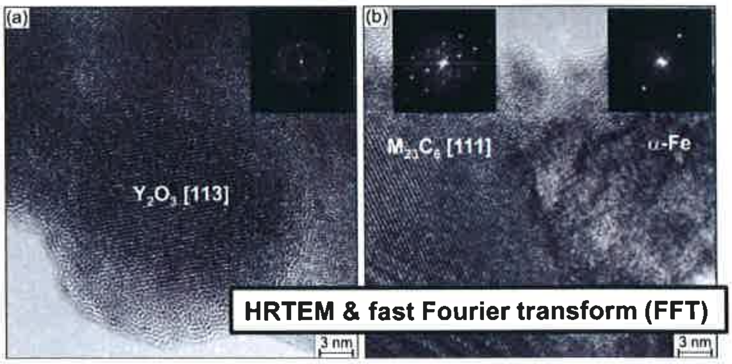
- Based on "conventional" T91 (9Cr-Mo-V-Nb)
- Obtained from GETMAT project
- Fabricated by KOBELCO Research Institute, INC in Japan

Element	Fe	C	Cr	Mo	Nb	V	N	Y_2O_3	Ex. O
Conc. in wt-%	Bal.	0.098	8.9	0.76	0.06	0.2	0.016	0.36	0.07

Material: ODS T91 - Microstructure





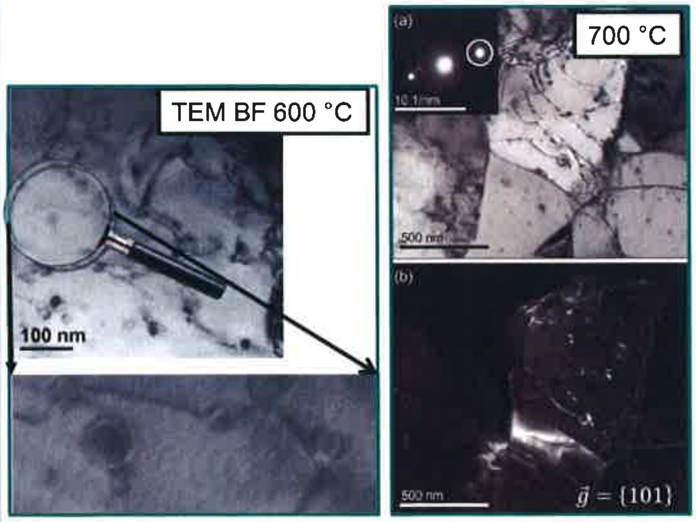


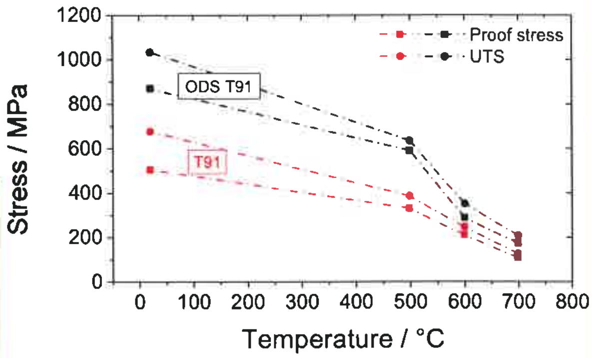
- Ferritic-martensitic
- Mean sub-grain size ~ 620 nm
- Unregularly shaped $M_{23}C_6$ carbides
- Y_2O_3 particles (~ 17 nm)

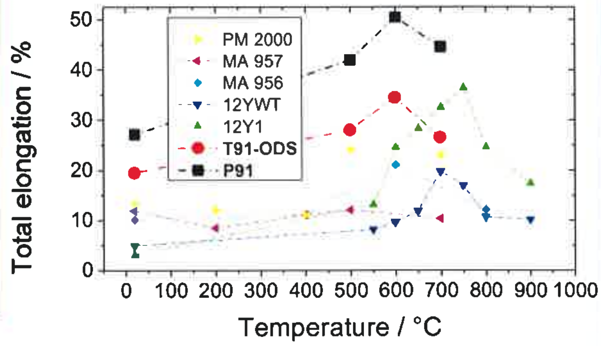
Strassberger et al., Mat. Sci. Tech., 2014

Mechanical properties

- ODS T91 shows higher strength at all measured temperatures compared to base material P91





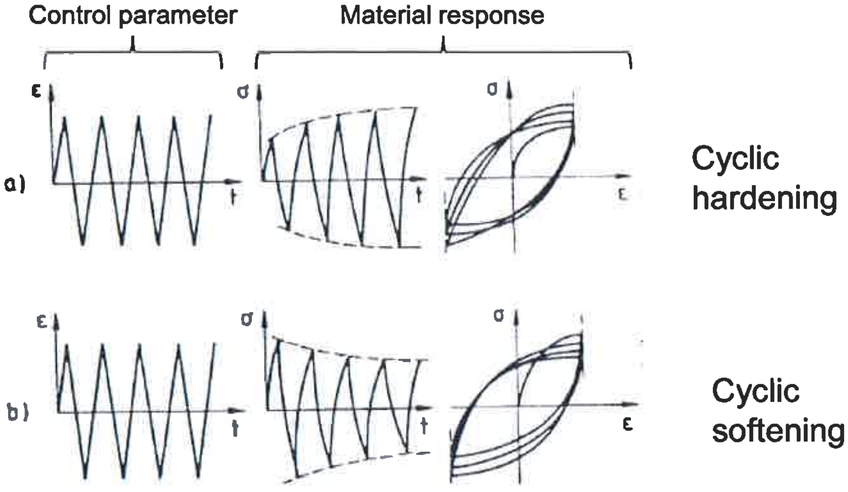


Strassberger et al., Mat. Sci. Tech., 2014

Cyclic deformation behavior

- **Cyclic hardening/ softening**
- Fatigue crack initiation
- Fatigue crack growth

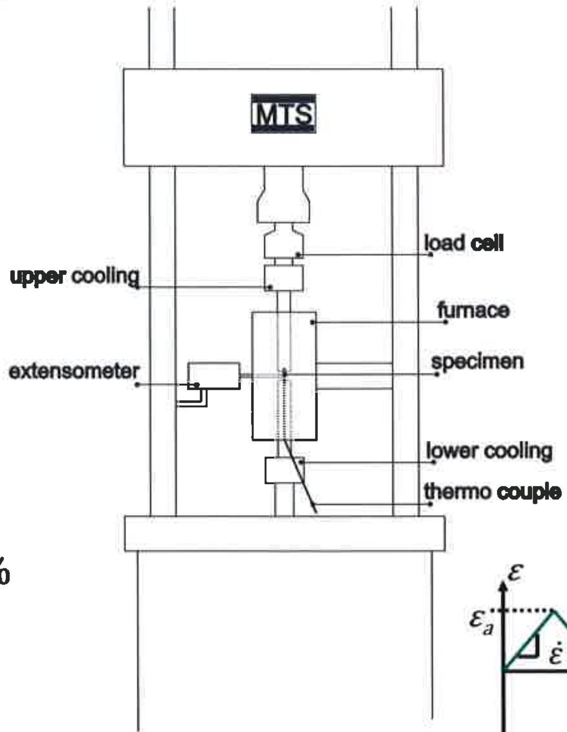
For strain controlled test & symmetric load conditions ($R = -1$)

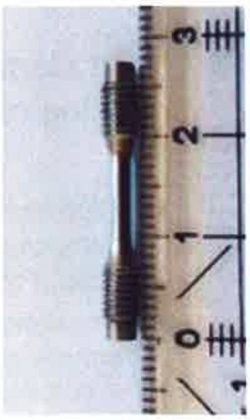


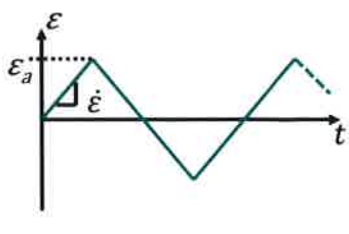
H.J. Christ, Wechselverformung von Metallen, Springer-Verlag, 1991

Experimental setup

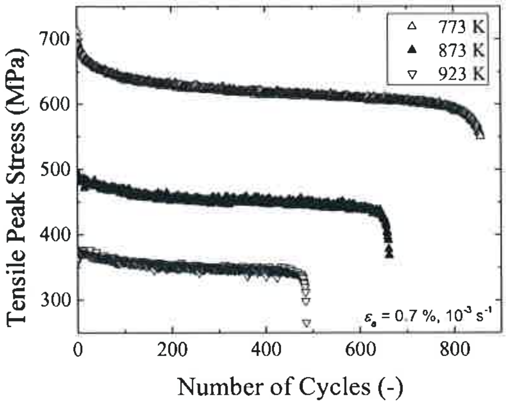
- MTS testing machine
- Strain controlled test
  $\dot{\varepsilon} = 10^{-3}s^{-1}$
- Symmetric load conditions
  $R = -1$
- Strain amplitude
  $\varepsilon_a = 0.5\%, 0.7\%, 0.9\%$
- Temperature:
  $500\ °C, 600\ °C, 650\ °C$

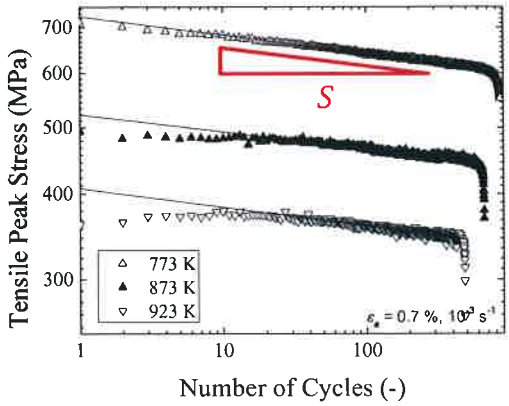






Cyclic deformation behavior of ODS T91





ODS T91 shows cyclic softening behavior:

- Non-linear decrease in strength during 1st part of life time
- No saturation cycle & reduced cyclic softening with constant slope
- Acceleration of cyclic softening due to damage

Aktaa and Schmitt, Fus. Eng. Des., 2006

Analytical expression:

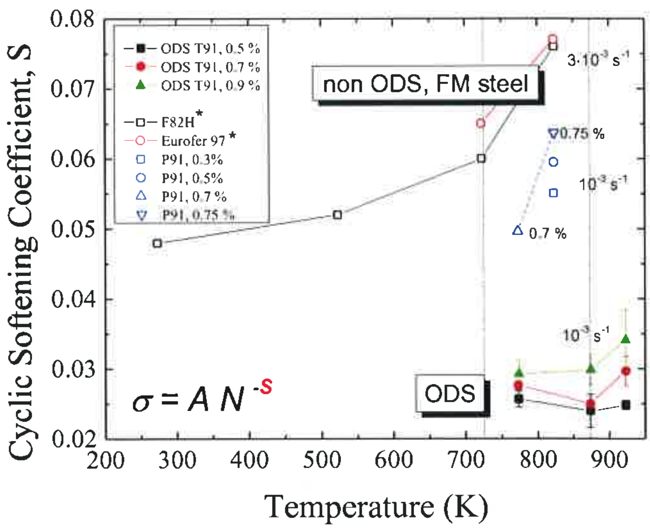
$$\sigma = A \cdot N^{-S}$$

S: Cyclic softening coefficient
A: Temperature dependent constant
N: Number of cycles

Armes, J. Nucl. Mat., 2002

Cyclic softening behavior of ODS T91

- Linear stage of cyclic softening curves:
  - ODS steel shows less cyclic softening compared to non ODS, FM steels
  - Dramatic increase of cyclic softening coefficient above 723 K **for non ODS, FM steels**
  - Increase of cyclic softening coefficient starts at 823 K **for ODS steel** only for $\varepsilon_a \geq 0.7\%$



* Armes, J. Nucl. Mat., 2002

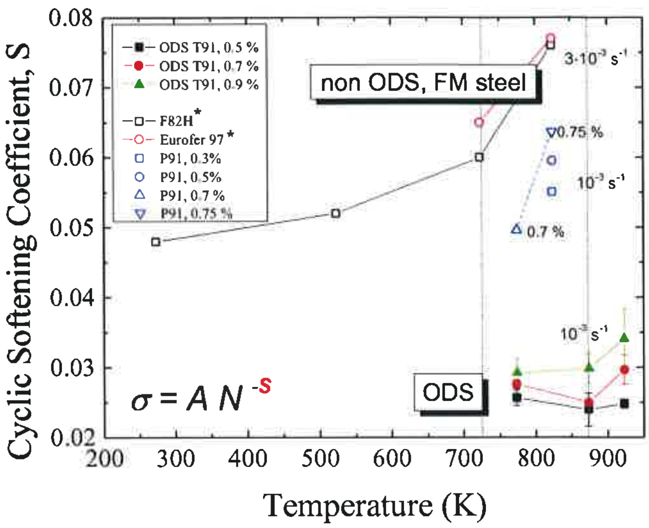
Cyclic softening behavior of ODS T91

For non ODS steels < 723 K:

- Rearrangement of initial high dislocation density to dislocation cell structure

For non ODS steels > 723 K:

- Coarsening of carbides leading to a marked recovery
- Recrystallization of microstructure as a result of the inability of precipitates to pin the martensitic lath boundaries

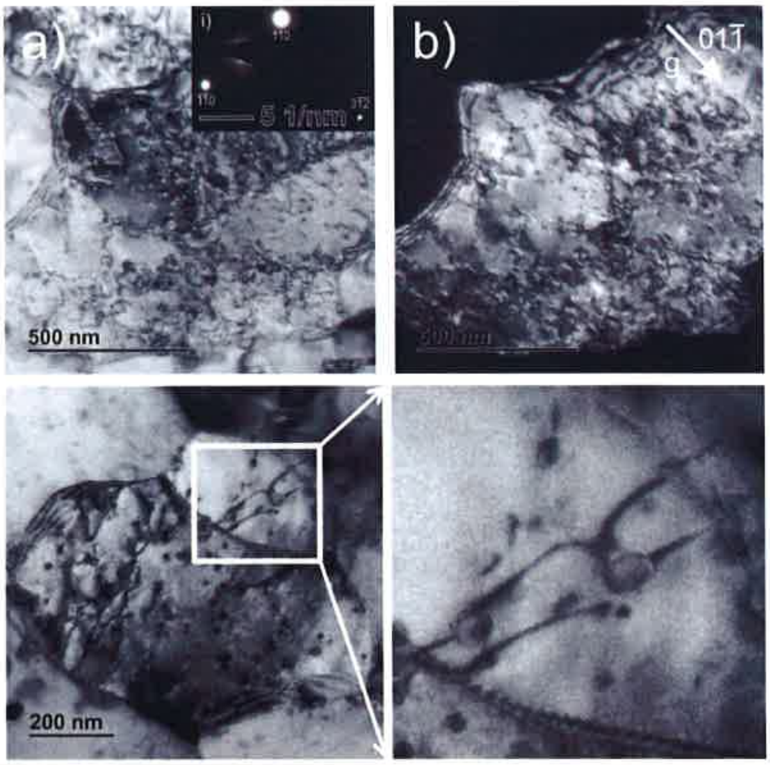


Dislocation structure of ODS steel

* Armes, J. Nucl. Mat., 2002

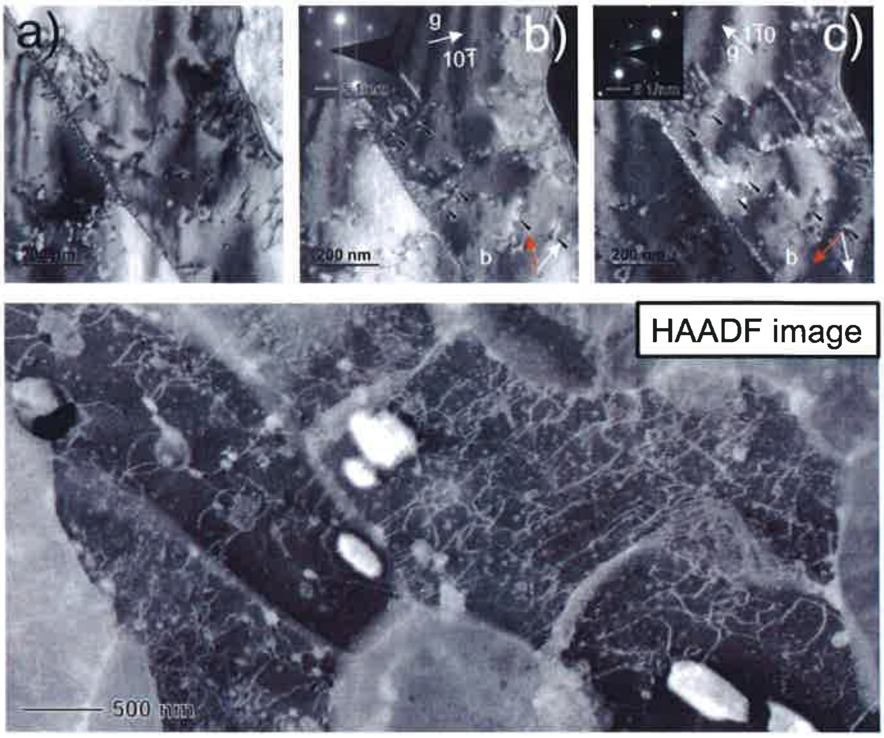
TEM: Dislocation structure at 500 °C

- High dislocation density
- Strong interactions of dislocations and particles
  - Tangles of dislocations
  - Pinning of dislocations at particles
  - Dislocations bow out

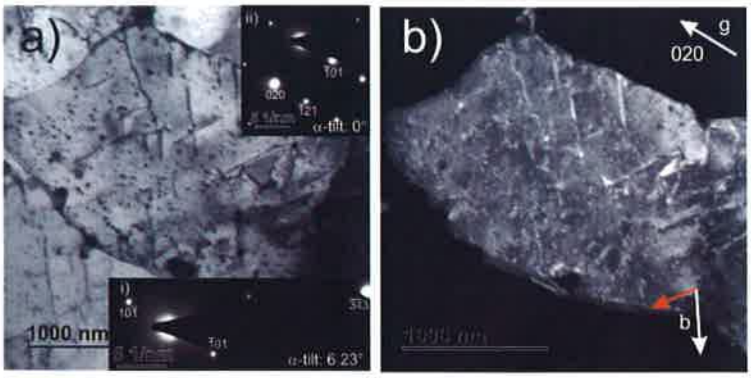


TEM: Dislocation structure at 600 °C

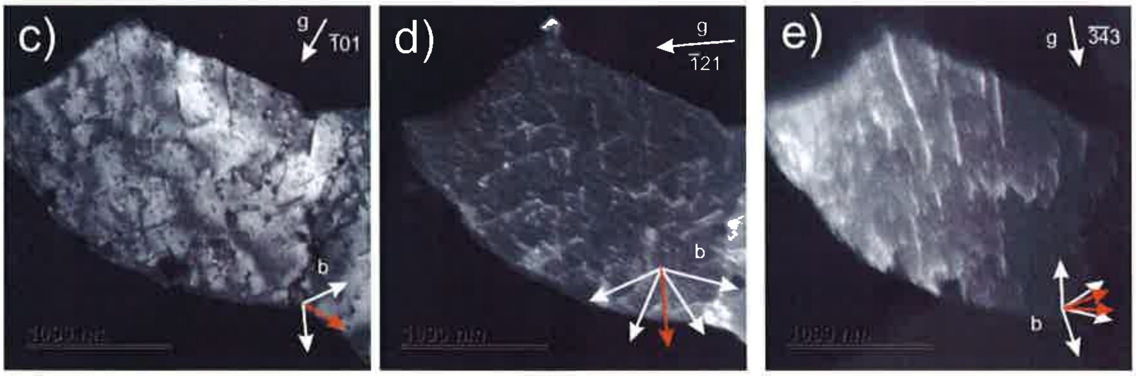
- Still regions with dislocation tangles and high dislocation density
- Regions where dislocations are rearranged into straight arrays.
- Dislocations are pinned at particles and bow out.



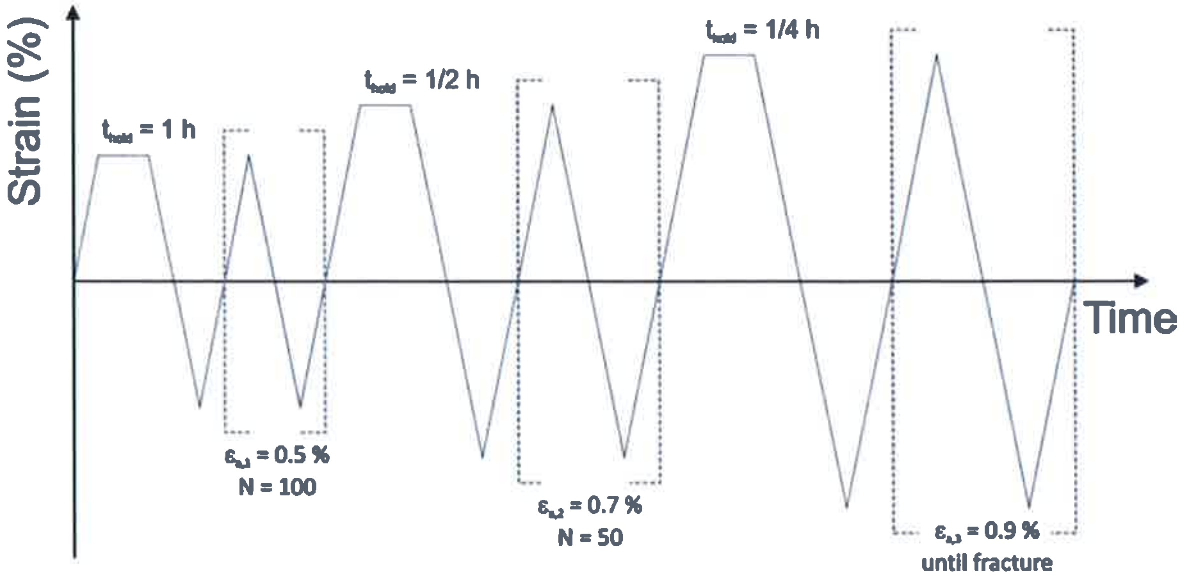
TEM: Dislocation structure at 650 °C



- Reduced dislocation density
- Almost no dislocation tangles
- Dislocations are arranged into straight arrays.

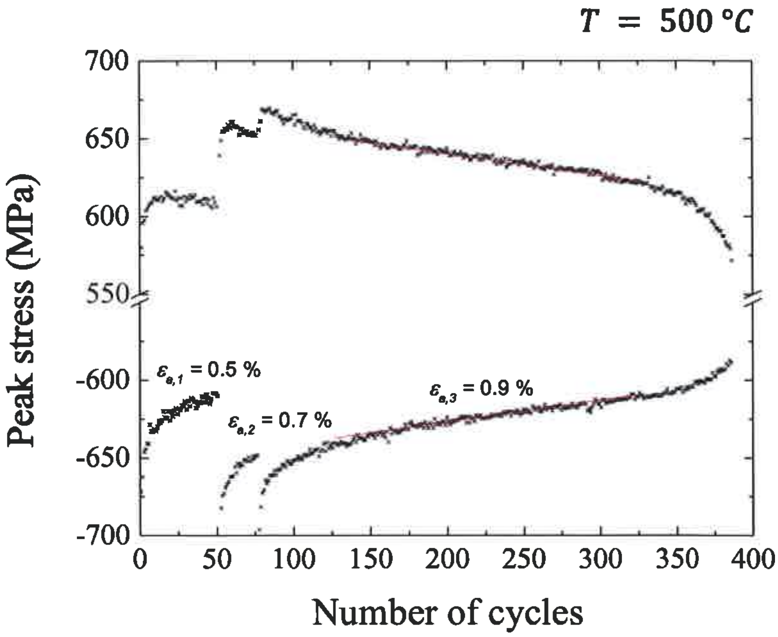


Influence of hold time



Influence of hold time

- Hold time under tension reduces tensile peak stresses directly after relaxation
- Recovery of peak stresses in subsequent cycles
- Softening behavior is same compared to separate cyclic tests



Summary

Cyclic deformation behavior:

- ODS T91 shows cyclic softening behavior.
- Cyclic softening is less pronounced compared to non ODS, FM steels.
- Compared to non ODS, FM steels cyclic softening increases at higher temperatures (~ 873 K)
- Hold time under tension reduces tensile peak stresses

TEM:

- Dislocation tangles and strong particle/dislocation interaction at 500 °C
- Rearrangement of dislocations into straight arrays at higher temperatures

Outlook

- Using modified Chaboche type of constitutive equations to describe the elasto-viscoplastic deformation behavior

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Thank you for your attention!