Explicit finite element implementation of a shape memory alloy constitutive model and associated analyses

Giulia Scalet[°,*], Elisa Boatti[†], Mauro Ferraro[§], Valentina Mercuri[°], Darren J. Hartl[^] and Ferdinando Auricchio[°]

[°] Dipartimento di Ingegneria Civile e Architettura
Università di Pavia
Via Ferrata 3, 27100 Pavia, Italy
e-mail: giulia.scalet@unipv.it/ valentina.mercuri01@universitadipavia.it / auricchio@unipv.it

[†] John A. Paulson School of Engineering and Applied Sciences
Harvard University
Cambridge, MA 02138, USA
Email: eboatti@seas.harvard.edu

[§] Institute of Bioengineering
École Polytechnique Fédérale de Lausanne, EPFL
BM 5125 Lausanne 1015, Switzerland
Email: mauro.ferraro@epfl.ch

[^] Department of Aerospace Engineering
Texas A&M University
College Station, TX 77843-3409, USA
Email: darren.hartl@tamu.edu

ABSTRACT

Shape memory alloys (SMA) represent an important class of smart metallic materials employed in various innovative applications thanks to their unique thermomechanical behavior. Since the 1980s, several SMA constitutive models have been proposed and implemented into both commercial and academic finite element analysis software tools [1]. Such models have demonstrated their reliability and robustness in the design and optimization of a wide variety of SMA-based components. However, most models are implemented using implicit integration schemes, thus limiting their applicability in highly nonlinear analyses.

The objective of this work is to present a novel explicit integration scheme for the numerical implementation of the three-dimensional Souza-Auricchio model [2], a phenomenological model able to reproduce the primary SMA responses (i.e., pseudoelasticity and shape memory effect). The model constitutive equations are formulated by adopting the continuum thermodynamic theory with internal variables, following a plasticity-like approach [2].

An elastic predictor-inelastic corrector scheme is here used to solve the time-discrete non-linear constitutive equations in the explicit framework. The proposed algorithm is investigated through several benchmark boundary-value problems of increasing complexity, considering both pseudoelastic and shape memory response in quasi-static conditions; a comparison with an implicit integration scheme is also performed. Such numerical tests demonstrate the ability of the algorithm to reproduce key material behaviors with effectiveness and robustness. Particularly, the analysis of SMA cables demonstrates the effectiveness of the explicit algorithm to solve complex problems involving widespread nonlinear contact, which prevent the convergence of the implicit scheme. Details such as mass-scaling options are also discussed.

REFERENCES

[1] C. Cisse, W. Zaki and T.B. Zineb. "A review of constitutive models and modeling techniques for shape memory alloys". *Int. J. Plasticity*, **76**, 244-284 (2016).

[2] A. Souza, E. Mamiya and N. Zouain. "Three-dimensional model for solids undergoing stress-induced phase transformations". *Eur. J. Mech. A/Solids*. **17**, 789-806 (1998).