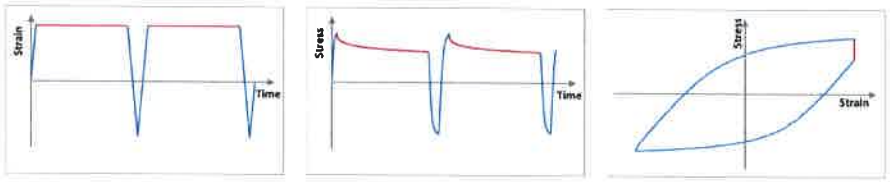
Karlsruher Institut für Technologie

Karlsruhe Institute of Technology

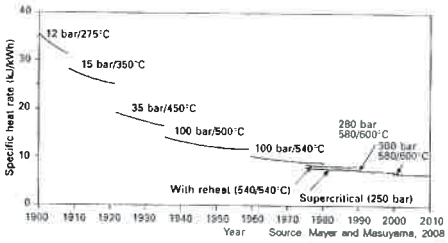
Cyclic softening of ferritic-martensitic steels under creep-fatigue loading

Ulrich Führer, Jarir Aktaa
AMPT 2015 – Madrid, Dec 16th 2015

Institute for Applied Materials – Solid and Biomechanics



Trends in conventional power plants



Source: Volker Quaschning, HTW Berlin

Higher coolant temperatures and pressures

Higher creep stresses, but reduced strength

Additional cyclic loading

Creep-fatigue interaction

Need for enhanced materials and/or improved understanding of the behavior of existing materials

Karlsruher Institut für Technologie

P91 steel

Nominal composition:

	C	Cr	Mo	Si	Mn	Ni	V	Nb	N
wt %	0.1	9.0	1.0	0.4	0.4	0.1	0.2	0.08	0.05

- High creep strength
- Low thermal expansion
- High thermal conductivity
- Good irradiation resistance

- Cyclic Softening

Picture: Kalyanasundaram et al., *Journal of ASTM International*, Vol. 8, No. 4

P91 steel

Nominal composition:

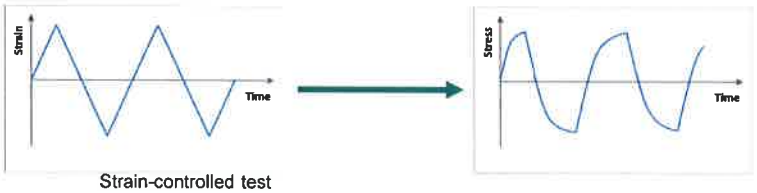
	C	Cr	Mo	Si	Mn	Ni	V	Nb	N
wt %	0.1	9.0	1.0	0.4	0.4	0.1	0.2	0.08	0.05

- Ferritic-martensitic microstructure, mean subgrain size ~400nm
- Laths with very high dislocation density (~$1.8*10^{14}/m^2$)
- Large $M_{23}C_6$ carbides on packet boundaries (100-300nm)
- Smaller MX carbides homogeneously distributed (30-50nm)
- Microstructure tailored to high creep strength

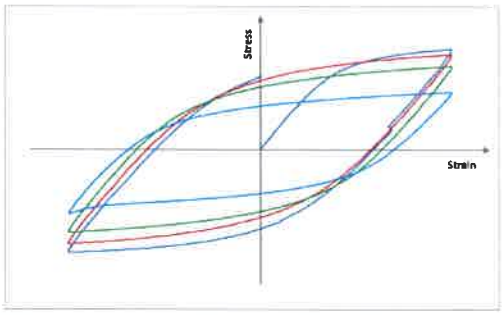
R.L.Klueh, *ORNL/TM-2004/176* (2004)
Fournier et al., *Int. Journal of Plasticity 27* (2011)

Karlsruher Institut für Technologie

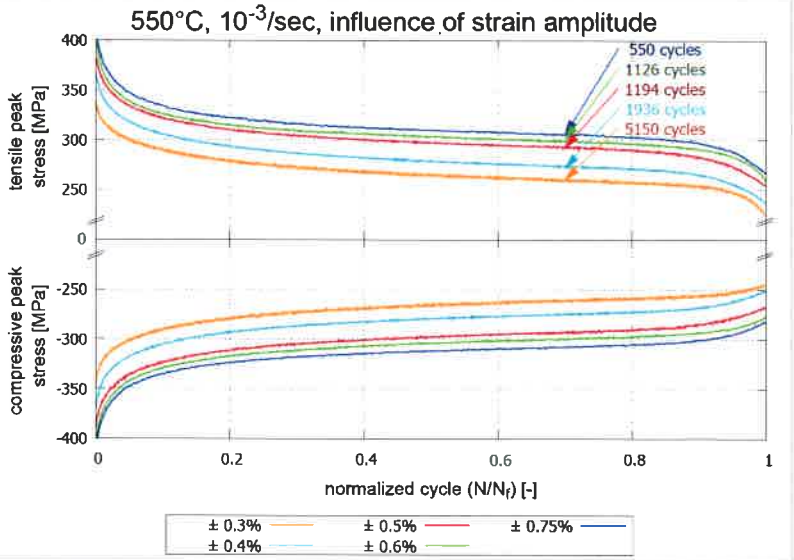
Cyclic Softening



Strain-controlled test



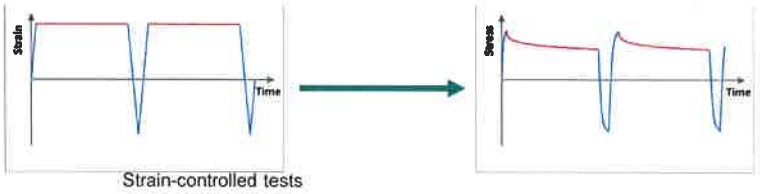
Results of tests without hold time



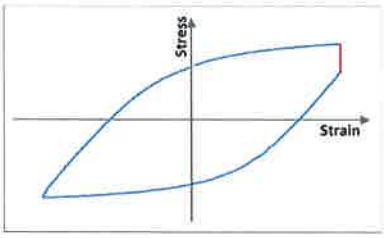
Karlsruher Institut für Technologie

Influence of hold times

What happens if relaxation periods are added to the LCF load path?

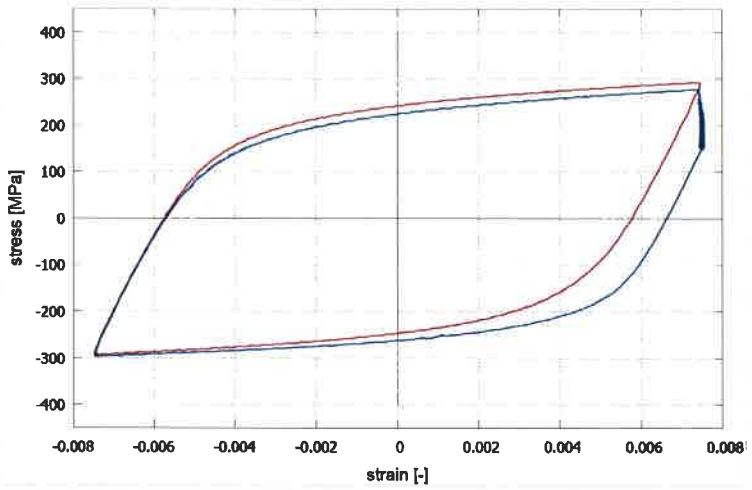


Strain-controlled tests

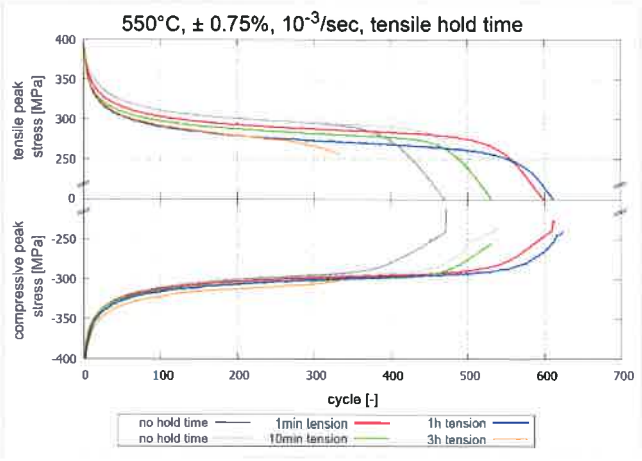


Influence of hold time on hysteresis loops

550°C, ± 0.75%, 10^{-3}/sec, with and without hold time

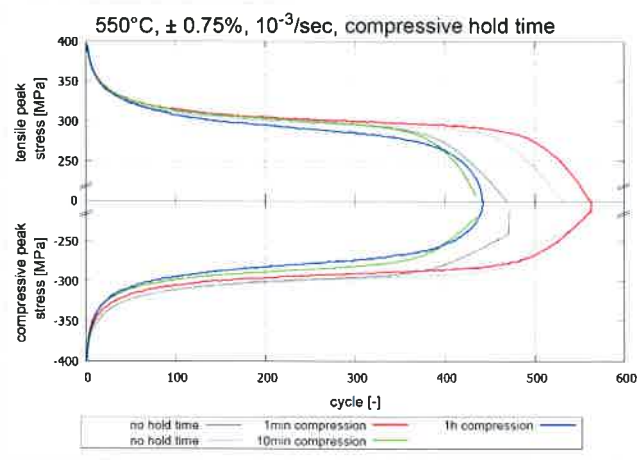


Influence of hold time under tension



➔ Hold time under tension yields additional softening under tension
➔ No additional softening observed for 3h hold time compared to shorter hold times

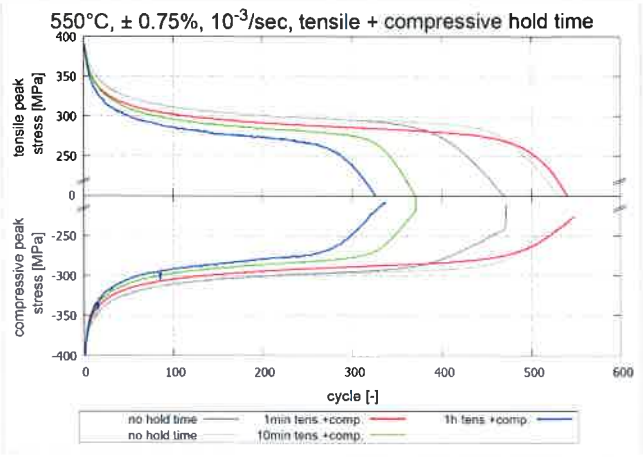
Influence of hold time under compression



➔ Hold time under compression yields additional softening under compression
➔ "Mirror image" of the behavior under tensile hold time

Karlsruher Institut für Technologie

Results of tests with combined hold time



➔ Combined hold time yields softening under tension and compression of the same magnitude as in tests with hold time on one side only

Summary

- P91 steel, and ferritic-martensitic steels in general, are favorable materials for high temperature/high pressure applications in power plants
- Cyclic softening is a major degradation mechanism of ferritic-martensitic steels
- Adding hold periods to the cyclic loading influences the softening and deformation behavior of the subsequent cycles – tensile hold periods yield further reduction in tensile peak stresses and vice versa
- This additional softening is linked to reduction in yield strength in the direction where hold time was introduced
- Slightly increased lifetime was observed for tests with tensile hold time up to 1h
- For each hold time duration, observed lifetime was shorter for compressive and shortest for combined hold times