MICROMECHANICAL AND NUMERICAL MODELING OF POLYMER-METAL COMPOSITES IN LARGE STRAIN REGIME

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1. Introduction

The micromechanical model of two phase polymer-metal composite is developed in the large strain framework [3, 4]. The tangent linearization method [3] is used to adopt the Eshelby result for the inclusion in an infinite matrix undergoing large strains. A long-term goal of research is to extend the sequential averaging scheme [2] to elastic-(visco)plastic materials and large strain regime. The proposed framework will be validated by computational homogenization employing the finite element method (FEM) [5].

2. Results of FE analyses

In order to validate the performance of micromechanical model ANSYS Mechanical APDL R18.0 software [1] was used to perform FEM analysis. Following numerical simulations were conducted. A spherical inclusion centrally placed in a cubic unit cell was considered, see Fig. 1. The inclusion was varying in radius R corresponding to the volume fractions c: 0.42%, 3.35%, 11.31%, 17.96%, 22.09%, 26.81%. Additionally, each problem (in terms of a volume fraction) was calculated in two configurations: 1st when the matrix is made from steel and the inclusion from polymer, 2nd – exactly reverse. Two limit cases were also calculated when both the inclusion and the matrix were represented by the same material, steel and polymer, respectively. The polymer phase is described by the hyperelastic Yeoh model, while steel is elastic-plastic with the Kirchhoff type hyperelasticity and the J2 plasticity. A unit cell was subjected to isochoric extension in z direction. It is observed that due to a large contrast in the elastic stiffness, for the case of polymer matrix, strain in a steel inclusion is negligible as compared to the strain in polymer.

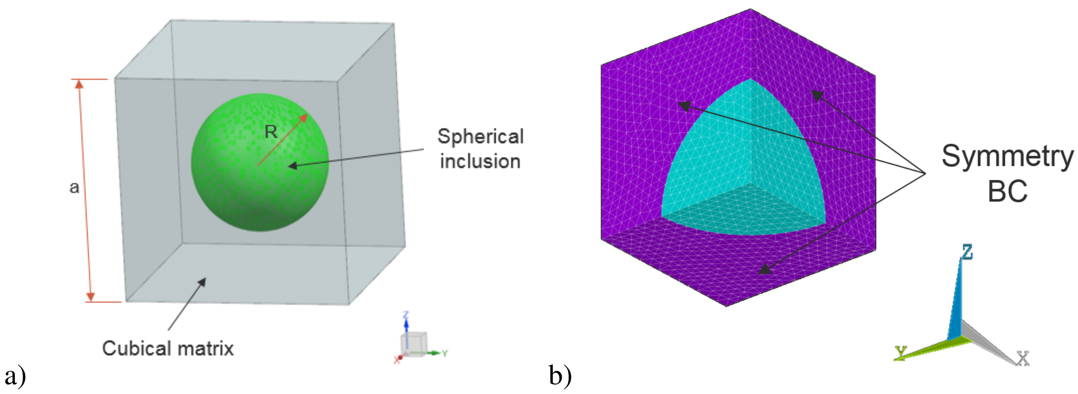
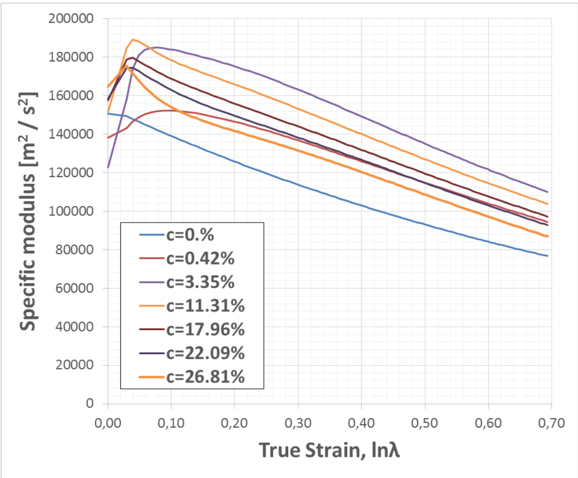


Figure 1: A composite unit cell (a) and its computational model analyzed in ANSYS. (b)

Overall and per-phase responses were studied. For the composite with a steel matrix addition of polymer inclusions increases the specific tangent modulus (i.e. the current modulus divided by the composite density). Considering results shown in Fig. 2a, it can be said that above 0.12 of true strain all results are stabilized, monotonically decreasing and tend to converge with each other. For the stabilized part of the curve the value of specific modulus for composite cases is always higher than for a pure steel case. At the same strain level, the specific modulus first increases with the polymer volume content, reaching the highest value for $c = 3.35\%$, and then decreases.

a) 

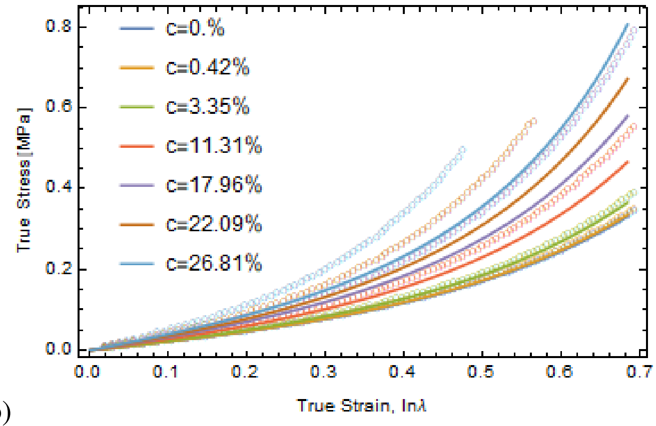
b) 

Figure 2: (a) Specific smodulus as a function of true strain for steel matrix configuration (only FE analysis) (b) Comparison of true strain-true stress curves obtained by FE analyses (circles) and using micromechanical model (continuous line) for polymer matrix configuration.

In the case of polymer matrix almost no strain is observed in the steel inclusions that behave as rigid. The overall true stress-true strain curves obtained for a different steel volume content c are demonstrated in Fig. 2b. For the same strain the stress level increases with c. Preliminary validation of the micromechanical scheme based on the incremental tangent linearization and the Mori-Tanaka averaging is also shown for this configuration. In the model the non-linear polymer behaviour (the Yeoh law) is linearized as follows

(1) $$\mathbf{T}_m = f(\mathbf{F}_m) \rightarrow \dot{\mathbf{T}}_m = \mathbf{L}_m^{tg} \cdot \dot{\mathbf{F}}_m \quad \text{where} \quad \mathbf{L}_m^{tg} = \frac{\partial f(\mathbf{F}_m)}{\partial \mathbf{F}_m}$$

and the interaction law takes the form

(2) $$\dot{\mathbf{T}}_i - \dot{\mathbf{T}}_m = -\mathbf{L}_*(\mathbf{L}_m^{tg}) \cdot (\dot{\mathbf{F}}_i - \dot{\mathbf{F}}_m)\,,$$

in which $\mathbf{F}_{m/i}$ and $\mathbf{T}_{m/i}$ are the deformation gradient and the first Piola-Kirchhoff stress in the matrix and inclusion, respectively, while $\mathbf{L}_*$ is the Hill tensor. Inclusions are assumed as rigid, therefore $\mathbf{F}_i = \mathbf{I}$ and $\mathbf{F}_m = 1/(1-c)(\bar{\mathbf{F}} - c\mathbf{I})$ ($\bar{\mathbf{F}}$ is the overall deformation gradient imposed in the analyses). It can be seen in Fig. 2b that the model agrees well with FE results for small volume content of steel inclusions, while for a higher c the stress level is under-predicted, especially for an increasing strain level.

Acknowledgments The research was supported by the project of the National Science Center (NCN) granted by the decision No. 2016/23/B/ST8/03418.

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