MATERIAL MODELLING FOR CYCLIC LOADING - A THERMO-MECHANICAL APPROACH

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1. Motivation

The mechanical properties of reinforced plastics in conventional or additive manufacturing are dominated by the properties of the matrix material. These materials exhibit a rate-dependent behaviour. An accepted material classification scheme depicts the rate-dependency in an equilibrium hysteresis when subjected to a relaxation process on the load path [5]. This statement holds for various other classes of materials and can be weighted as increasingly important for high-perfomance structural components under cyclic loading.

Secondly, a temperature evolution in specimens or components under cyclic loading is observed. An increased temperature in the specimen can be attributed to external or internal heat sources or, which is the main subject in this work, to dissipative phenomena in the material itself. The dissipative phenomena are basically related to viscoplastic deformations.

As a matter of course in common loading regimes, the dissipation amount per cycle is small compared to the stored total free energy. Nonetheless, the dissipated energy is transferred into heat, the dissipation process accumulates and leads to a characteristic temperature evolution field. By including a temperature field measurement in the procedure of material characterisation, we can exploit quantitative observations to improve and refine the material model. Therefore a thermo-mechanically coupled analysis based on general principles from continuum mechanics is introduced to study the effect of deformation mechanisms of different material classes.

The complexity in terms of low- and high-cycle fatigue of metals incorporating viscoplasticity has been widely studied (e.g. [2]) and is nowadays transferred to new material classes like additive manufactured plastics. To cover the different micro-mechanical phenomena the applied material models and the experimental procedures to establish the set of material parameters need to be adapted. Additionally through the application of thermography, the consideration of an evolving temperature field opens an opportunity to verify the chosen modelling approach and creates further possibilities for proof [3, 4, 6].

2. Governing principles and equations

General material models are represented by simple networks of basic material properties related to spring, friction or damper elements. A more differentiated network can always be reduced to one of the four main classes outlined by HAUPT (see [5]). More importantly, the network representation gives hold of a main principle - the additive decomposition of physical entities.

To incorporate an evolving temperature due to mechanical loading we start with the two fundamental laws of thermodynamics. Eq. (1) shows the CLAUSIUS-DUHEM inequality for the one-dimensional case.

(1) $$\delta = \frac{1}{\varrho}\sigma\dot{\varepsilon} - \dot{e} + \theta\dot{s} - \frac{1}{\varrho\theta}q\frac{\partial\theta}{\partial x} \geq 0$$

By the introduction of the HELMHOLTZ free energy ψ and the straightforward additive split in terms of stress, strain and energies (see eq. (2)) according to the assumed network the implementation point of experimentally motivated material models is achieved.

(2) $$\psi = \psi_{th} + \psi_{el} + \psi_{iso} + \psi_{kin} + \ldots$$

Then the summands of the internal dissipation in eq. (3) are associated with network members as well.

$$\delta_{mech} = \delta_{vis} + \delta_{iso} + \delta_{kin} + \ldots \quad (3)$$

Taking the yield condition and the flow rule for viscoplasticity into account, we need to solve a system of evolutionary equations in a PERZYNA type formulation.

For a specific metal alloy under simple loading condition a deep theoretical quantitative discussion was published in [1], whereas YU *et.al.* [7] apply this methodology to PA6 for up to 1 000 cycles and show a reasonable agreement with experimental data.

3. Parametric study for experimental setup

With the presented study, the setup for our experimental investigations for different material classes and loading definition are prepared. Suitable sensitivity analyses with respect to material parameters influencing the amount of internal dissipation result in a better understanding for appropriate material models as depicted in Fig. 1.

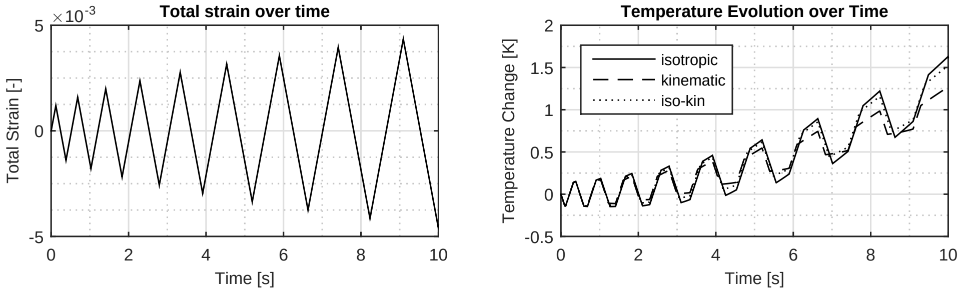

Figure 1: Sample temperature evolution for a viscoplastic material with hardening

Conclusions to the required IR-camera resolution will be drawn by discussing upper and lower bounds based on idealized thermal boundary conditions. Strategies to identify the enlarged number of material parameters are outlined.

The usage of a modern servo-hydraulic testing machine with climate chamber brings likewise an optimized loading regime (e.g. load amplitude, load frequency or intermediate relaxation time) into focus.

4. References

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