VALIDATION OF MEAN-FIELD APPROACHES FOR THE DESCRIPTION OF ELASTIC-PLASTIC TWO-PHASE COMPOSITES

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1. Introduction

Multiscale analyses and multi-objective optimization of thermo-mechanical properties of composite materials, particularly in a non-linear regime, still need relevant and computationally efficient models. Micromechanical mean-field estimates of effective properties of composites can provide a tool for optimal designing, characterization of performance and techniques applied for processing of newly-developed materials. Analytical micromechanical estimates can be desirable for preliminary selection of an optimal two-phase composites for a specific future application [4]. This work presents a synthetic approach to estimating the effective properties of metal-matrix composites (MMC). Selected micromechanical schemes and finite element unit-cells estimates are analysed and verified. Both, micromechanical and FE estimates of effective elastic-plastic properties of two-phase composites are compared to each other and validated with respect to experimental data. Such comprehensive study of the three types of data for different MMC is hardly to be found in the literature. The validation with respect to experimental data is crucial for modelling nonlinear behaviour because the estimated overall properties of composites are strongly affected by the method applied [3].

2. Averaging schemes for a two-phase isotropic composite

Among the available micromechanical mean-field estimates the attention is focused on the Mori-Tanaka (MT), self-consistent (SC) and generalized self-consistent (GSC) methods. The incremental linearization is applied at each time step using so-called tangent ($\mathbf{L}^{\mathrm{t}}$) or secant ($\mathbf{L}^{\mathrm{s}}$) stiffness moduli for the matrix representing an elasto-plastic medium

$$\dot{\boldsymbol{\sigma}} = \mathbf{L}^{\mathrm{t}} \cdot \dot{\boldsymbol{\varepsilon}}\,, \quad \boldsymbol{\sigma} = \mathbf{L}^{\mathrm{s}} \cdot \boldsymbol{\varepsilon}\,. \tag{1}$$

It is assumed that the ceramic phase is linearly elastic and the metal matrix is elasto-plastic. The metal matrix is described by the standard Huber-von Mises yield function with an associated flow rule. Both phases are assumed to be isotropic. The resultant tangent elasto-plastic stiffness tensor of the metal matrix is anisotropic and can be isotropized in order to take the form [1]

$$\mathbf{L}_{\mathrm{m}}^{\mathrm{t(iso)}} = 3K_{\mathrm{m}}\mathbf{I}^{\mathrm{P}} + 2G_{\mathrm{m}}^{\mathrm{t}}(\varepsilon_{\mathrm{eq}}^{\mathrm{p}})\mathbf{I}^{\mathrm{D}}, \tag{2}$$

where the bulk modulus K_{m} is constant and the current shear modulus $G_{\mathrm{m}}^{\mathrm{t}}(\varepsilon_{\mathrm{eq}}^{\mathrm{p}})$ evolves with an accumulated plastic strain $\varepsilon_{\mathrm{eq}}^{\mathrm{p}}$. It has been assumed that ceramic inclusions have spherical shape.

3. Unit cell models

Finite element analysis is restricted to the simplified one-particle cells: spherical (FE-S) and cylindrical (FE-C), Fig. 1. The composite is subjected to the axially symmetric loading. The FE analyses have been performed in the AceFEM environment [2]. The problems have been calculated as two dimensional axi-symmetric ones using four node standard finite elements available in the program.

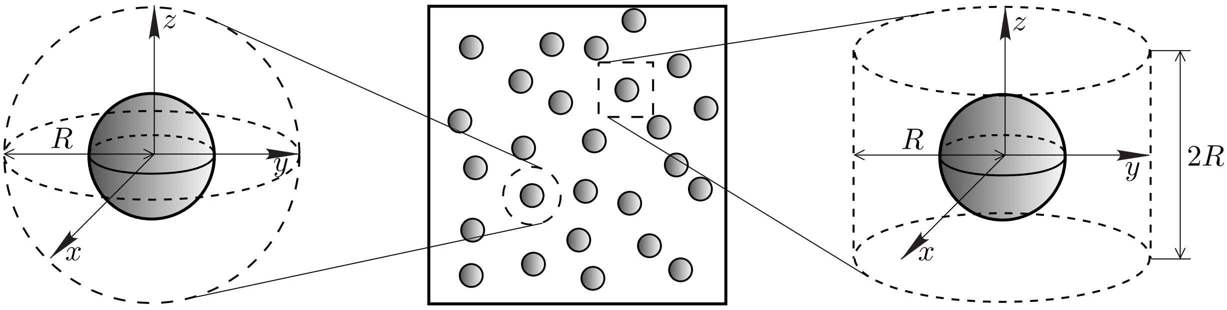

Figure 1: Spherical (FE-S) and cylindrical (FE-C) unit cells.

4. Results

All analytical mean-field averaging schemes have been implemented using a simple and universal algorithm of the incremental iterative procedure. Tension and compression tests have been modelled using those analytical schemes and the two FE unit cell models. The analysis of results has revealed that the generalized self-consistent (GSC) and Mori-Tanaka (MT) estimates provide very good agreement with FE results in the whole range of volume content of ceramic phase, Fig. 2. The mean-field estimates are computationally more efficient than FE analyses of the unit cells so that they can be applied when quick and robust assessment of overall composite properties in the non-linear elastic-plastic regime is needed.

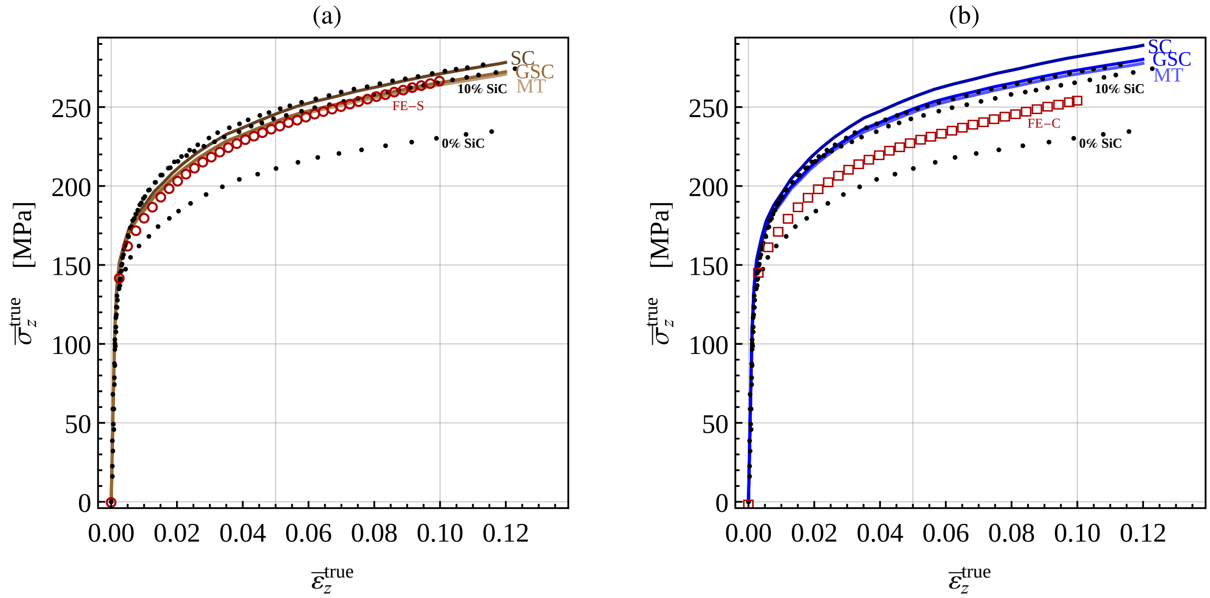

Figure 2: Comparison of stress-strain response in compression for AA6061-10%SiC composites obtained experimentally and with use of SC, GSC and MT averaging schemes using tangent (a) or secant (b) linearization, as well as the FE results of two unit cells, FE-S (a) and FE-C (b).

References

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