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MICROMECHANICAL ANALYSIS OF POROUS SHAPE MEMORY ALLOYS

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Over the last decades Shape Memory Alloys (SMA) have been used for a large number of applications in numerous engineering fields, from aerospace to medical device industries.
Recently, driven by biomedical applications, a great interest has arisen concerning a particular class of SMA: the porous SMA. The possibility of producing SMA in porous form has opened new fields of applications owing to their low-weight with high energy dissipation properties.
In the biomedical field, thanks to their high biocompatibility and their capacity to exhibit high strength, NiTi foams have been tested as bone implant materials, effectively exhibiting a considerable amount of bone ingrowth.
In the last years, applications of porous SMA in the field of Civil and Mechanical Engineering have also been considered. The potential applications of porous SMA exploit their ability to carry significant loads and their high energy absorption capability. In fact, the porous SMA shows a higher specific damping capacity under dynamic loading conditions with respect to the dense SMA, because the pores facilitate an additional absorption of the impact energy.
In order to correctly describe the behavior of the porous SMA the development of accurate models describing their properties is needed.
The porous SMA material can be treated as a composite with SMA as the matrix and pores as the inclusions. Several works available in literature, e.g. for instance [1][2], developed micromechanical averaging techniques in order to derive the mechanical response of porous SMA.
Indeed, different micromechanical and homogenization techniques can be applied to model porous SMA, such as the Eshelby dilute inclusion technique, the Mori-Tanaka method or the self-consistent one. An interesting approach that has been adopted to study the behavior of porous materials is based on the assumption of having a periodic distribution of pores. In this case, the problem can be solved by using a computational homogenization technique based, for instance, on nonlinear finite element analyses of a single unit cell with suitable boundary conditions.
The behavior of porous SMA under cyclic loading conditions has been studied in [3], where the constitutive law has been enhanced to account for the development of permanent inelasticity due to stress concentrations in the porous microstructure.

The aim of the present contribution is to present a micromechanical study of porous SMA using different homogenization techniques. In particular, the response of porous SMA will be derived adopting:

- the classical Eshelby dilute inclusion technique, or Mori-Tanaka method, a micromechanical;
- the nonlinear finite element micromechanical analysis, considering periodicity conditions;
- a simplified approach that considers the porous SMA as a damaged dense material;
- the nonuniform TFA homogenization technique based on piecewise interpolation functions of the inelastic field proposed by Sepe et al. [4].

According to the latter homogenization procedure, a representative volume element (RVE) with SMA as the matrix and pores as the inclusions is considered and divided into subsets. In each subset a nonuniform distribution of the inelastic strain, which accounts for all the nonlinear effects that arise in the SMA matrix, is adopted. In particular, the inelastic strain in each subset is given as a linear combination of selected analytical functions depending on the spatial variable. The coefficients of the linear combination are determined solving the evolutive problem.

The SMA model proposed in [5][6] is adopted to simulate the behavior of the SMA matrix.

Numerical applications are developed in order to test the ability of the presented procedures to well capture the overall behavior of the special composite, correctly reproducing the key features of the Shape Memory Alloys: the pseudoelastic and the shape memory effects.

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