Thermo-Mechanical Finite Element Simulation and Fatigue Life Assessment of a Copper Mould

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ABSTRACT

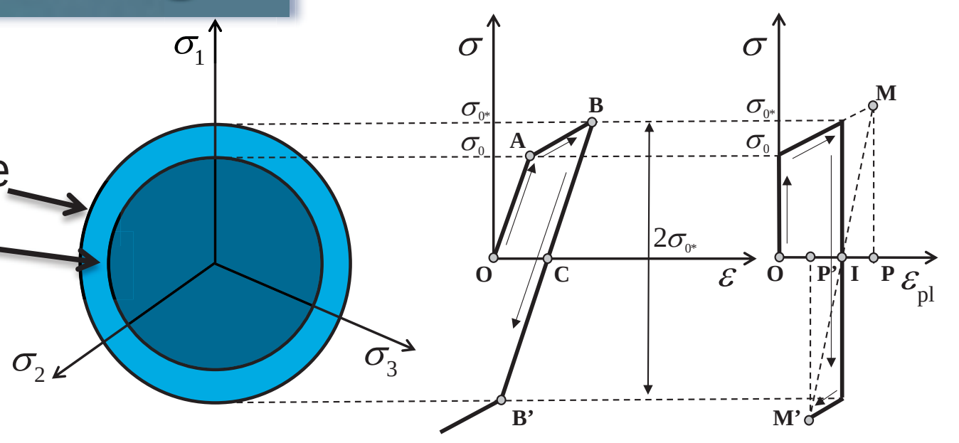
This work describes the thermo-mechanical analysis of a copper mould for continuous steel casting. During the continuous casting process, the molten steel passes through a water cooled mould. The inner part of the component is subjected to a huge thermal flux. Consequently large temperature gradients occur across the mould, especially in the region near to the meniscus. As a result, considerable stresses and plastic strains are induced, which leads to deformations and thermal cracks at the inner surface. In order to assess the fatigue life of the copper mould, a three-dimensional finite element model is analyzed in dependence with different material models (combined nonlinear kinematic and nonlinear isotropic, linear kinematic, stabilized and accelerated material models). Material coefficients for adopted material models and fatigue curves are estimated from isothermal low cycle experimental fatigue data at different temperature levels (20 ºC, 250 ºC and 300 ºC). The fatigue life is also assessed depending on different material models.

Modelling

Hardening models - define evolution of the yield surface

Isotropic hardening

Linear

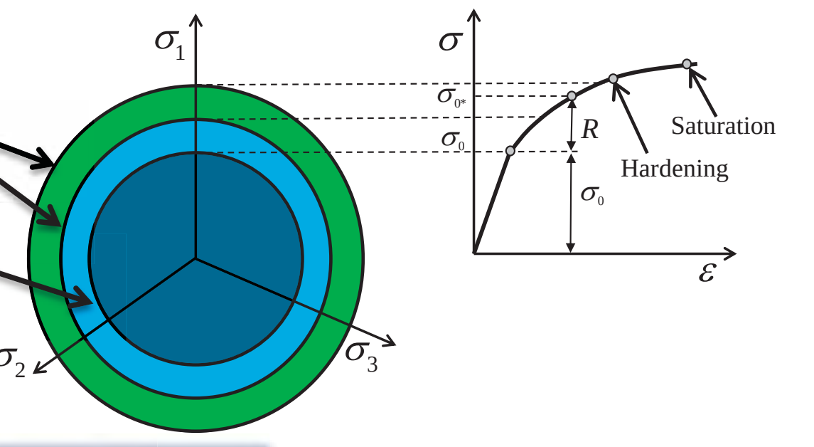


Subsequent yield surface

Initial yield surface

$$R = R(\varepsilon_{pl,acc})$$

Nonlinear



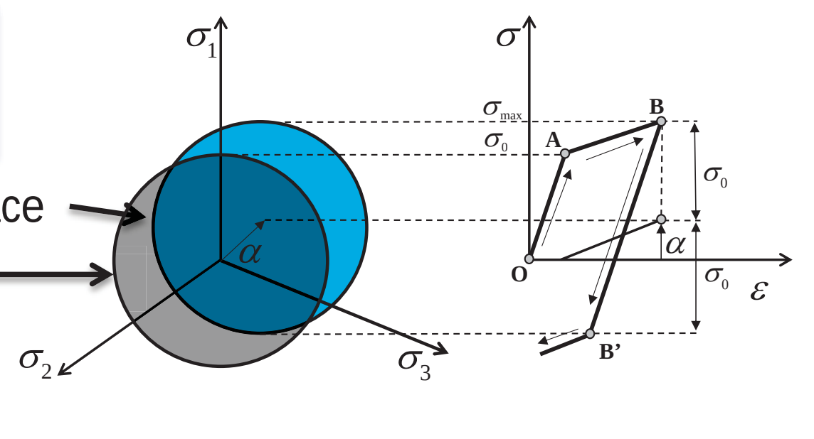
Subsequent, expanded yield surface after plastic deformation

Initial yield surface

$$R = \sigma_0 + R_\infty\left[1-\exp\left(-b\varepsilon_{pl,acc}\right)\right]$$

Kinematic hardening

Linear
(Prager)

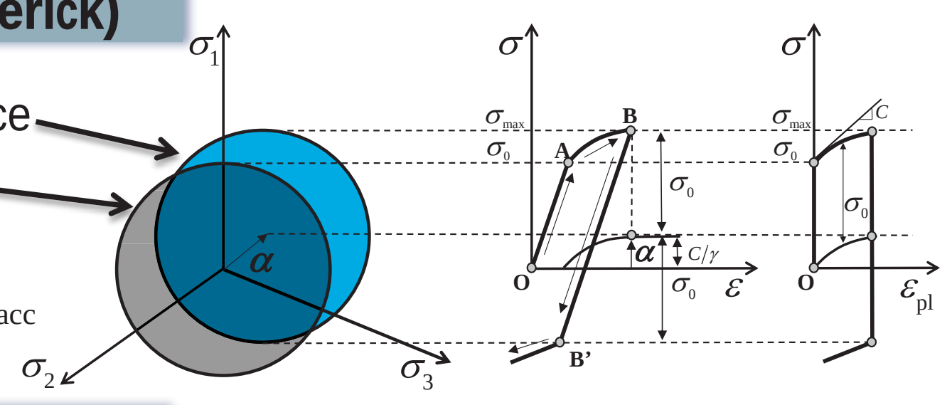


Subsequent yield surface

Initial yield surface

$$\mathrm{d}\boldsymbol{\alpha} = \frac{2}{3}C\mathrm{d}\boldsymbol{\varepsilon}_{pl}$$

Nonlinear
(Armstrong & Frederick)



Subsequent yield surface

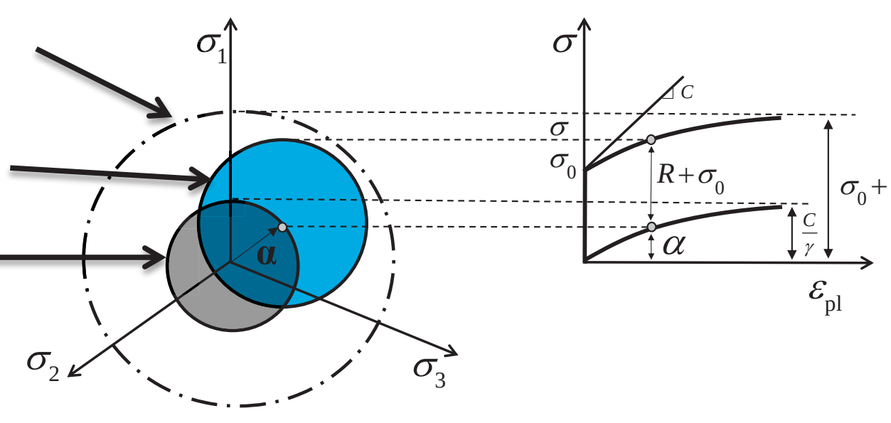
Initial yield surface

$$\mathrm{d}\boldsymbol{\alpha} = \frac{2}{3}C\mathrm{d}\boldsymbol{\varepsilon}_{pl} - \gamma\boldsymbol{\alpha}\mathrm{d}\varepsilon_{pl,acc}$$

Nonlinear
(Chaboche)

$$\boldsymbol{\alpha} = \sum_i \boldsymbol{\alpha}_i \quad \mathrm{d}\boldsymbol{\alpha}_i = \frac{2}{3}C_i\mathrm{d}\boldsymbol{\varepsilon}_{pl} - \gamma_i\boldsymbol{\alpha}\mathrm{d}\varepsilon_{pl,acc}$$

Combined hardening
(Nonlinear Iso. + Nonlinear Kin.)



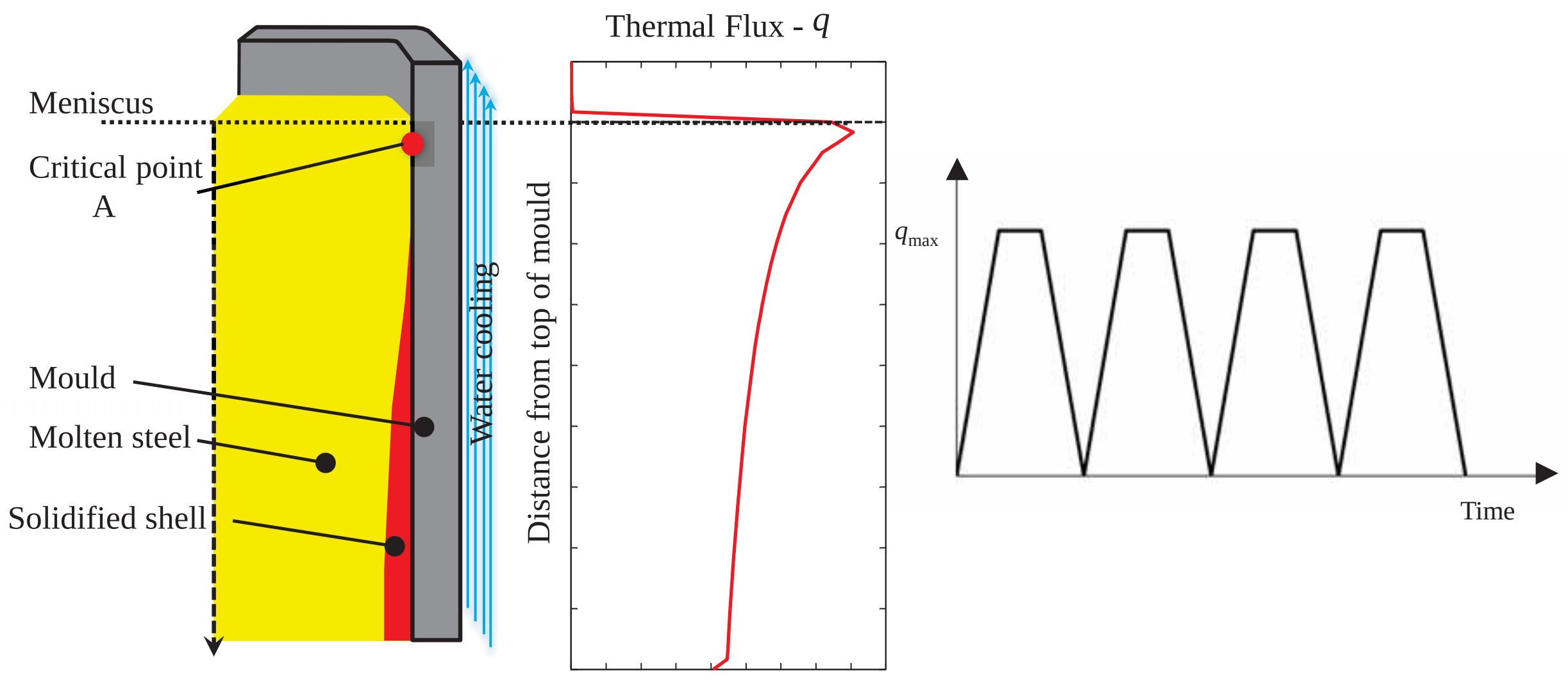
Limiting yield surface

Current yield surface

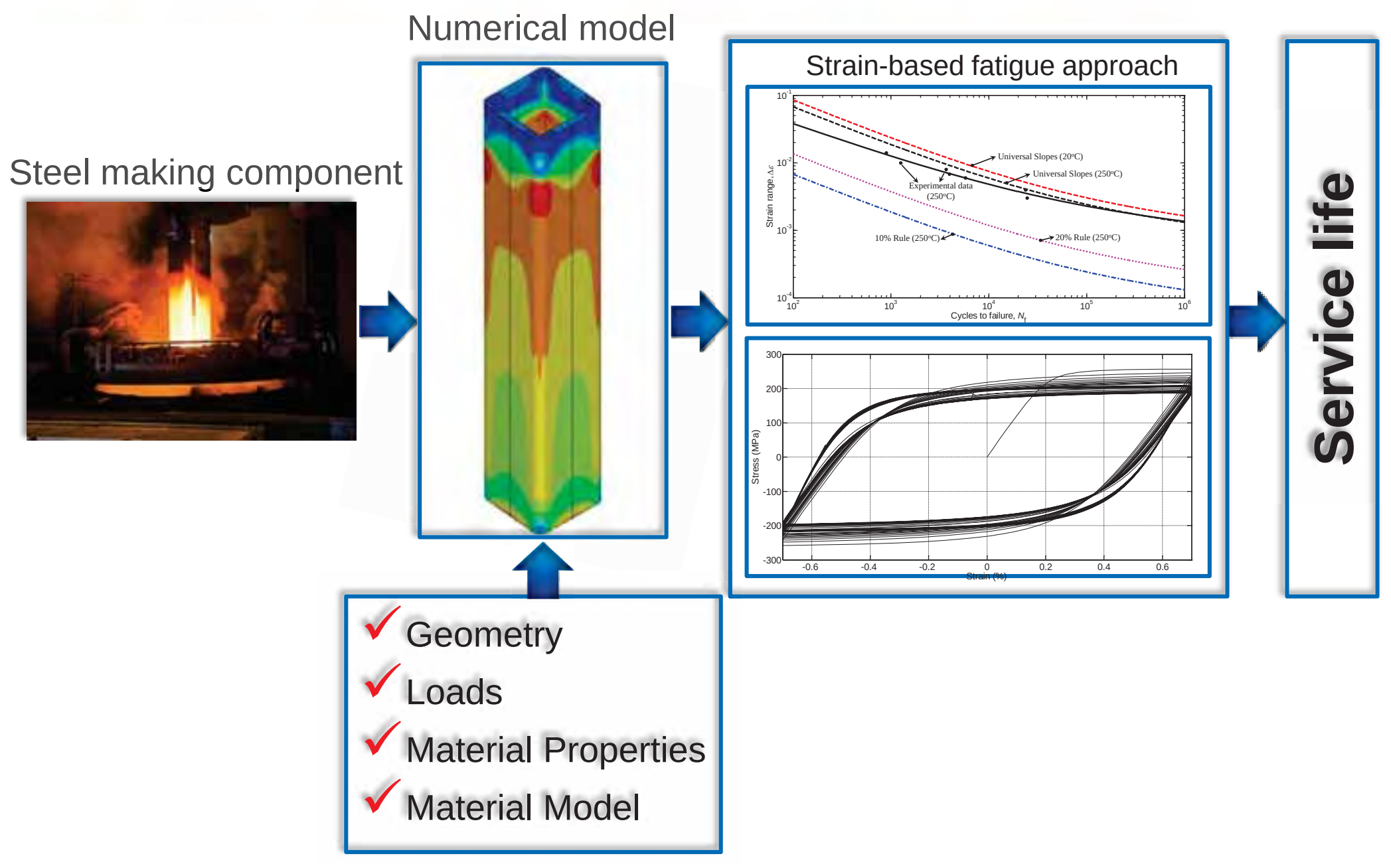
Limiting value of $\boldsymbol{\alpha}$

Description of component

The molten steel flows from the upper part of the mould to the bottom part where the steel exits with a thin solidified shell. During the solidification of the steel, a huge thermal flux, q, passes from the molten steel to the inner surface of the mould, which is then subjected to high temperatures. The thermal flux varies according to a loading condition called macro cycle. Macro cycle is when the plant is switched on and the thermal flux increases until reaching the maximum value q_{max}, while thermal flux is absent once the plant is switched off.



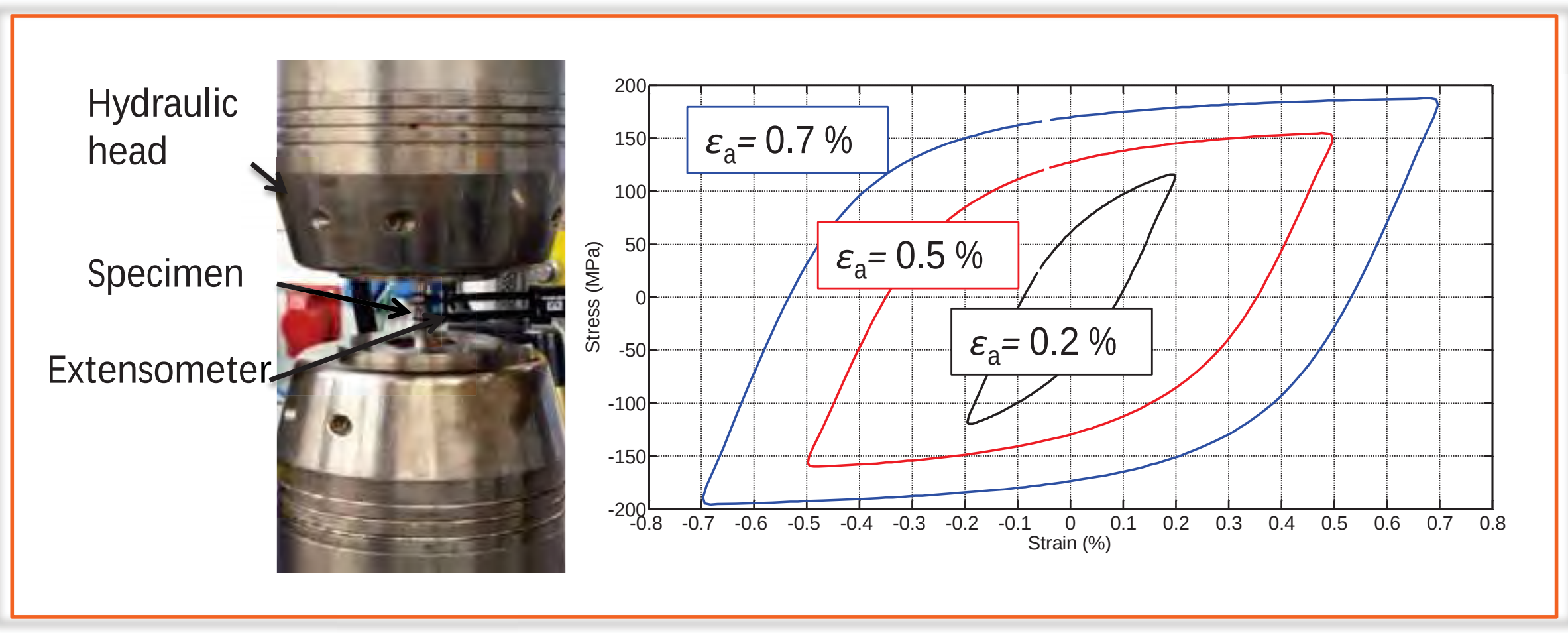
Structural integrity and FEM



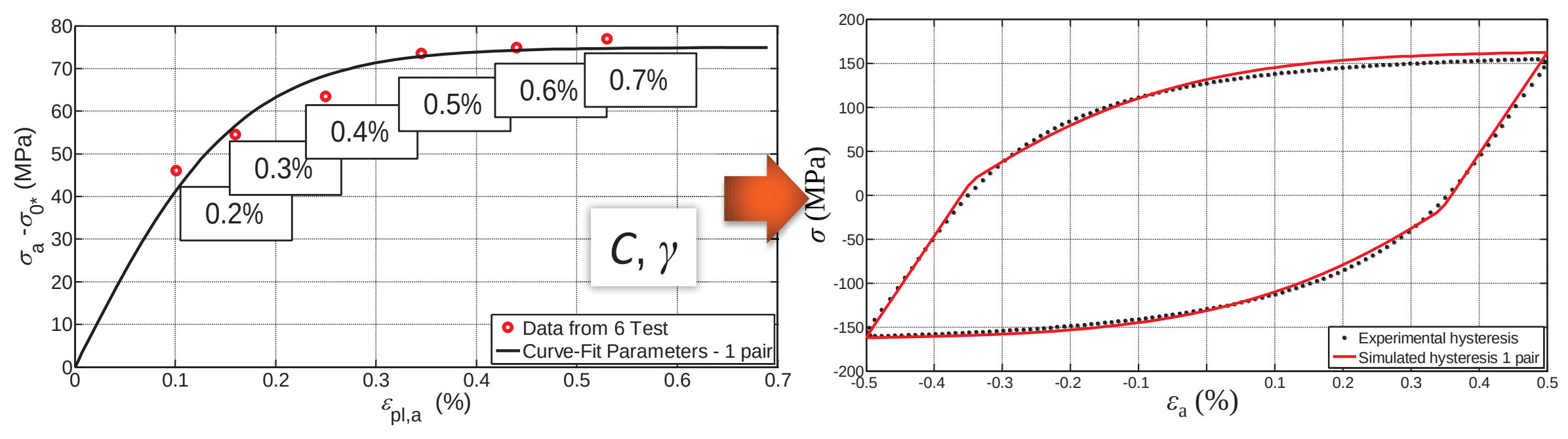
- ✓ Geometry
- ✓ Loads
- ✓ Material Properties
- ✓ Material Model

Calibration of material models

Low cycle fatigue tests are performed for CuAg material at 20ºC, 250ºC and 300ºC and at different strain amplitudes, ε_a.



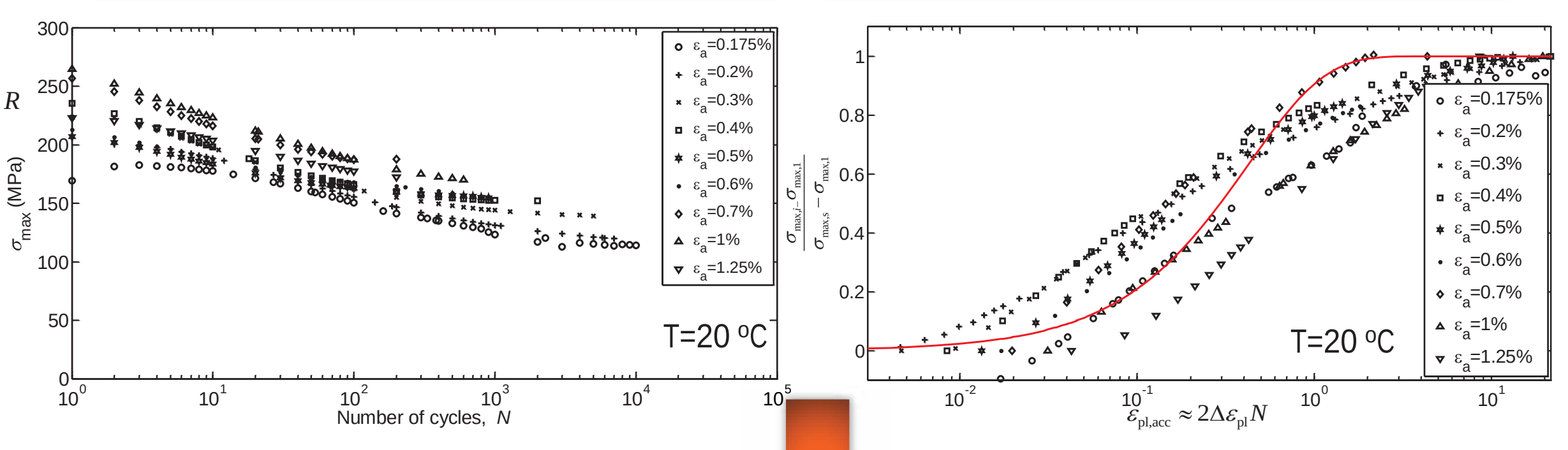
1) Parameters identification for nonlinear kinematic model



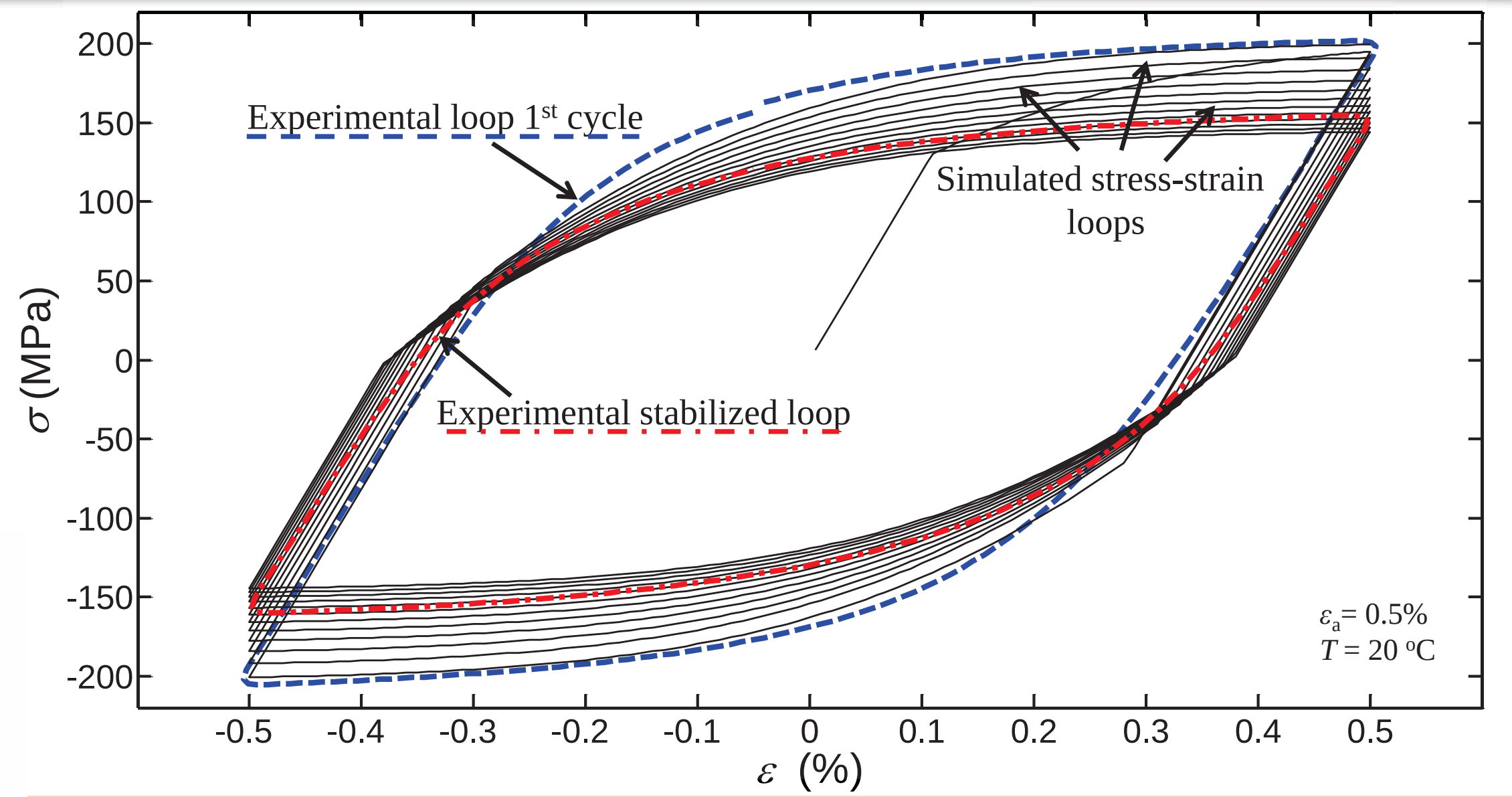
2) Parameters identification for nonlinear isotropic model

Estimation of material parameter R_∞

Estimation of material parameter b



Experimental vs. simulated stress-strain loops



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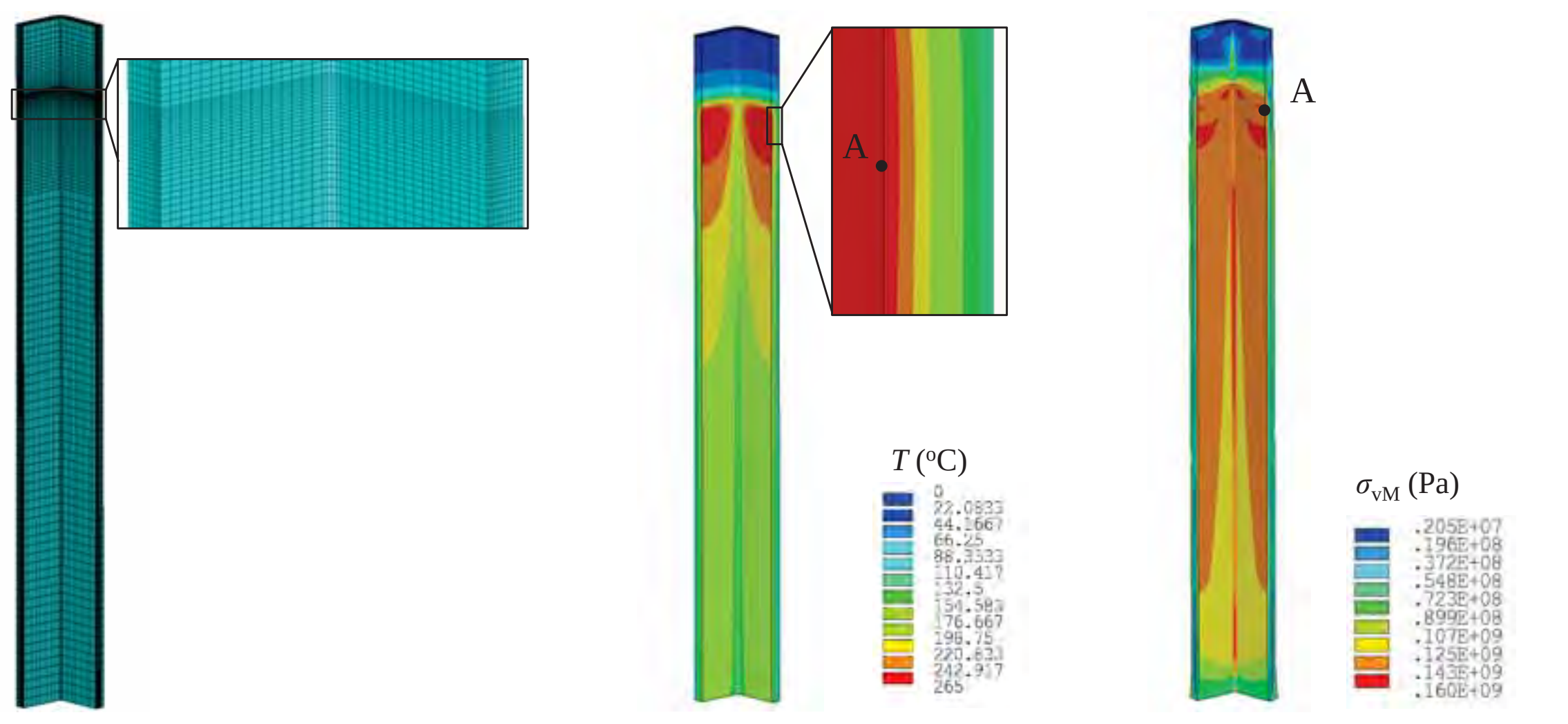
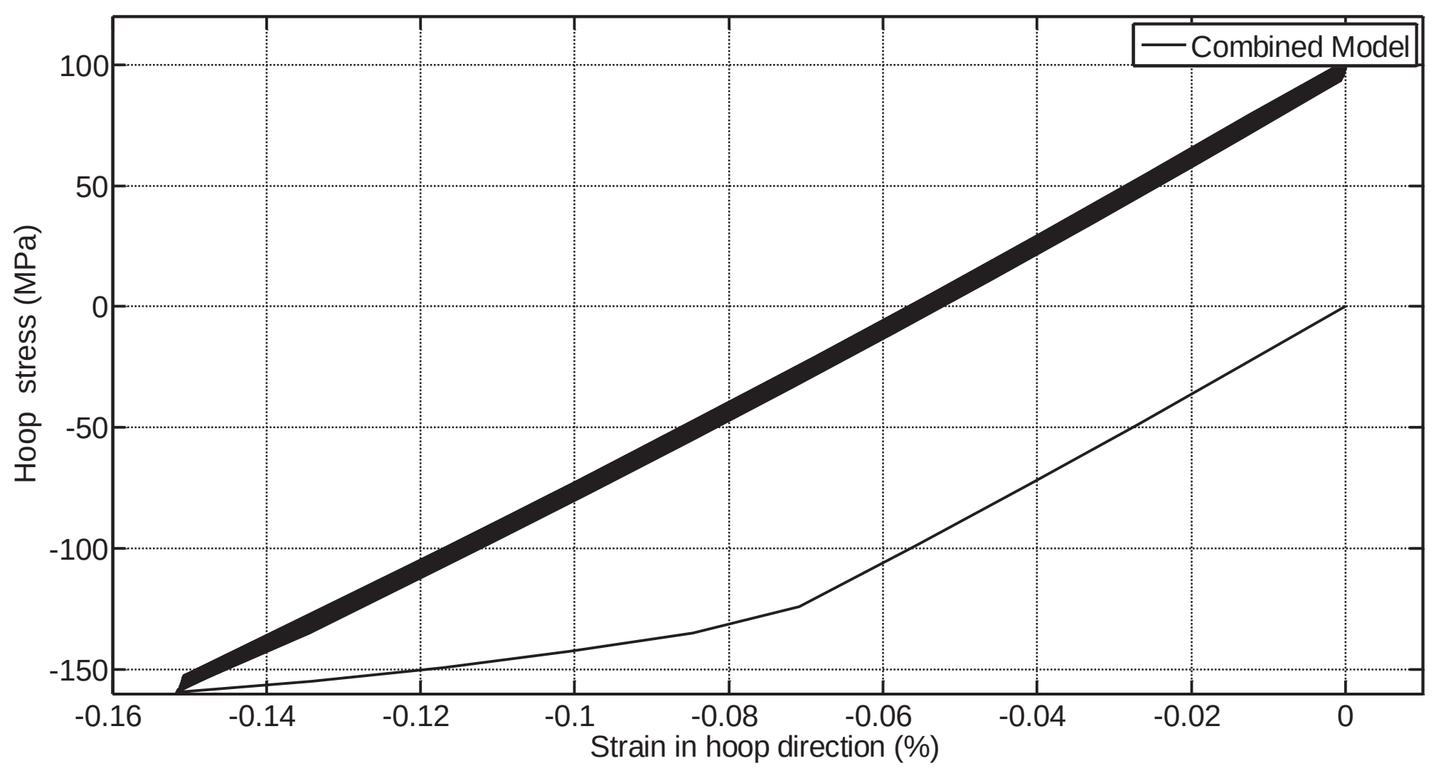
- Chaboche J.L., *Time-independent constitutive theories for cyclic plasticity,*Int. J. Plasticity, 2(2), 149-188, 1986
- Chen W.F.,Han D.J., *Plasticity for Structural Engineers,* Springer-Verlag, New York,1988

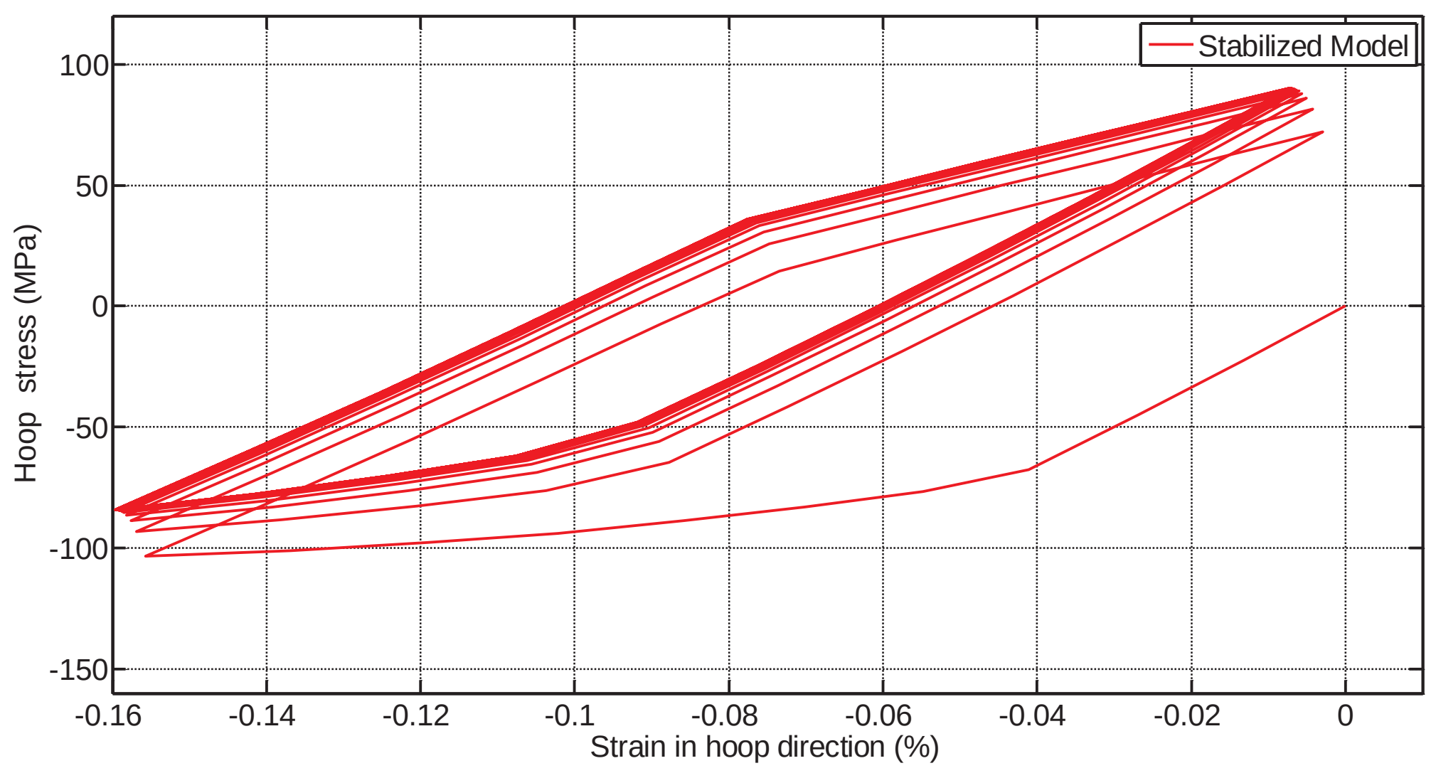
Numerical simulation

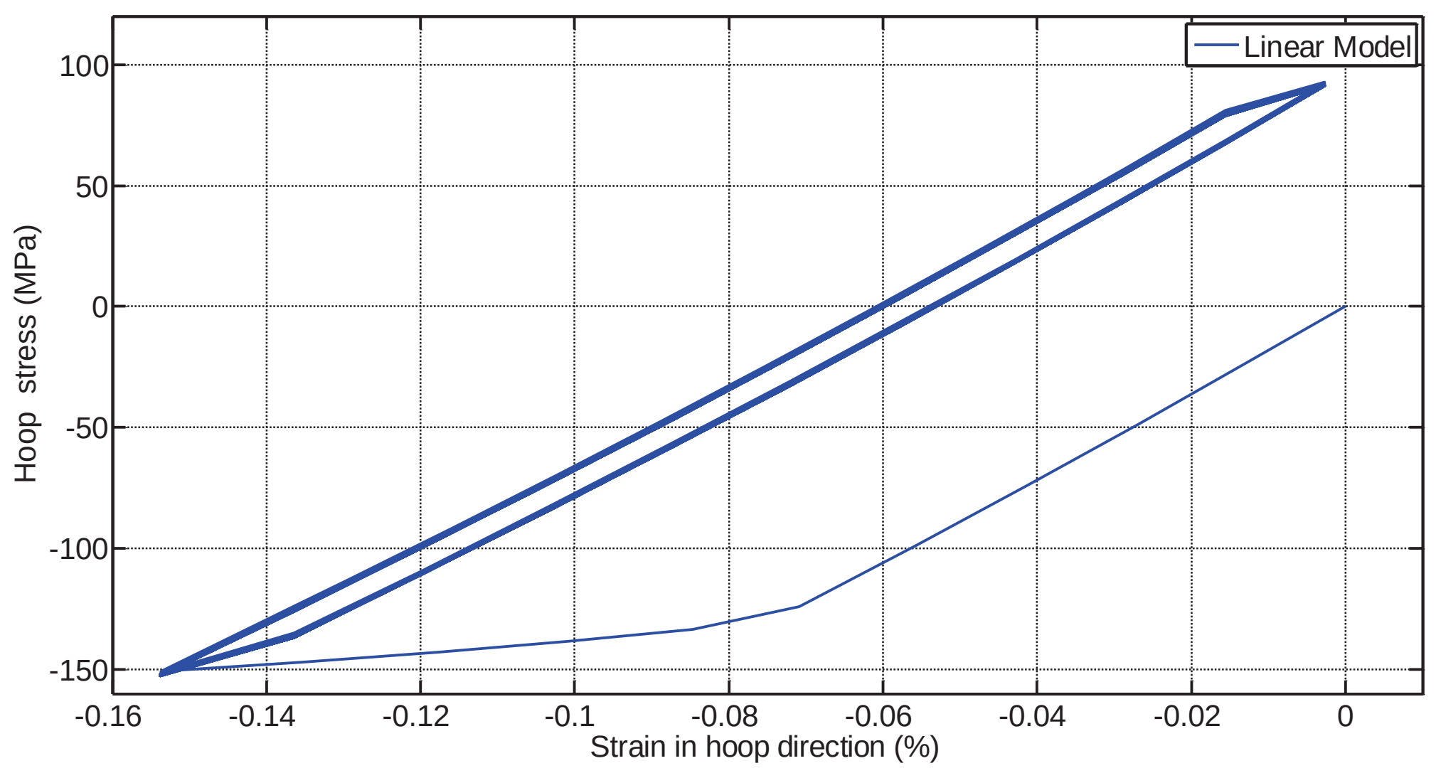
Temperature and von Mises stress distribution at q_{max}

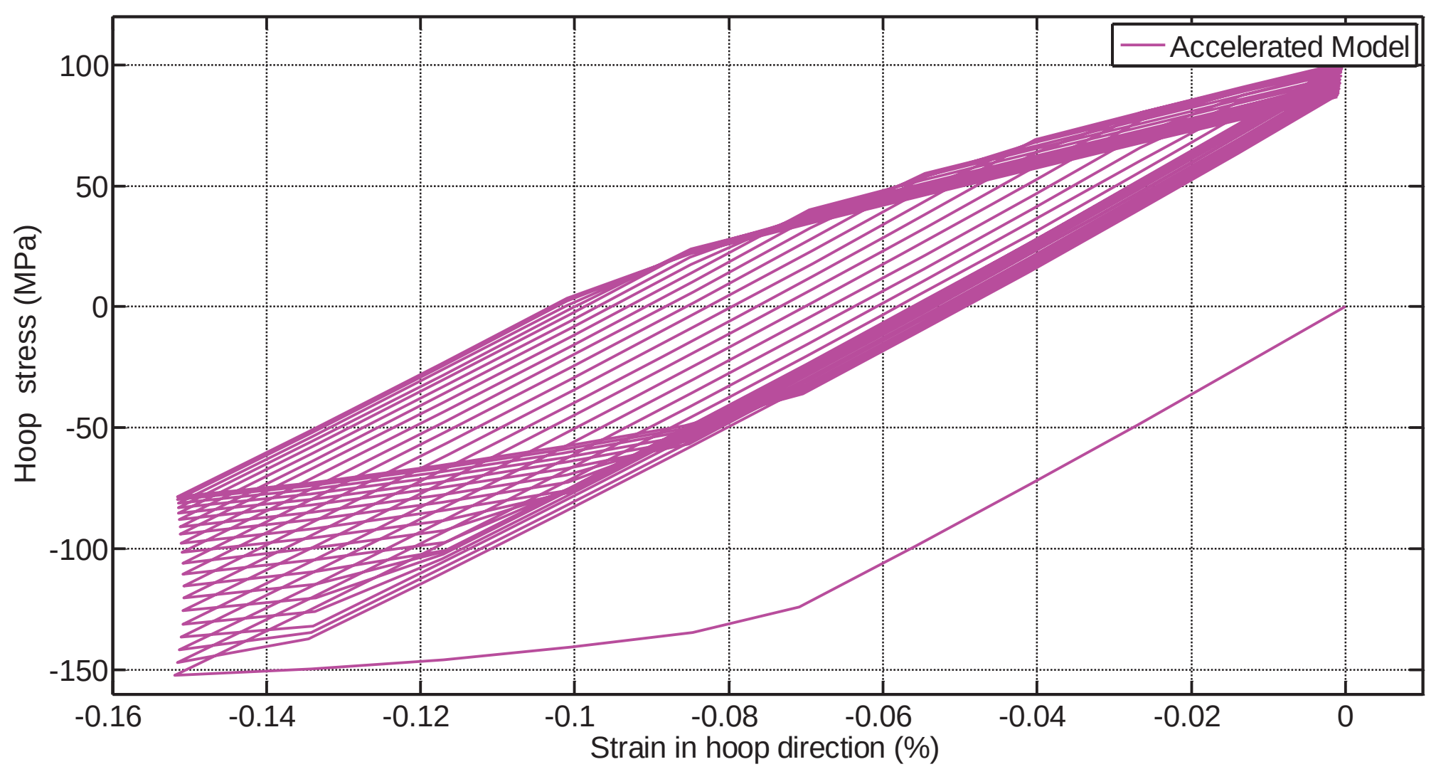


Evolution of hoop stress-strain for the critical point A in relation with different material models:









Fatigue life assessment (strain-based approach)