A MULTISCALE APPROACH FOR THE THERMOMECHANICAL MODELING OF SHAPE MEMORY ALLOY FIBER REINFORCED COMPOSITES

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ABSTRACT
We propose a numerical tool for modeling the effective behavior of SMA / polymers composites based on the multilevel finite element (FE²) method. It is an iterative numerical approach where the deformations calculated at any integration point of the structure are applied as boundary conditions at the level of the associated RVE. The SMA phase behavior is described by a constitutive law based on a thermodynamic approach where the driving forces associated with the internal martensite volume fraction and mean transformation deformation are derived from the postulate of Gibbs free energy expression. The behavior of the polymer is assumed to be linear and isotropic elastic. The FE² method is adopted for multiscale modeling. It can realize the transition of numerical scale between a complex heterogeneities microstructure discretized by finite elements and the macrostructure, where the responses in two scales are calculated simultaneously and coupled. The procedure is implemented in the ABAQUS finite element code via the UMAT routine. The state of constraints, volume fraction of transformation, and the corresponding tangent operators are thus calculated and considered as input at each point of integration of the mesh of the structure for the calculation of the global equilibrium. This multi-scale approach is validated on thermomechanical test cases in the literature. It will subsequently be used for the designing of a composite SMA / polymer application.

KEYWORDS: SHAPE MEMORY ALLOYS; COMPOSITES; NUMERICAL HOMOGENIZATION; MULTI-SCALE FINITE ELEMENT METHOD.

INTRODUCTION
Hybrid materials with multi-physical behavior could contribute to the emergence of innovative applications taking advantage of the interesting properties of shape memory alloys (SMAs) and polymer components. The fiber-matrix or multilayer composites SMA / polymers could result in applications in energy recovery and conversion or in sensor-actuators, see [Fatemi Dehaghani et al., 2017]. It is therefore important to have numerical tools for predicting the multi-physical, multi-scale and non-linear behavior of these composite materials. The present work deals with a generic 3D multiscale finite element homogenization model (FE²) on ABAQUS to study the pseudo-elasticity (PE) and the shape memory effect (SME) of the SMA fiber reinforced composites. The implementation of the multiscale modeling approach is introduced at first. Then, a brief introduction of the adopted SMA constitutive model is presented, see [Chemisky et al., 2011]. At last, applications for SMA fiber reinforced composite are studied in both PE and SME cases.

MULTISCALE MODELING
Considering a composite as a continuous macroscopic structure with infinite periodic microscopic structure, each point of the macroscopic structure can be represented by a RVE, see Figure 1. Then, a macroscopic finite element model describing the composite structure and a microscopic finite element model representing the microscopic structure of the composite are implemented on the commercial finite element software ABAQUS and linked via its user defined subroutine (UMAT), see [Xu et al., 2018]. The strain on each macroscopic integration point is transferred to the corresponding RVE with periodic boundary conditions (PBCs), while the total effective constitutive behavior and stress of each RVE are transferred to the associated macroscopic integration point.

![Figure 1: Multiscale finite element homogenization](image-url)

The adopted SMA behavior in the microscopic scale is developed by [Chemisky et al., 2011], where the phase
transformation, martensite reorientation, twin accommodation, tension-compression asymmetry and internal loops during partial loadings are considered.

APPLICATIONS FOR SMA FIBER REINFORCED COMPOSITE

In this section, the proposed model is used for the simulation of SMA fiber reinforced composite. A 3D bending composite beam is considered with face $Z = 0$ mm fully clamped and face $Z = 100$ mm subjected to a transversely surface load $\sigma = 33.33$ MPa. The microscopic structure is composed by an SMA fiber with $E_f = 70000$ MPa embedded on elastic polymer matrix with $E_m = 20000$ MPa. The fiber volume fraction is 26.7%. The macroscopic model is meshed by 32 C3D8I incompatible mode elements, while the RVE is meshed by 224 C3D8 linear elements, see Figure 2. Figure 3 depicts the PE response of the cantilever beam in comparison with the results in reference, see [Fatemi Dehaghani et al., 2017]. Considering that two SMA models are not completely the same, the responses in Figure 3 show a good agreement. Figure 2 gives the stress distributions of the macroscopic beam and two microscopic RVEs. It is observed that one RVE above neutral plane is under tensile loading and another below neutral plane is under compressive loading.

CONCLUSION

The proposed 3D generic multiscale finite element method for modeling the PE and SME behaviors of SMA fiber/epoxy matrix composite is studied in this work. The constitutive model developed by [Chemisky et al., 2011] is used for modeling the SMA fiber embedded on elastic matrix. The multiscale finite element method is adopted for building the multiscale analysis of fiber reinforced composite. This proposed model could be applied for predicting the response of fiber reinforced composite taking advantage of SMAs’ PE and SME behaviors.

REFERENCES

