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MICROMECHANICS BASED STRUCTURAL ANALYSES OF MMC COMPONENTS UNDER FINITE STRAINS

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ABSTRACT

The present paper is concerned with the computational simulation of the thermo-elastic-plastic properties of metal matrix composites (MMCs) in the finite strain regime. In particular, the focus is put on the prediction of the structural response of parts and components made from MMCs within the framework of the Finite Element Method (FEM).
Hierarchical modeling at the macro, meso, and micro scales is used by appropriately combining various approaches for performing homogenization and localization. The transition between the macro and the meso scale is provided by FEM utilizing an analytical thermo-elastic-plastic constitutive material law. For this purpose a micromechanics based Mean Field approach is employed. Between the meso and the micro scale this approach operates on the basis of averaged phase fields. As a second method the numerical unit cell method is used to verify the mesoscopic behavior and to predict highly resolved microfields as response to prescribed loading scenarios. As is common for metals Cauchy stresses, logarithmic strains, and additive strain decomposition are employed.

The macroscopic response of the component is solved by FEM which requires an appropriate material model. As such, the meso scale behavior of the MMC is introduced as constitutive material law based on the Incremental Mori Tanaka (IMT) formulation [1,2] adopting modifications to the instantaneous matrix behavior. It is implemented as user defined subroutine in ABAQUS/Standard (SIMULIA, Providence, R.I., USA). For spherical isotropic reinforcements it is extended to account for finite strains both for the matrix material and for the overall behavior. It can handle temperature dependent material data of the MMC constituents and is formulated implicitly using an Euler backward scheme.
As the second method the Periodic Microfield Approach (PMA) is used which employs unit cells developed in [3]. It is extended into the finite strain regime and non-linear evaluation of the unit cell response is performed [2]. General loading conditions which are applied to the unit cell are determined from the FEM-IMT predictions as tri-axial strain histories at selected locations.

A component made from an MMC with 20%vol ceramic particles is investigated at different length scales with respect to some general loading history. The response of a cylindrical sample under overall

uniaxial compression is computed by FEM, where the constitutive behavior of the MMC is prescribed by the IMT. By this approach the structural response is computed as well as the mesoscopic stress and strain fields. Also accessible are the phase averaged fields in both the matrix and the reinforcements, as well as the tractions at the interface between matrix and reinforcements.
More detailed analyses at the micro scale are performed by PMA. Loading histories serving as input to the unit cell computations are extracted from the FEM-IMT investigations. For selected locations the meso strain tensors and their evolution with overall loading are computed. These are applied to the unit cells as (meso) displacement loading history. The non-linear (meso) stress response predicted by the two approaches shows excellent agreement, also for loading scenarios which are highly non-proportional.

The IMT is a tool for performing structural analyses of MMC components with reasonable computational effort. This is compromised by the assumptions of average microfields and, typically, the results on the microfields are less reliable compared to those of PMA predictions. The latter yield highly resolved accurate microfields but require considerable computational power. Thus, at present, the PMA is too expensive computationally to serve as constitutive material description in structural analyses. The limits of applicability and the reliability of IMT predictions are assessed by comparison to PMA results. This way, the assumptions concerning the physics of MMCs as well as concerning the algorithmic approach are evaluated. Since the IMT results serve as input to PMA the accuracy of the former is a crucial point for the present multiscale approach.
The presented methodology is general in formulation which makes it applicable to a wide range of materials. Restrictions are introduced, however, by assigning a specific constitutive behavior to constituents. As long as the constituent materials can be modeled sufficiently accurate (i.e. the assumptions on their behavior hold) and the micro to meso transfer works consistently the validity of the simulations is maintained.

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