



# THERMO-MECHANICAL FATIGUE BEHAVIOR OF REDUCED ACTIVATION FERRITE/MARTENSITE STAINLESS STEELS

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## Overview:

- Motivation
- TMF testing facility
- Mechanical and microstructural results
- Conclusion



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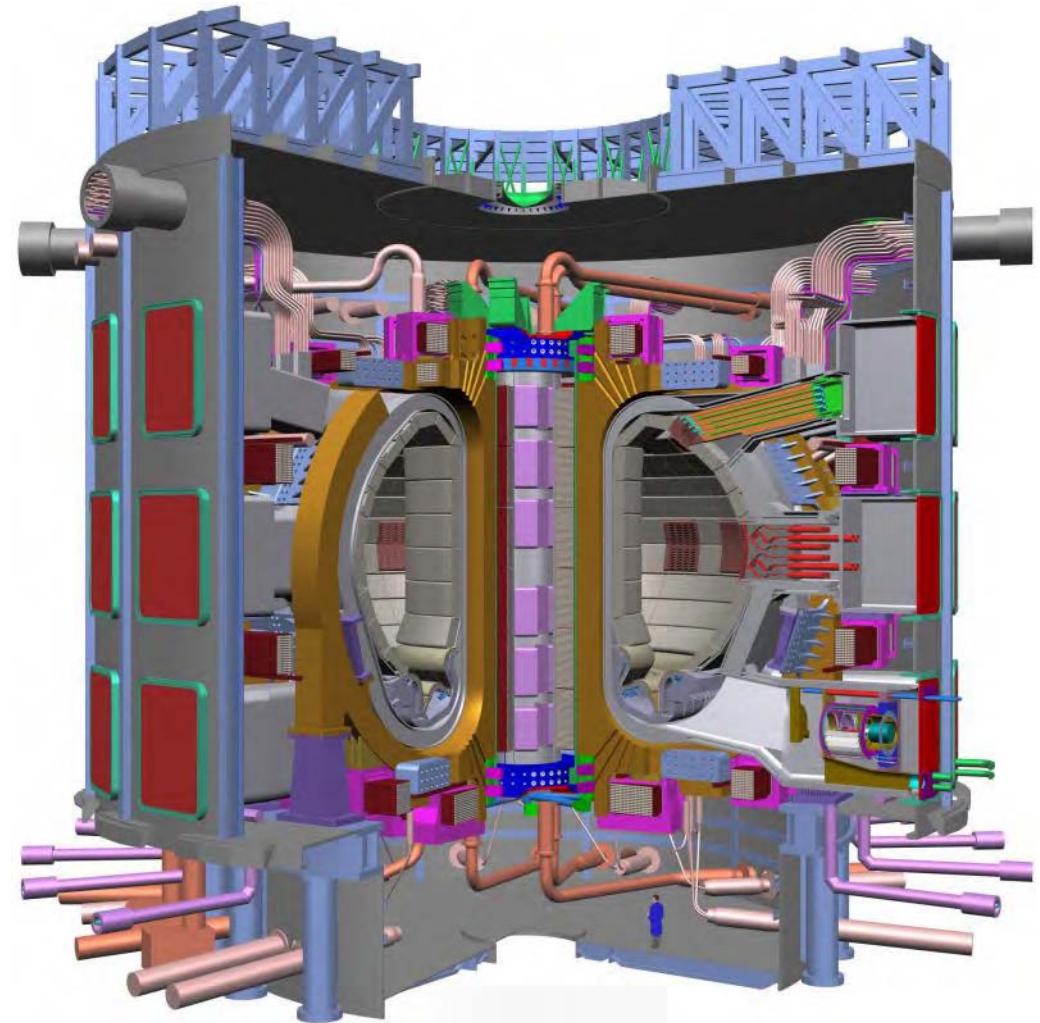
## ■ Motivation

Scientists and engineers from **China, Europe, Japan, Korea, Russia, and the United States** are working in an unprecedented cooperation on the next major step for the development of nuclear fusion - **ITER** (which means "the way" in Latin).

**ITER's mission** is to **demonstrate the scientific and technological feasibility of fusion energy** for peaceful purposes.

To do this, ITER will demonstrate **moderate power multiplication**, demonstrate essential **fusion energy technologies** in a system integrating the appropriate **physics and technology**, and test key elements required to use fusion as a practical energy source.

On **28<sup>th</sup> June 2005** it was decided to **built ITER** at the **EU - Cadarache site** in southern France.



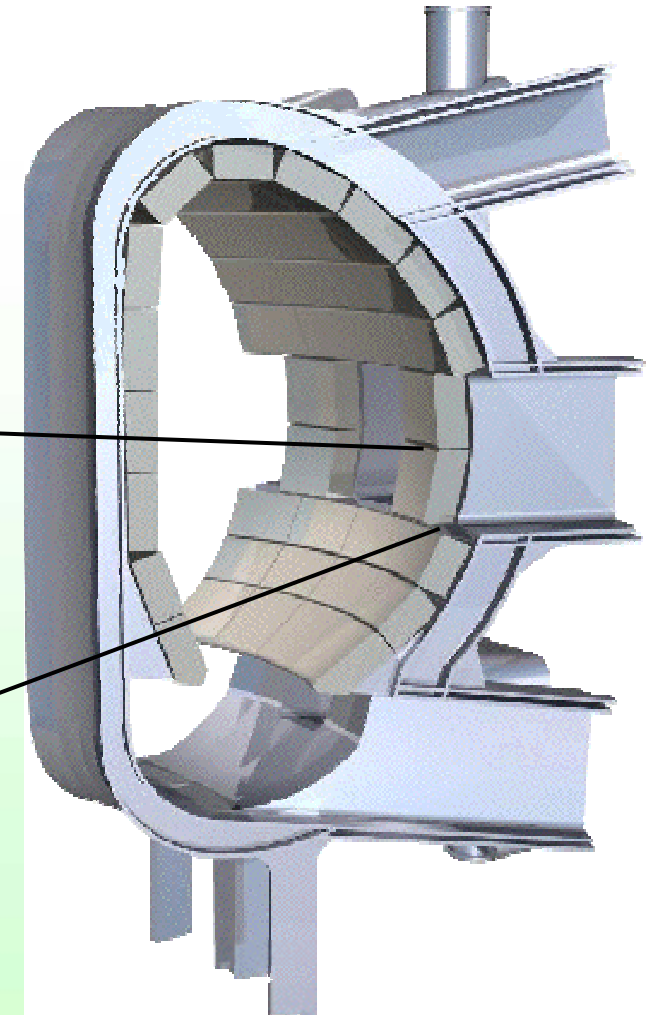
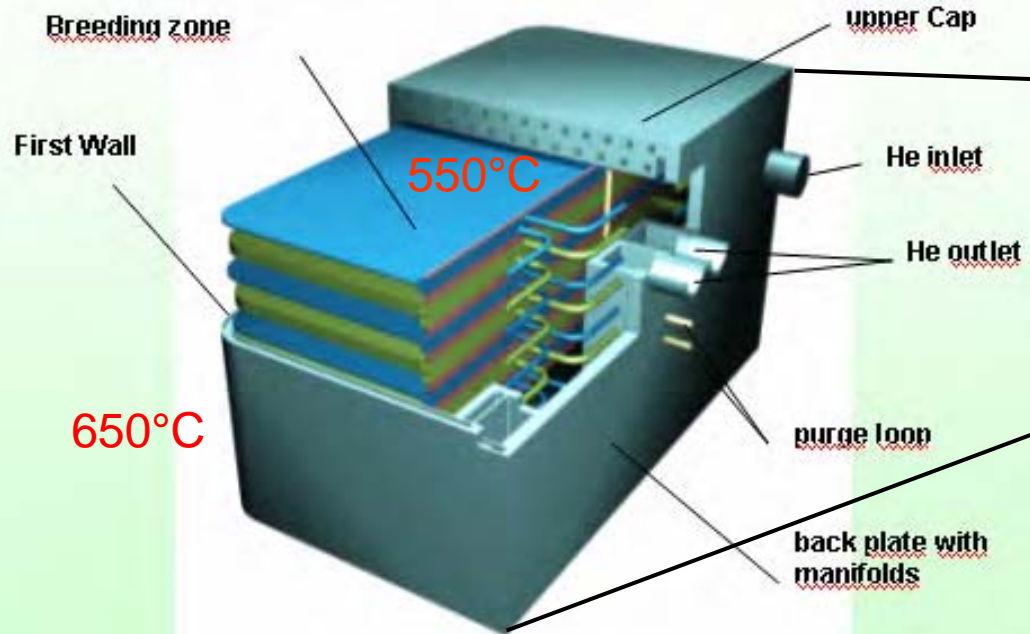
ITER scheme



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**Test Blanket Module (TBM) and ITER details**

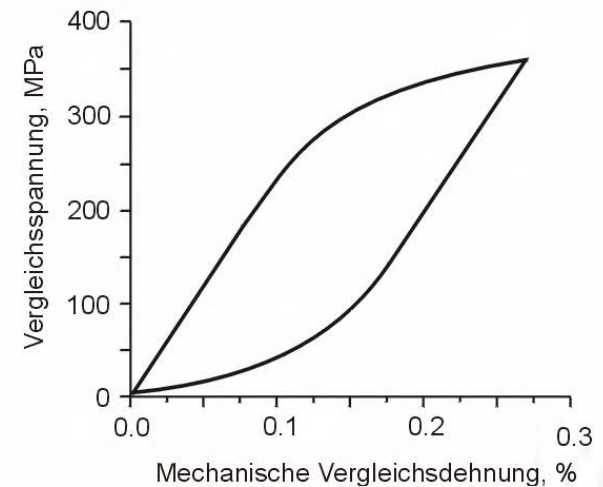
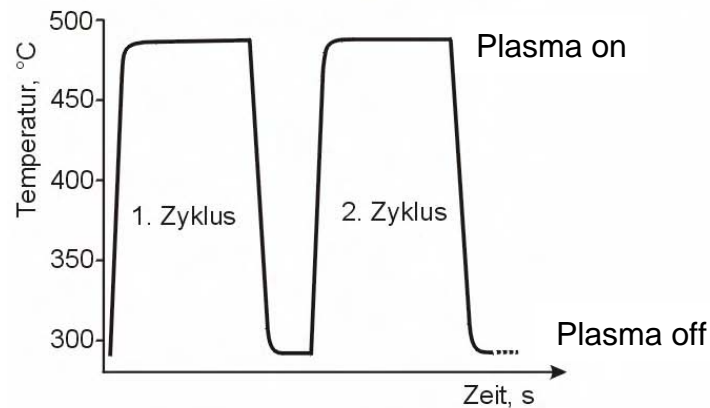
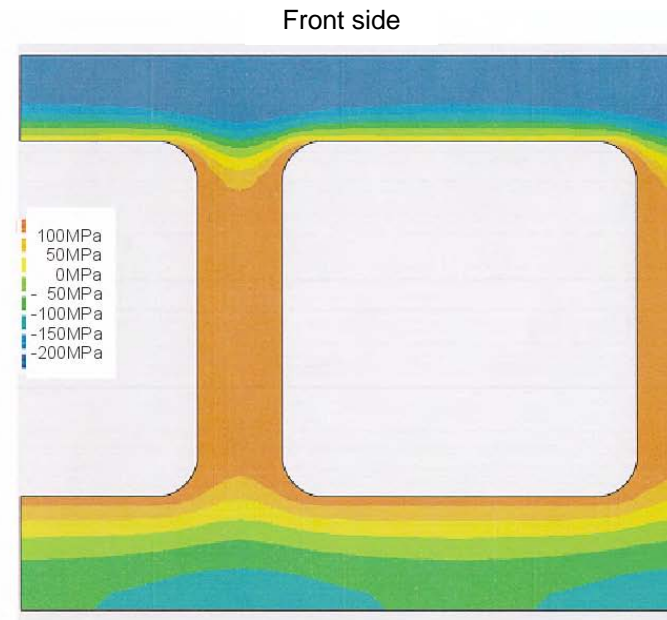
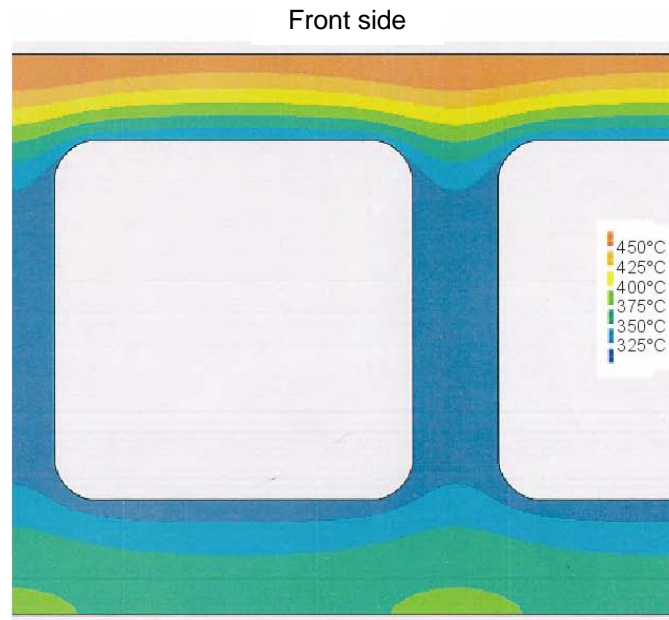
Isometric view of the TBM without external manifolds and mechanical attachments to ITER





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Temperature and stress distribution in the First Wall of the Blanket





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**From atomic structure to materials data base**

**Alloy design**

**Neutron Irradiation**

**Nuclear data & activation calculations**

**Mechanical properties**  
 Tensile, **TMF**, **Fatigue**, **Creep-Fatigue**, Toughness ..

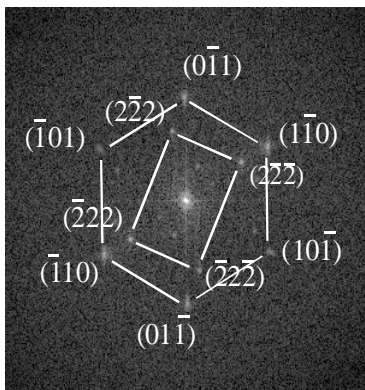
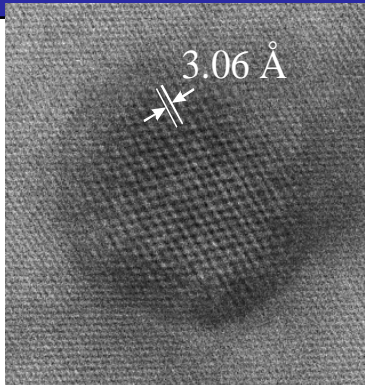
**Microstructure & metallurgy**

**Fabrication & joining**

**Lifetime prediction rules**

**Constitutive equations**

**Design rules**





Chemical composition of 9 to 12 % Cr ferritic/martensitic steels (wt %)

550°C

	C	N	Si	Mn	Ni	Cr	Mo	Al	V	Ti	Nb	Cu	W	Ta
EUROFER 97	0.12	0.018	0.06	0.47	0.022	8.93	0.0015	0.008	0.2	0.01	-	0.004	1.07	0.14
OPTIFER IV	0.1	0.06	-	0.6	-	9.35	-	-	0.23	-	-	-	1.2	0.1
F82H	0.09	0.007	-	0.16	0.019	8.16	0.0018	-	0.15	-	0.01	-	2.2	0.03
MANET II	0.10	0.03	0.14	0.75	0.65	10.3	0.57		0.19		0.14			
W-Nr. 1.4923	0.21		0.37	0.50	0.42	11.2	0.83	<0.05	0.21	<0.05	<0.05	0.1		

Elements < 1 wppm are indicated by a bar

Also other elements, e.g. Co, Bi, Cd, Ag, etc., so called tramp impurities must be restricted to extremely low levels.

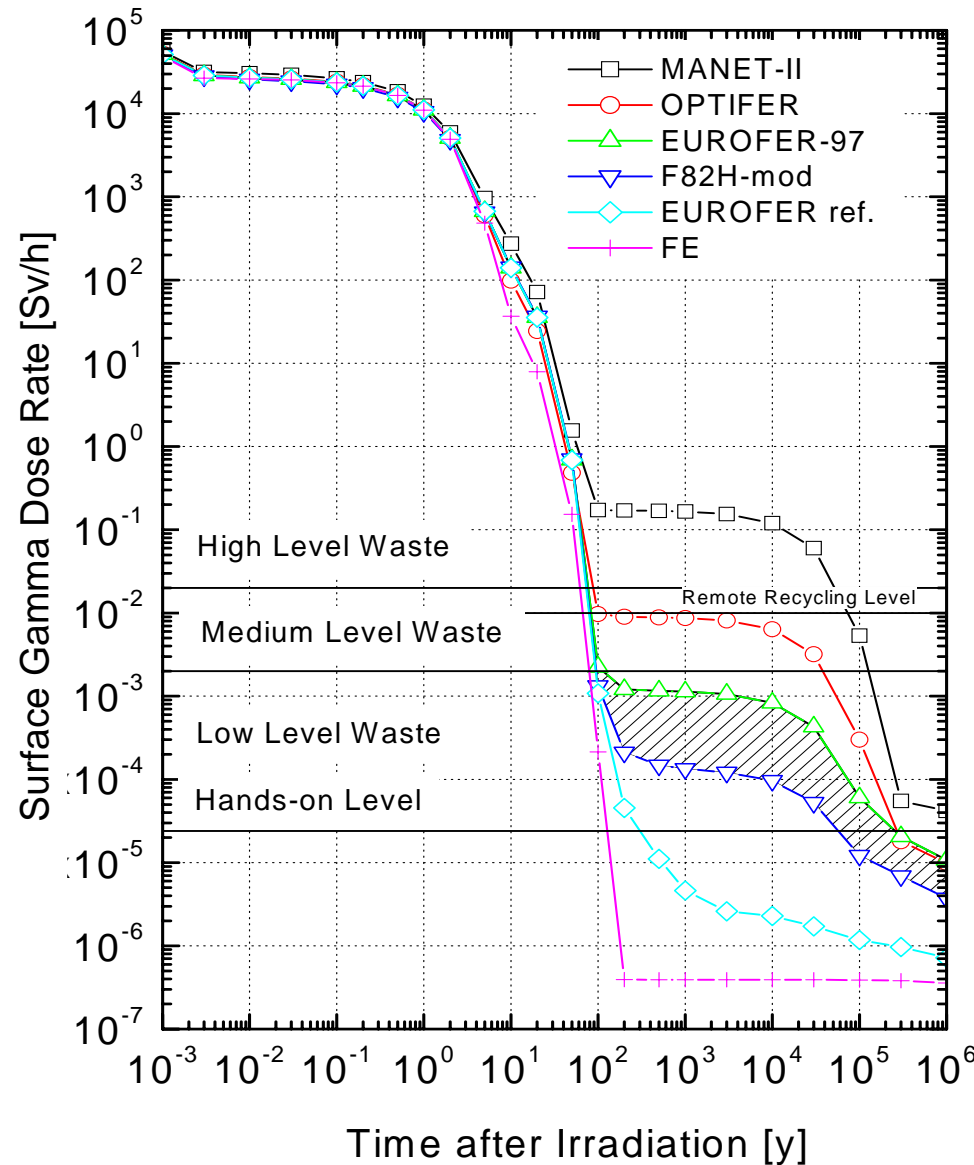
Alloy	Heat	C	Si	Mn	Cr	V	W	Ta		Y <sub>2</sub> O <sub>3</sub>
EUROFER	E 83699	0.12	0.06	0.42	8.87	0.19	1.10	0.14	+	0.3 or 0.5

650°C





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**Decay of  $\gamma$ -Dose rate**

- **Reduced Activation Ferritic Martensitic (RAFM) steels offer significant improvement**
- **Low level waste already after ~ 100 years**
- **No long-living waste disposal**

**Conditions for calculations:**

Long term irradiation  
 (12.5 MWa/m<sup>2</sup>) of a  
 DEMO reactor first wall





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■ TMF testing facility

Our 7 TMF-facilities under air atmosphere for out-of-phase thermal fatigue are built up with:

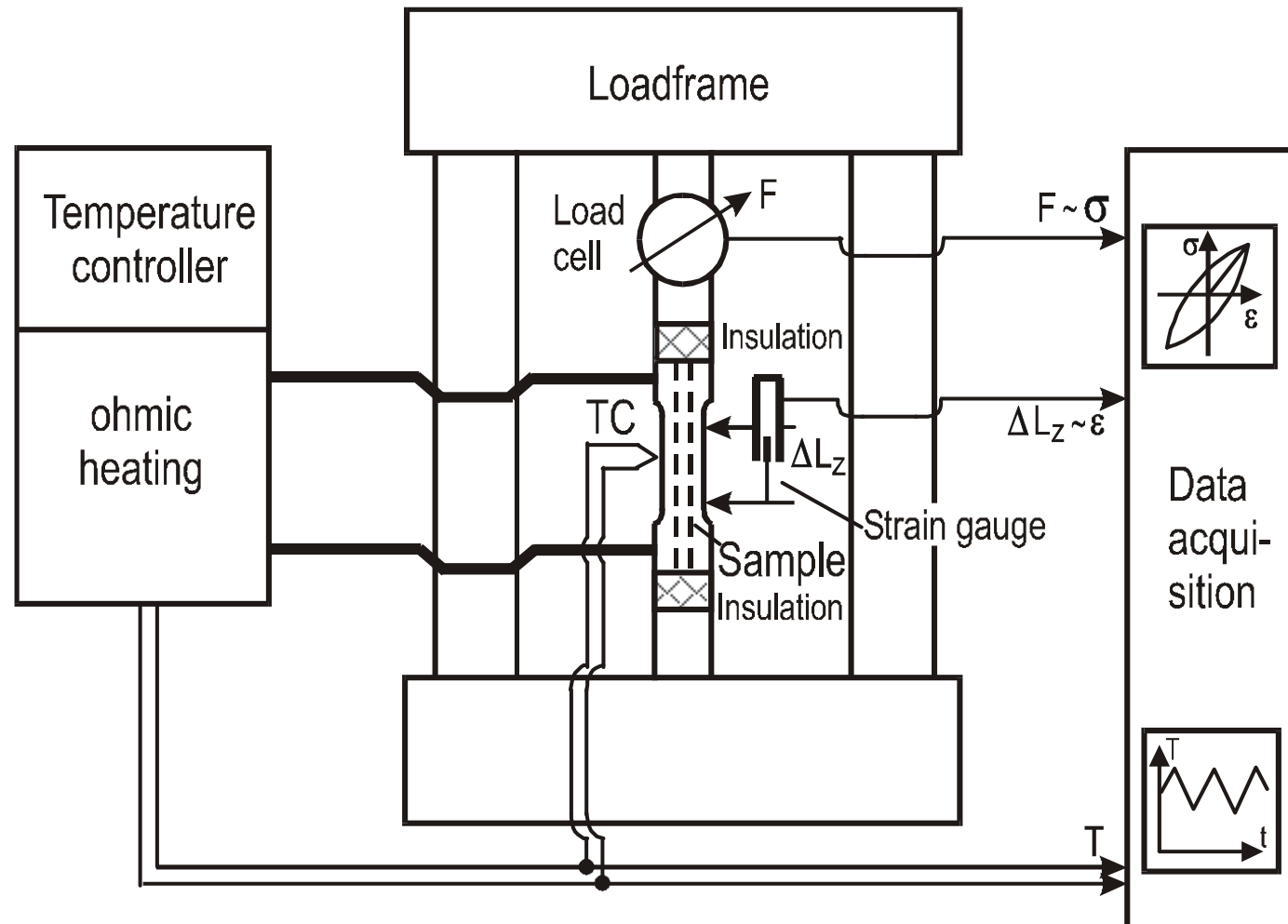
- digital controlled ohmic heating,
- a stiff, three column load frame and
- a personnel computer for feeding load cell and strain gauge as well as for data acquisition.





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## Scheme of Testing Facility





## Parameters of Testing Facility

With „natural cooling“, i.e. without any additional inner gas cooling of the hollow specimen, experiments in the following parameter field can be performed:

Parameter	Range	Remarks
Tmax	100 – 1200°C	Depending of thermocouple
Tmin	RT – 1100°C	Depending of thermocouple
Heating rate	till +20 K/s	Depending of specimen
Cooling rate	till -10 K/s	without inner gas cooling
Dwell time	1 till 1000 s	at Tmin and/or Tmax

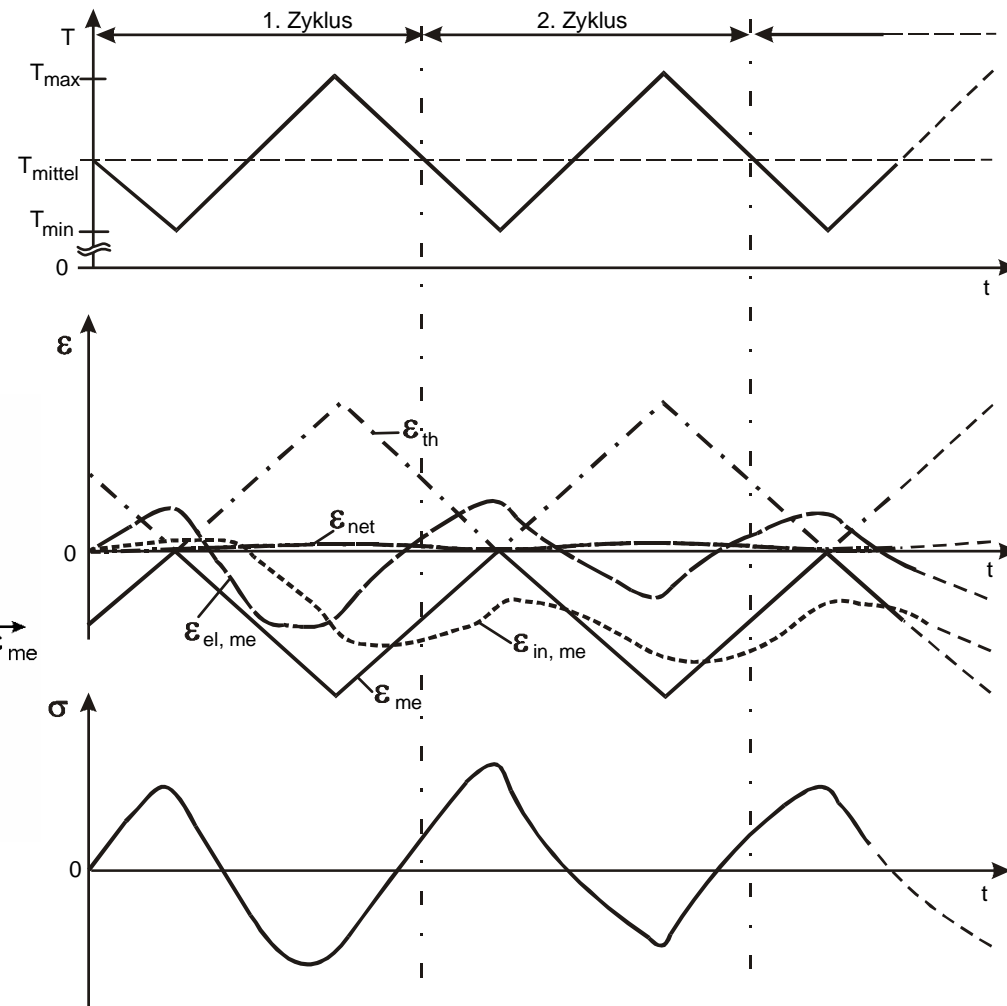
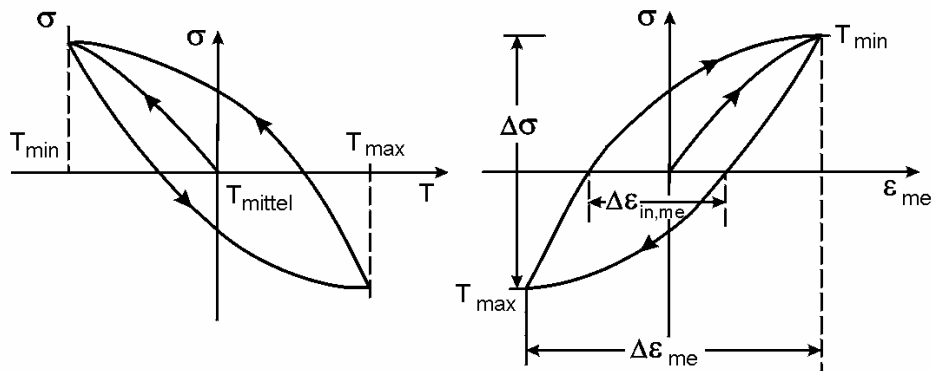




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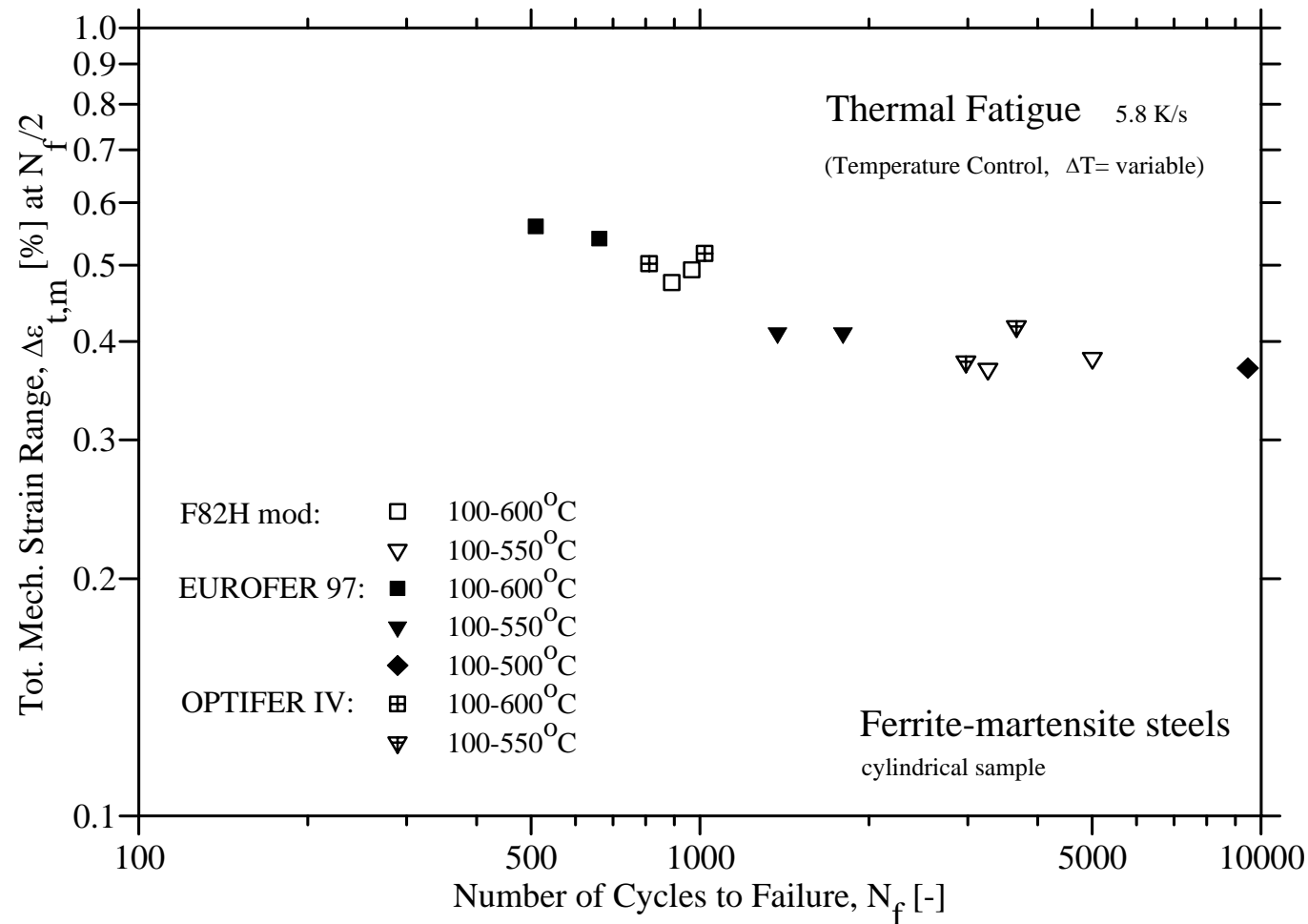
■ Mechanical and microstructural results

Principles of Thermo-mechanical Fatigue





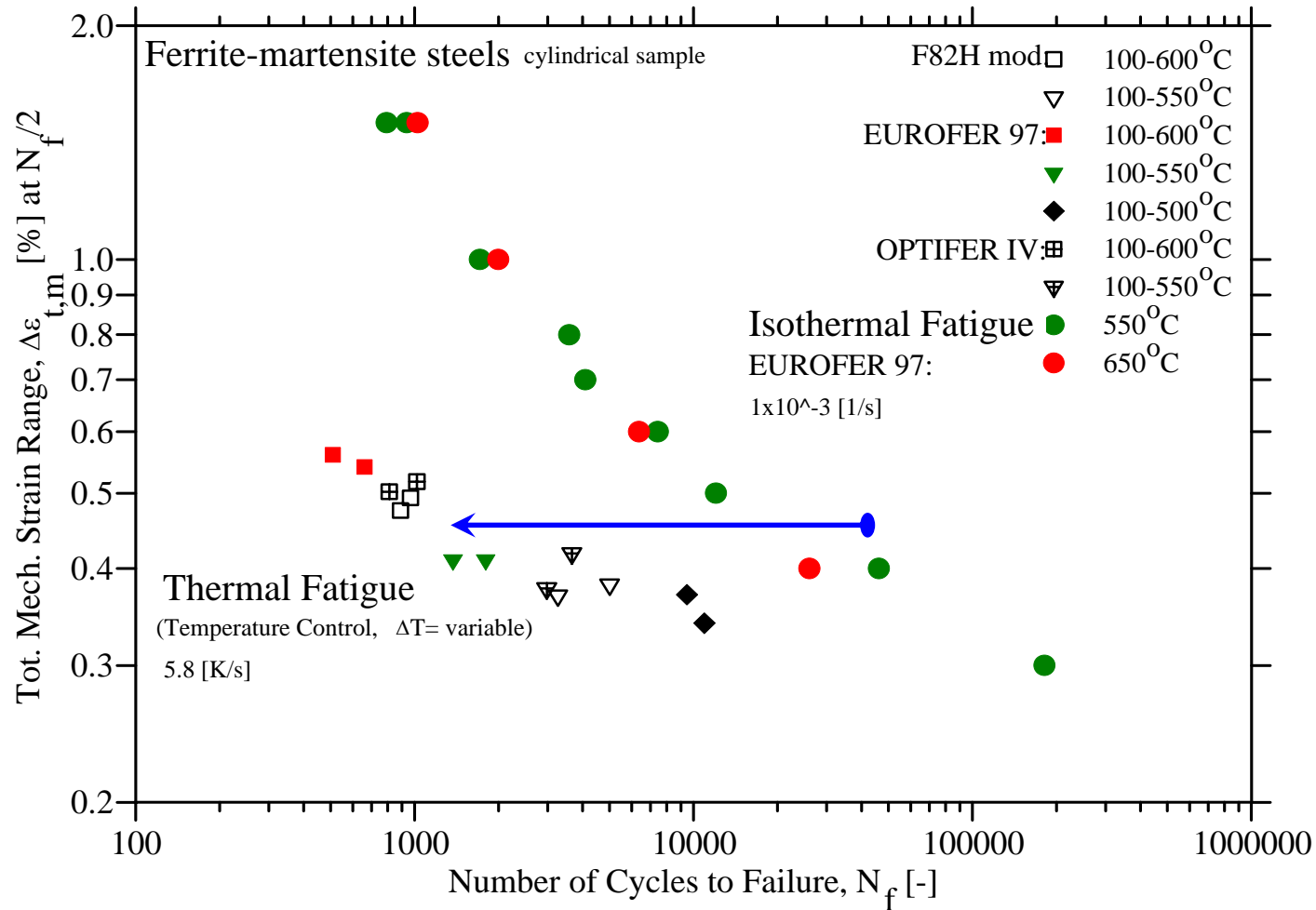
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**Comparison of different materials in the temperature ranges of 100°C to 550°C and 100°C to 600°C.**



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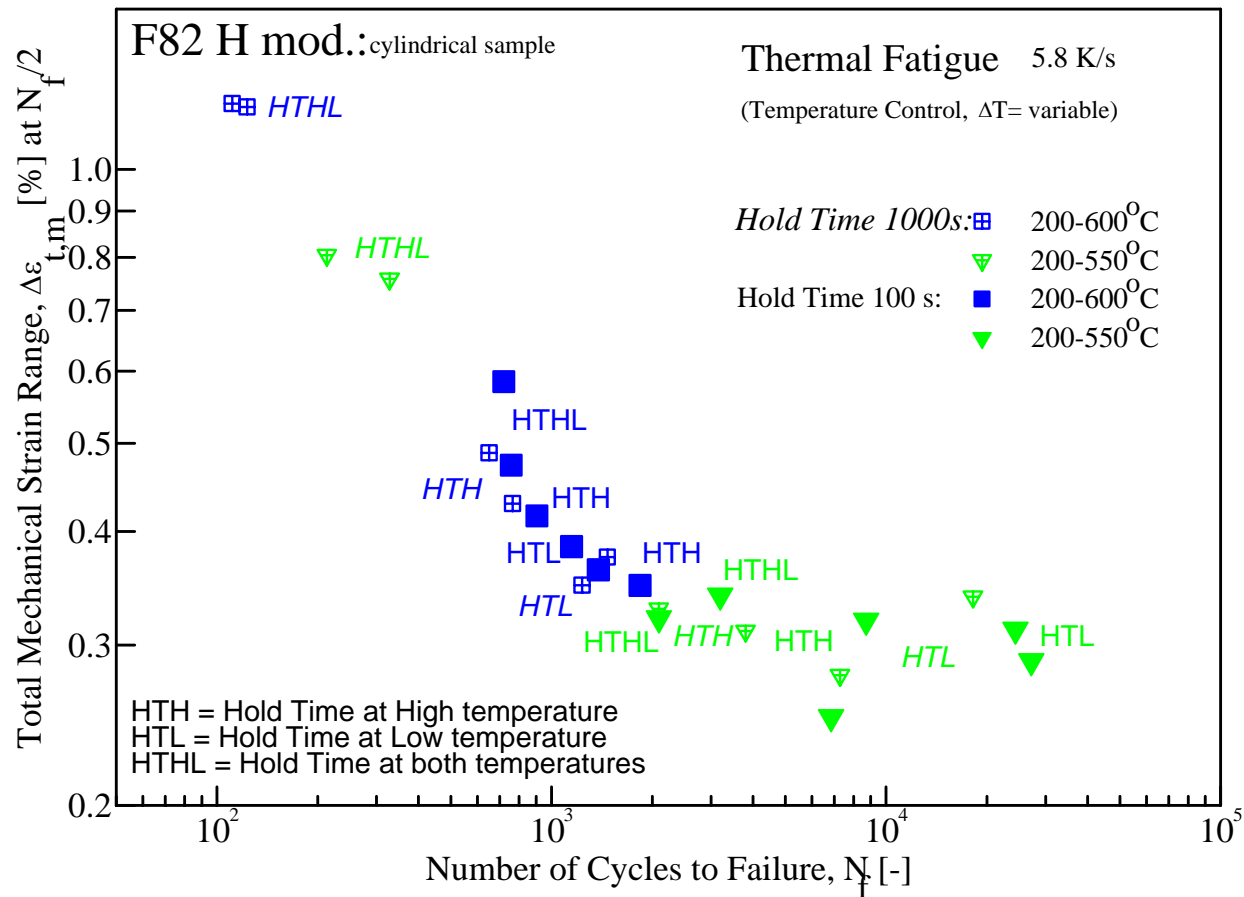


Comparison of Isothermal Fatigue and TMF data at maximum temperatures of 550°C to 650°C.





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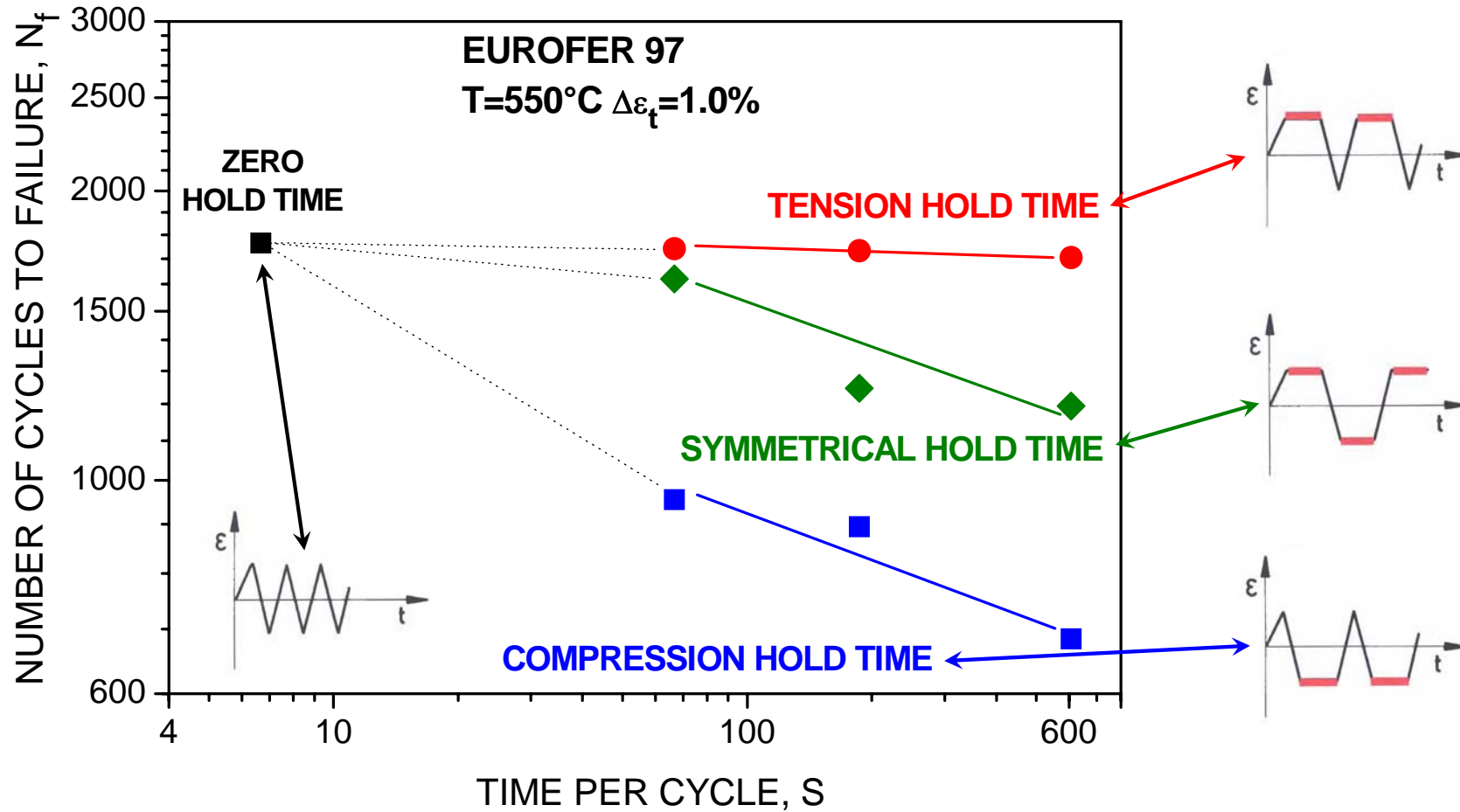


Comparison of different hold times in the temperature ranges of 200°C to 550°C and 200°C to 600°C.





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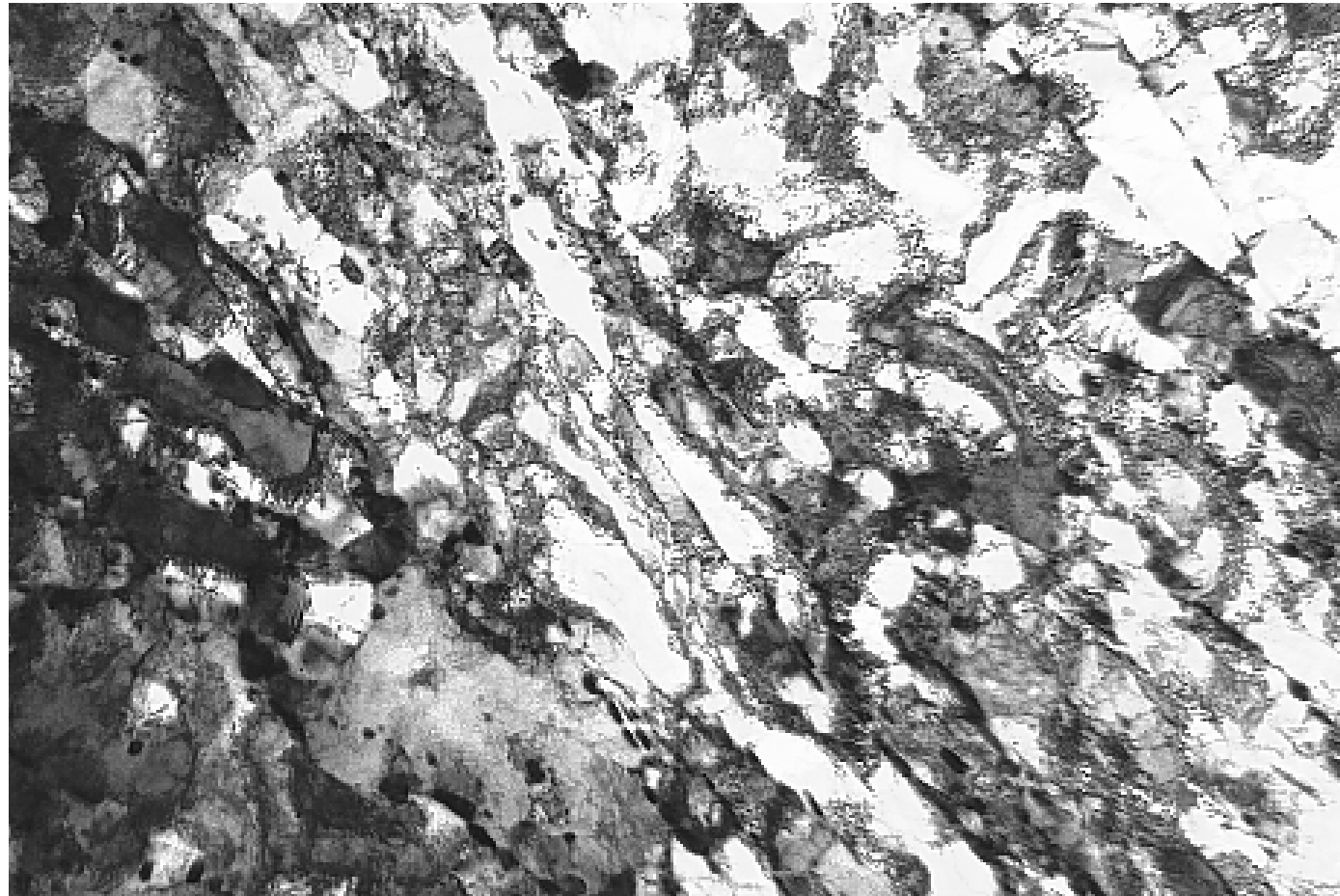
Comparison of different hold times under Isothermal Fatigue at 550°C.



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■ Mechanical and microstructural results

Initial structure of  
tempered  
Ferritic/Martensitic  
steels



1  $\mu\text{m}$



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MANET II:

TMF- test, 200 – 600°C.

micrograph taken at

$N_f = 14296$ .





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MANET II:

TMF- test, 200 – 650°C.

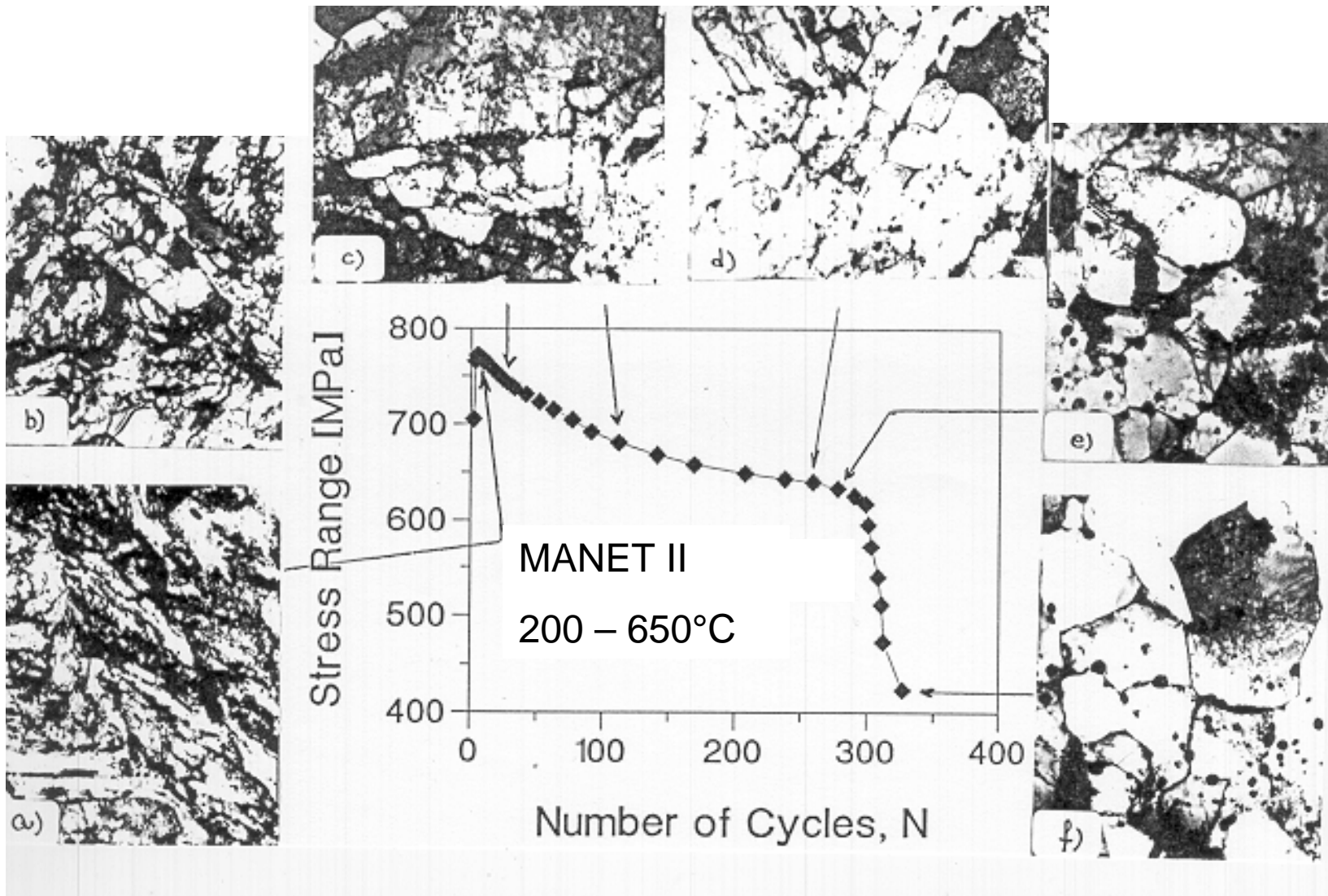
micrograph taken at

$N_f = 1820$ .





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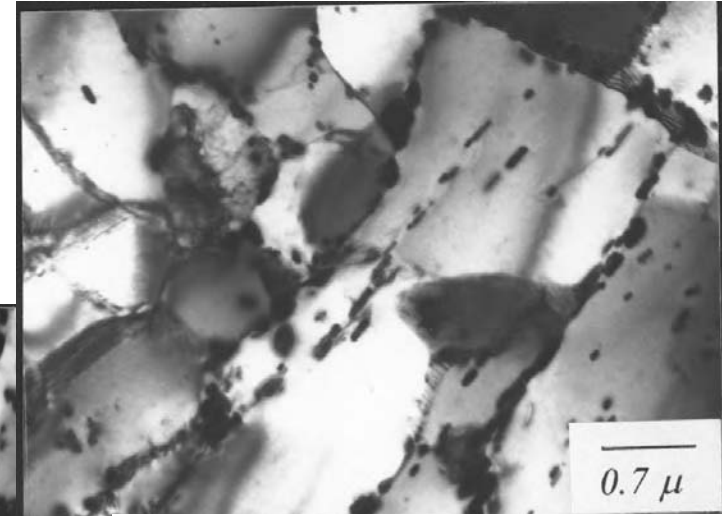
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## Microstructure at isothermal LCF Loading

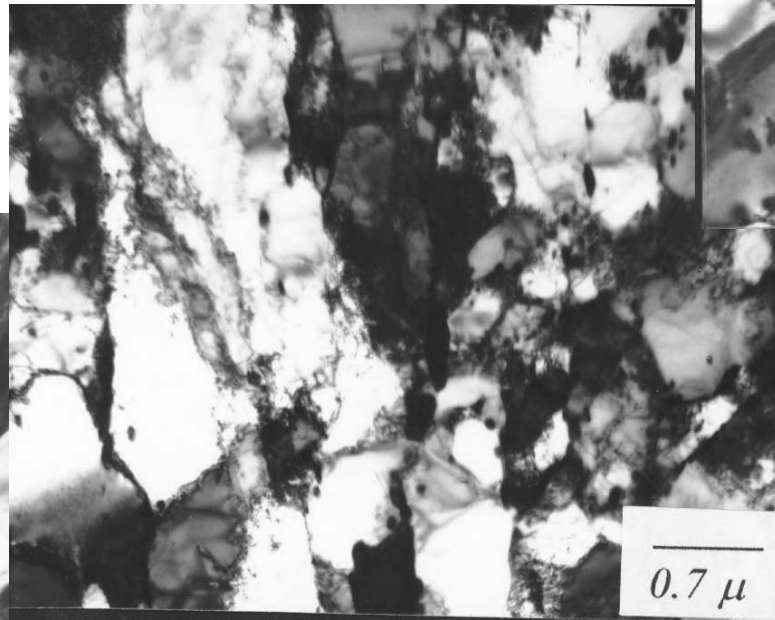
F82H mod. with tempered Martensite at:

0,6 % strain amplitude

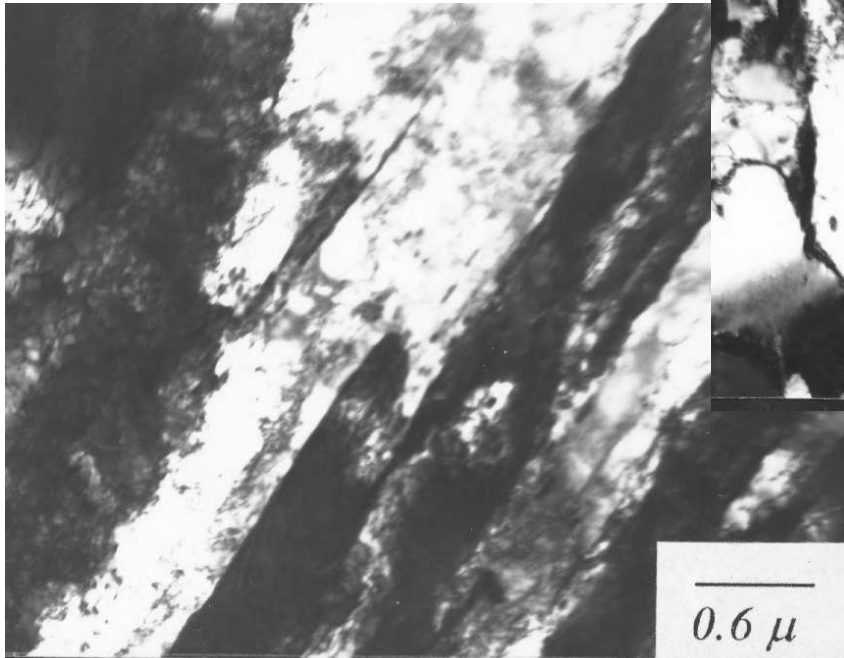
450°C



$N_f = 1800$



1000 Cycles



100 Cycles



## ■ Conclusion

- A TMF experiment at a maximum temperature of 550°C, leads to a number of cycles to failure of about one order of magnitude lower than an isothermal LCF experiment at 550°C.
- At isothermal LCF hold times are most damaging in the compression cycle, whereas at TMF those at both cycles are the most damaging.
- From the microstructural examination no difference in the damage behavior of thermocycled and isothermal strain controlled cycled specimens can be derived.
- Due to the fact that TMF is not standardized, design rules for components as the first wall of a fusion reactor are not able to use these TMF data. Therefore fatigue life still has to be examined in isothermal LCF tests for materials data generation and in TMF for verification of design codes.

Coworker: R. Schmitt and M. Pfeifenroth, as well as A. F. Armas\*, M. Avalos\* and I. Alvarez\*.

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