TAMPERE UNIVERSITY OF TECHNOLOGY

A unified LCF-HCF model based on continuum mechanics

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Introduction - fatigue models

Problems in fatigue analyses:

- Low-cycle- and high-cycle -fatigue regimes are treated separately
- Mostly based on well defined cycles.
- Multiaxiality.

A more fundamental approach for HCF based on *evolution equations* proposed by Ottosen, Stenström and Ristinmaa in IJF 2008.

In this study this idea is combined with a plasticity model to obtain a unified model.

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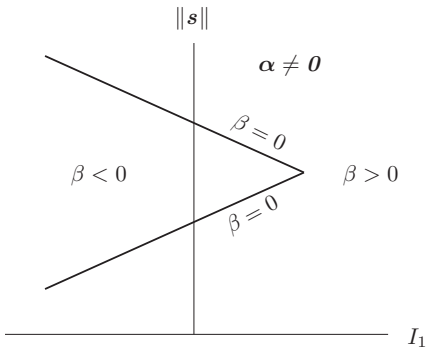
Evolution equation based HCF model

Key ingredients are:

Endurance surface

$$\beta(\boldsymbol{\sigma}, \{\boldsymbol{\alpha}\}; \text{parameters}) = 0,$$

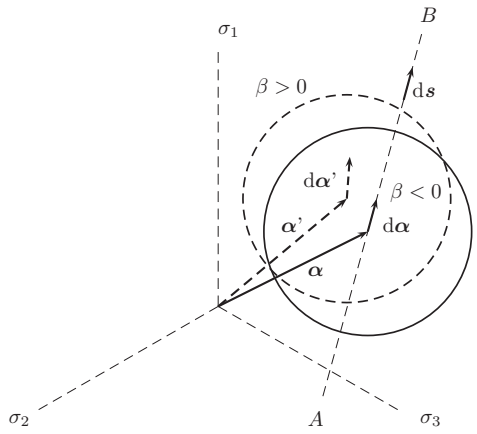


evolution equations for damage D and the internal variables $\{\boldsymbol{\alpha}\}$

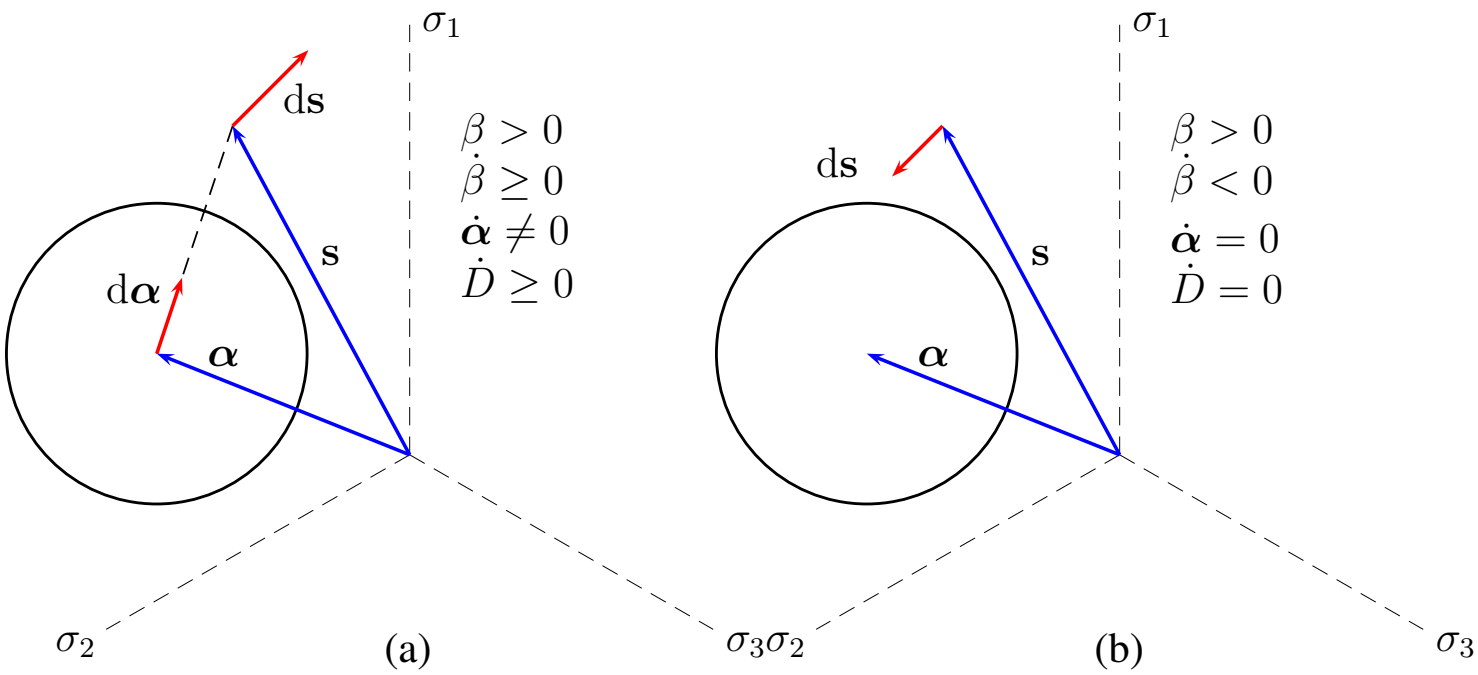
$$\{\dot{\alpha}\} = \{\boldsymbol{G}\}(\boldsymbol{\sigma}, \{\boldsymbol{\alpha}\})\dot{\beta},$$

and

$$\dot{D} = g(\beta, D)\dot{\beta}.$$



Conditions for evolution



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Endurance surface

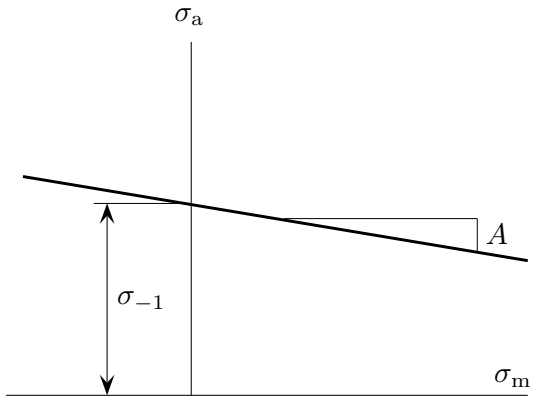
Original formulation by Ottosen et al. for isotropic fatigue

$$\beta = \frac{1}{\sigma_{-1}}\left[\sqrt{3\bar{J}_2} + AI_1 - \sigma_{-1}\right] = 0,$$

where $\bar{J}_2 = \frac{1}{2}\mathrm{tr}\,(\boldsymbol{s}-\boldsymbol{\alpha})^2$, $\quad I_1 = \mathrm{tr}\,\boldsymbol{\sigma}$, $\quad A = \sigma_{-1}/\sigma_0 - 1$, and

$$\sigma_{-1} = \sigma_{\mathrm{af},R=-1}$$

$$\sigma_0 = \sigma_{\mathrm{af},R=0}$$



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LCF-HCF approach

Evolution equation for the $\boldsymbol{\alpha}$-tensor

$$\dot{\boldsymbol{\alpha}} = C(\boldsymbol{s} - \boldsymbol{\alpha})\dot{\beta}$$

and for damage

$$\dot{D} = K \exp[L\exp(-\xi\bar{\varepsilon}_{\mathrm{p}})\beta + M\langle \mathrm{sgn}(f)\rangle\bar{\varepsilon}_{\mathrm{p}}]\dot{\beta}$$

Plasticity model based on Armstrong-Frederick model

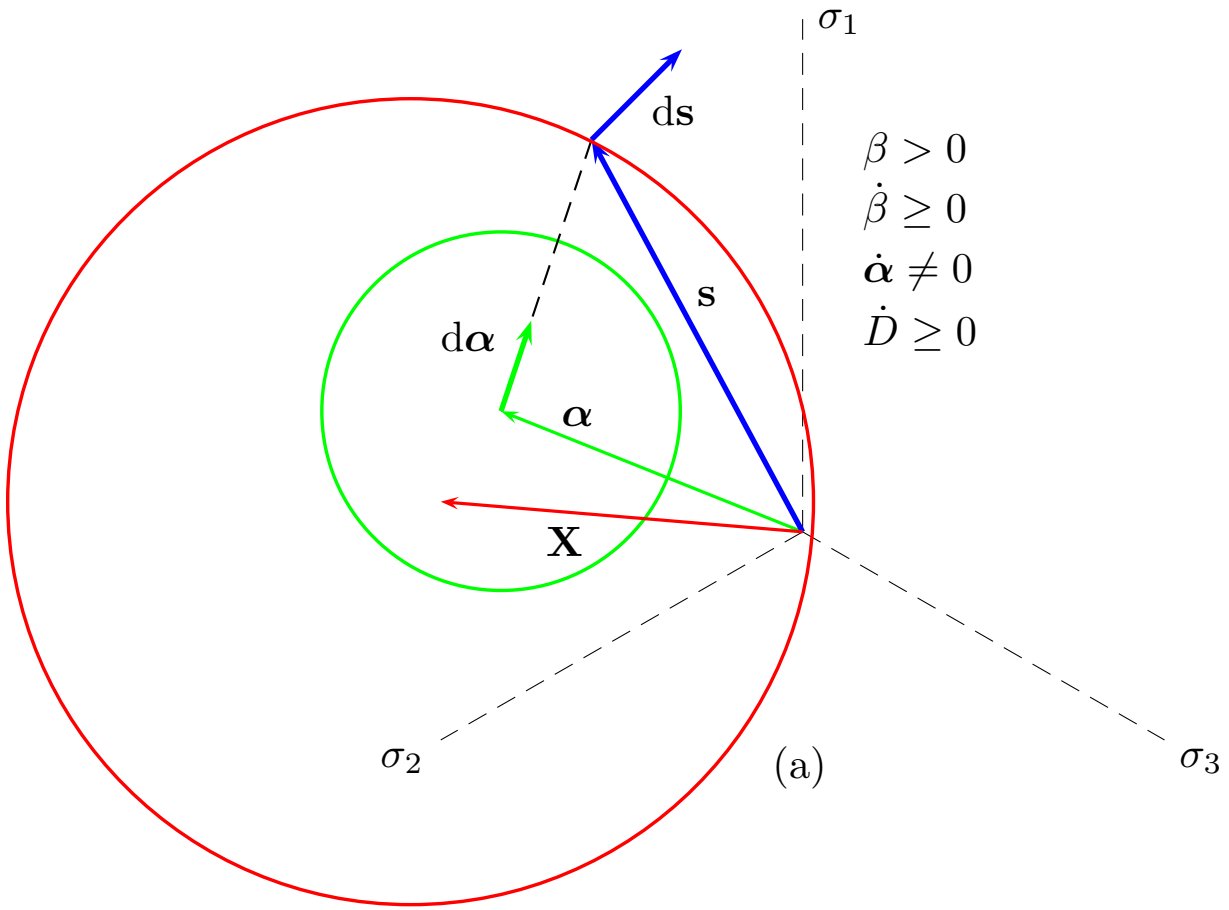
$$f(\boldsymbol{\sigma}, \boldsymbol{X}, R) = \sqrt{\tfrac{3}{2}(\boldsymbol{s} - \boldsymbol{X}) : (\boldsymbol{s} - \boldsymbol{X})} - (\sigma_{\mathrm{y}} + R) = 0$$

$$\dot{R} = \gamma R_{\infty}\left(1 - R/R_{\infty}\right)\dot{\bar{\varepsilon}}_{\mathrm{p}}$$

$$\dot{\boldsymbol{X}} = \tfrac{2}{3}X_{\infty}\dot{\boldsymbol{\varepsilon}}_{\mathrm{p}} - \gamma\dot{\bar{\varepsilon}}_{\mathrm{p}}\boldsymbol{X}$$

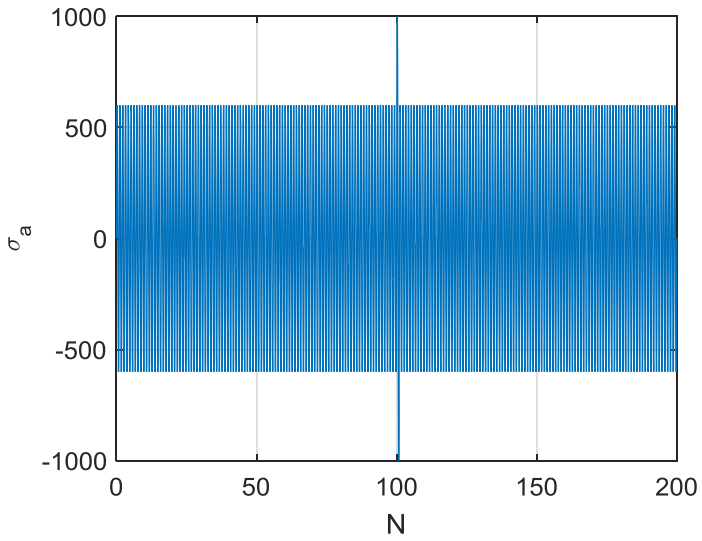
$$\dot{\boldsymbol{\varepsilon}}_{\mathrm{p}} = \dot{\lambda}\frac{\partial f}{\partial \boldsymbol{\sigma}}$$

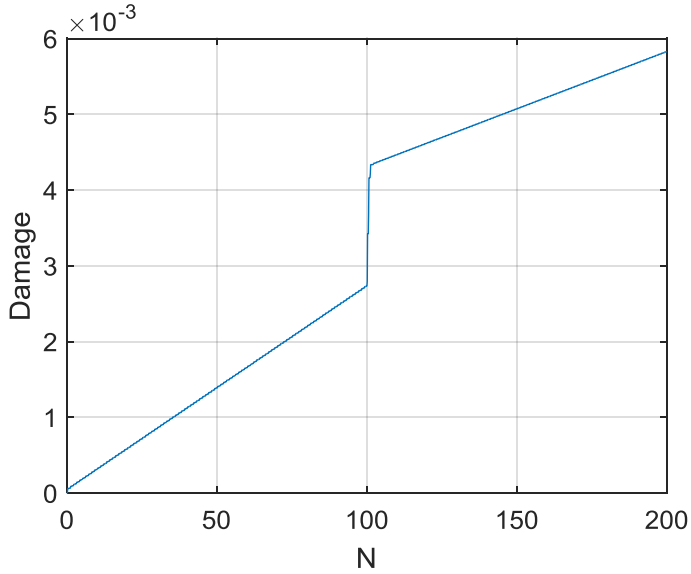
Illustration in deviatoric plane



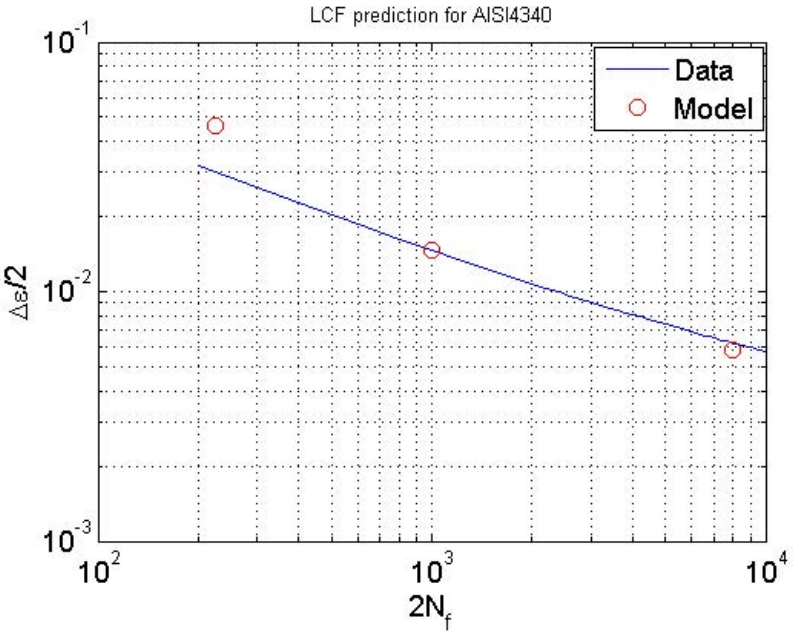
Some results

Effect of overstress in fatigue damage evolution





$\Delta\varepsilon$-N curve in LCF-regime - AISI 4340



ASTM Handbool (Coffin-Manson + Basquin):

$$\frac{\Delta\varepsilon}{2} = 0.58(2N_\mathrm{f})^{-0.57} + 0.0062(2N_\mathrm{f})^{-0.09}$$

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Concluding remarks and future work

- Continuum based Unified LCF-HCF model
- Multiaxial, applicable to arbitrary loading history
- *Better plasticity model*
- *Parameter estimation*
- *Micromechanical motivation of the evolution equations.*

Watercolor by
Pia Erlandsson

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Thank you for your attention!