Karlsruhe Institute of Technology

Institute for Applied Materials

Characterization and modelling of hold time influences on cyclic softening of ferritic-martensitic steel

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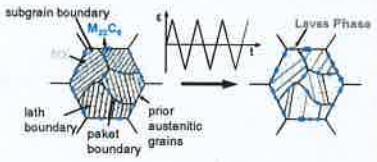
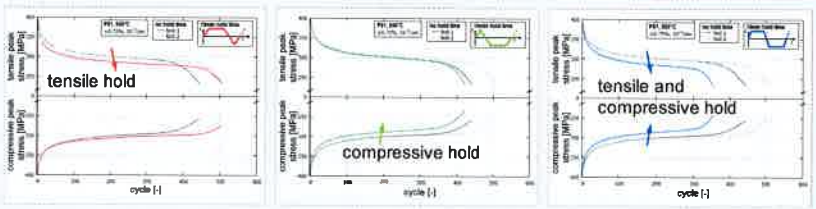
Background

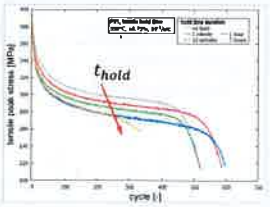
Ferritic-martensitic (F/M) steels are mostly used for high temperature/pressure piping and heat exchangers in steam-based power plants. Additionally, they are a candidate structural material for Generation IV fission power plants. However, microstructural degradation under cyclic loading leads to non-saturating softening of F/M steels[1]. This softening behavior is even more pronounced under combined creep-fatigue loading[2]. A better understanding of this phenomenon is needed to avoid over-conservative design rules as well as for modelling material's behavior.

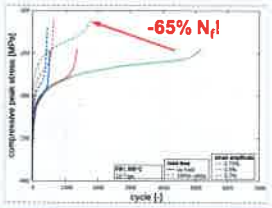


Experimental Results

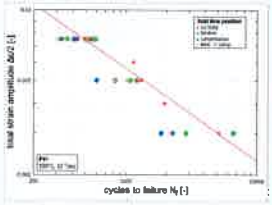
- **Influences on cyclic softening**
  - Hold time position
    - Tensile hold → further reduction of tensile peak stresses
    - Compressive hold → further reduction of compressive peak stresses
    - Combined hold under tension and compression → further reduction of peak stresses under tension and compression
  - Hold time duration
    - Longer hold times → more pronounced softening
    - Saturation after temperature- and strain-dependent hold time duration
  - Strain amplitude
    - Softening effect and influence on lifetime are more pronounced for smaller total strain amplitudes
    - Underestimation of softening effect at typical high-strain lab testing

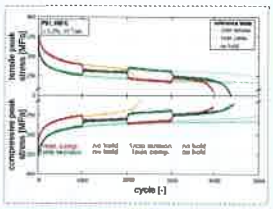






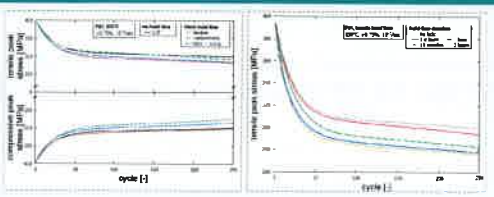
- **Influences on lifetime**
  - Ambiguous influence of tensile holds with slightly longer lifetime for short holds
  - Detrimental influence of compressive holds
- **Tests with multi-step loading**
  - Additional softening due to hold time in pure-cycling segments
  - Softening independent of previous hold position
  - Lifetime independent of hold time order



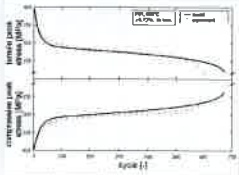


Modelling Results

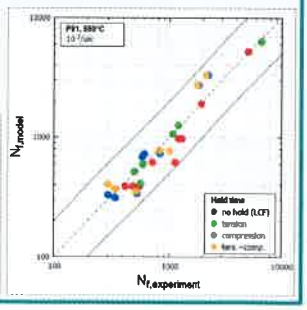
- Extension of the AKTAA AND SCHMITT[3] viscoplasticity model by proper modifications to the evolution equations of cyclic softening
- Coupling between deformation and damage model
- Additional second kinematical hardening term for improved description of mean stress developed due to hold time
- Improved description of cyclic softening by separation of strain-dependent and time-dependent terms into separate evolution equations



Modelling of softening with hold time



Modelling of lifetime for hold time tests



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References
1. R.L. Klueh and D.R. Harries. High-Chromium Ferritic and Martensitic Steels for Nuclear Applications. American Society for Testing and Materials, 2001.
2. U. Führer und J. Aktaa. Creep-fatigue interaction and cyclic softening of ferritic-martensitic steels. Proc. of Baltica X, VTT Technology 261, 2016.
3. J. Aktaa and R. Schmitt. High temperature deformation and damage behavior of RAFM steels under low cycle fatigue loading: Experiments and modeling. Fusion Engineering and Design 81, pp. 2221-2231, 2006.

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