8th. World Congress on Computational Mechanics (WCCM8)
5th European Congress on Computational Methods in Applied Sciences and Engineeering (ECCOMAS 2008)
June 30 –July 5, 2008
Venice, Italy

FE simulation of the deployment of a NiTi stent into the arteria femoralis

*** D. Christ[1], S. Reese[1]**

[1] Institute of Solid Mechanics , TU Braunschweig
Schleinitzstr. 20, 38106 Braunschweig, Germany
d.christ(s.reese)@tu-bs.de, http://www.tu-braunschweig.de/fm

Key Words: *FE modelling, Shape memory alloys, Finite strains, Medical application.*

ABSTRACT

Patients with peripheral artery occlusive disease (PAOD) have a higher risk for cardio- and cerebrovascular complications. Nearly 55% of the patients die as a result of the desease. Through the instertion of stents into the arteria femoralis, the results from an exclusive/singular percutaneous dilatation via baloon catheter can be explicitly improved and thus increases the probability of survival. Overall stents made of Nickel-Titanium have shown a very good performance in the field of intravascular stenting. Nickel-Titanium is proved well for biocompatibility and the mechanical properties (pseudoelasticity effect: strength, flexibility and material robustness) cannot be achieved by common materials such as steel or polymers. However, the producer of Nickel-Titanium stents have still a demand on objective criteria for judging the proportional load on the arteria femoralis superficialis (AFS) during daily exposures (walking, standing, bending). Currently available stents are not optimized to the effective exposure on the AFS. Particularly, the results of recent studies with drug coated Nickel-Titanium stents reveal a high rate of stent failures in the AFS [1]. Aim of this project is the development of reliable systems of Nickel-Titanium stents which are optimized to the exposure in the lower extremities, particularly in the AFS.

Within this project we must consider a combination of very complex physical and structural problems. One of the challenges is the accurate modelling of the stent system. Since the stent consists of Nickel-Titanium, a typical shape memory alloy, we have to choose an adequate material model. So far, there exist several material models which are capable to describe the pseudoelasticity effect of shape memory alloys [2],[3]. However, only a few of them are developed in the framework of large strains. But particularly in case of stent modelling, the huge radial shrinking of the stent during the introduction into the catheter leads to large rotations and increased strains up to 8%. As shown in [4], these conditions yield a wrong material response if we use material models basing on a small strain formulation. Hence, we have developed a new material model for shape memory alloys which is derived in the framework of finite strains and which has been proven as a reliable tool in complex FE computations [5]. The second challenge is the choice of the element formulation. The stent consists of a combination of joints and ligaments, both in a very small seize. While the ligaments are predestined for beam elements, the geometry of the joints does not allow the applying of such a structural element. The joints would be

favourably discretized by volume elements. However, the combination of a beam-like structure for the ligaments and a volume structure for the joints is not possible with common element formulations. On the other hand, if we also use volume elements for the ligaments, the number of elements and therewith the number of degrees of freedom would exceed the computational capacity. Hence, we apply a special element formulation, proposed in [6]. This formulation is based on the Q1SP concept which is enhanced to a solid-shell and solid-beam formulation (see [7]). In both formulations, as in the original Q1SP concept, only one Gauß point over the length (or in shells in the two shell directions) is necessary. In the direction of the bending moment the number of Gauß points can be varied. So that on one hand we use an efficient element formulation with a decreased number of Gauß points and on the other hand a coupling of the classical Q1SP elements (used for the joints) with the new developed solid-beam elements (used for the ligaments) is possible without any further assumptions. A secondary benefit of solid elements is the better behaviour in contact problems (stent-arterie wall) compared to structure elements. The last topic is the modelling of the AFS. Here, we rely on the material model proposed in [8]. It contains the orthotropic and hyperelastic behaviour of soft tissues and is developed in the framework of finite strains.

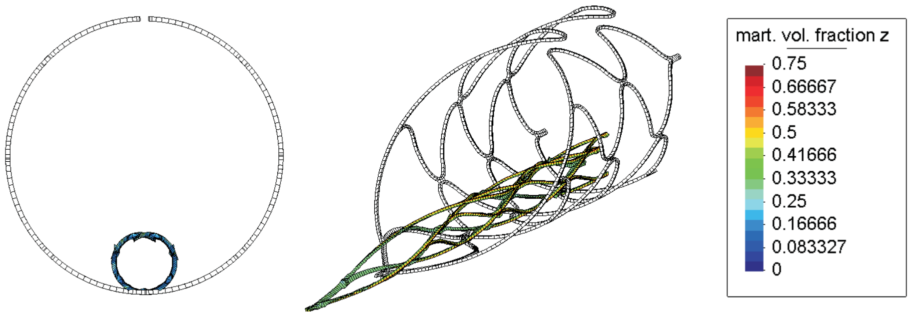

Figure 1: Stent geometry in the initial (white) and the deformed (coloured) state and the distribution of the martensitic volume fraction at the end of loading.

REFERENCES

[1] S.H. Duda et al. "Sirolimus-eluting stents for the treatment of obstructive superficial femoral artery disease: six-month results." *Circulation*, Vol. **106**, 1505-1509, 2002.

[2] F. Auricchio and L. Petrini. "A three-dimensional model describing stress-temperature induced solid phase transformations: solution algorithm and boundary value problems." *Int. J. Numer. Meth. Engng.*, Vol. **61**, 807-836, 2004.

[3] D. Helm and P. Haupt. "Shape memory behaviour: modelling within continuum thermomechanics." *Int. J. Sol. Struc.*, Vol. **40**, 827-849, 2003.

[4] D. Christ and S. Reese. "Is it necessary to model shape memory alloys within the scope of large strains?" *Proc. SPIE*, Vol. **6170**, 247-257, 2006.

[5] S. Reese and D. Christ. "Finite deformation pseudo-elasticity of shape memory alloys - Constitutive modelling and finite element implementation." *Int. J. Plas.*, doi:10.1016/j.ijplas.2007.05.005

[6] S. Reese. "On a physically stabilized one point finite element formulation for three-dimensional finite elasto-plasticity." *Comp. Meth. Appl. Mech. Engng.,* Vol. **194**, 4685-4715, 2005

[7] S. Reese. "A large deformation solid-shell concept based on reduced integration with hourglass stabilization." *Int. J. Num. Meth. Engng.*, Vol. **69**, 1671-1716, 2007

[8] G.A. Holzapfel et al. "A new constitutive framework for arterial wall mechanics and a comparative study of material models." *Journal of Elasticity*, Vol. **61**, 1-48, 2000