Shape-Memory Alloys: 3D Constitutive Modeling and Biomedical Device Investigation

F. Auricchio[†], **E. Bonetti**[‡], **M. Conti**[†], **S. Morganti**[†]
A. Reali[†], **G. Scalet**[§], **M. Aiello**[*], **A. Valentini**[*]

[†]Dipartimento di Meccanica Strutturale, Universitá di Pavia, Pavia, Italy
auricchio@unipv.it

[‡]Dipartimento di Matematica, Universitá di Pavia, Pavia, Italy

[§]DICAM, Universitá di Bologna, Bologna, Italy

[*]IRCCS Foundation Policlinico San Matteo, Viale Golgi 19, Pavia, Italy

ABSTRACT

Smart materials exhibit special properties that make them a suitable choice for industrial applications in many branches (e.g., aeronautical, biomedical, structural, and earthquake engineering). Among them, shape memory alloys (SMA) have unique features (pseudo-elasticity, one-way and two-way shape memory effects), consequence of reversible martensitic phase transformation between a high symmetric austenitic phase and a lower symmetric martensitic phase. For thermally induced transformation, the result is multi-direction martensite with no macroscopic deformation; for loading induced transformation, the result is martensite oriented in the direction of the applied stress, exhibiting a macroscopic deformation.

In the last years SMA have been deeply investigated, from the point of view of modeling, analysis, and computation. In particular, the research has been developed also towards flexible and accurate phenomenological models. However, some of the well performing models (e.g., see [5]) have still limitations, in particular they are not able to properly describe the material response under low values of stresses, which however corresponds to the most adopted conditions in several applications.

Accordingly, the present work tries first of all to develop a more effective and general constitutive model, along the lines of what recently proposed [1]. The new model describes multiple possible phase transition as well as a reorientation process, being at the end able to take into account martensite reorientation, asymmetric response between tension/compression, different kinetics between forward and reverse phase transformations. However, due to the model increased complexity, standard predictor-corrector methods are no more suitable and a different approach is pursued, based on replacing the set of Kuhn-Tucker conditions by the so-called Fischer-Burmeister complementary functions [4]. The model and its numerical implementation are tested for several proportional and non-proportional loading conditions as well as on some boundary value problem of industrial interest.

In the second part of the work we apply the experience on SMA modeling and integration scheme to solve complex realistic boundary value problems taken from the world of biomedical applications. In particular, we focus on valve failure, which represents a considerable contribute

to cardiovascular disease, the leading cause of death in Western countries. Over the last decade, minimally-invasive procedures have been developed to avoid large risks associated with conventional open-chest valve replacement techniques [2, 3]. For this purpose, percutaneous valves are adopted to restore valve functionality: a heart valve, sewn inside a stent, is crimped and properly placed in the patients heart by means of a catheter. Such a recent and innovative procedure represents an optimal field for virtual computer-based simulations: nowadays, in fact, computational engineering is widely used to deepen many problems belonging to the biomedical field of cardiovascular mechanics and, in particular, minimally-invasive procedures. In this study, we focus on the Edwards SAPIEN transcatheter aortic valve and we reproduce its implantation by means of computational tools. In particular, Finite Element Analysis (FEA) is performed to simulate the transcatheter aortic valve implant (TAVI) moving from a patient-specific aortic root model obtained by processing medical images.

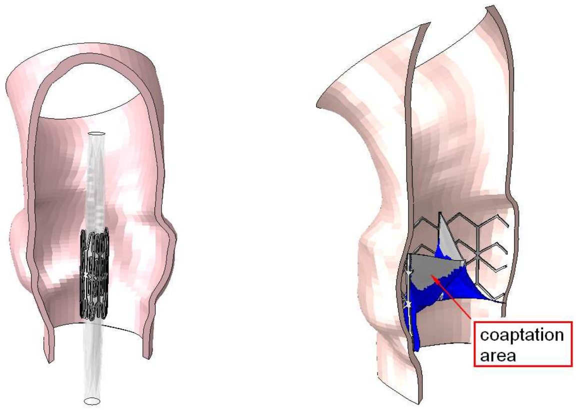

Figure 1: Folded balloon is assembled within patient-specific aortic root and the crimped stent to perform stent expansion simulation. The simulation may give indications on postoperative valve performance in terms, for example, of coaptation area.

References

[1] F. Auricchio and E. Bonetti, A new 3D macroscopic model for shape memory alloys describing martensite reorientation. *Discret. Contin. Dyn. Syst. Ser. S*, in press.

[2] A. Cribier, Percutaneous transcatheter implantation of an aortic valve prosthesis for calcific aortic stenosis: first human case description. *Circulation* 106:3006-3008, 2002.

[3] E. Grube, J.C. Laborde, U. Gerckens, T. Felderhoff, B. Sauren, L. Buellesfeld, R. Mueller, M. Menichelli, T. Schmidt, B. Zickmann, S. Iversen and G.W. Stone, Percutaneous implantation of the corevalve self-expanding valve prosthesis in high-risk patients with aortic valve disease: the Siegburg first-in-man study. *Circulation* 114:1616-1624, 2006.

[4] M. Schmidt-Baldassari, Numerical concepts for rate-independent single crystal plasticity. *Comput. Meth. Appl. Mech. Eng.* 192:1261-1280, 2003.

[5] A.C. Souza, E.N. Mamiya and N. Zouain, Three-dimensional model for solids undergoing stress-induced phase transformations. *Eur. J. Mech. A-Solids* 17:789-806, 1998.