DAMAGE EVOLUTION IN THE ELASTIC PLASTIC MATERIAL REINFORCED BY BRITTLE INCLUSION

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1. Introduction

In the present work a general constitutive model of the elastic plastic materials that are reinforced by the second phase is proposed. It is assumed here that matrix is an elastic plastic material in which we can observe ductile damage evolution and inclusions behave like elastic material with brittle damage evolution. Moreover, the content of the secondary phase may undergo changing as a consequence of plastic strain induced phase transformation. Among metallic materials, that are characterized by the mentioned above dissipative phenomena, we can find austenitic stainless steels. These materials preserve ductility practically down to 0K, thus they are applied for components of superconducting magnets and cryogenic transfer lines: tubes, cylinders, thin walled shells (like bellows expansion joints) or massive parts like vacuum barriers. In the present research 316L stainless steel is chosen as a reference material for application of the proposed model.

2. Constitutive model

Continuum damage mechanics approach applied in the present work provides the constitutive modeling in the framework of thermodynamics of irreversible processes with internal state variables. This approach is based on a concept of the effective quasi-continuum. The material heterogeneity (on the micro and mesoscale) is smeared out over the representative volume element (RVE) of the piecewise discontinuous material. The true state of a real material within RVE, represented by the topology, size, orientation, and number of micro-rearrangements, is mapped to a material point of the effective quasi-continuum. This transformation between RVE in the real material and the effective quasi-continuum is a linear map which is represented by the fourth rank tensor $\mathbb{Q}(\mathbf{D},\xi)$ which depends on current damage state, $\mathbf{D}$, and secondary phase content, ξ. The explicit form of this tensor is obtained by the use of *total energy equivalence principle*, originally proposed by Saanouni at al. [1] in the case of elastic-plastic-damage materials, which is extended here to other dissipative phenomena like phase transformation.

3. FEM implementation of the model

Thanks to the implementation of the constitutive model of a material undergoing the plastic strain-induced phase transformation in the finite element software, the mechanical behaviour of different structures made of this material can be easily computed and the evolution of two-phase continuum created during the transformation can be investigated. As an example, the finite element analysis of an expansion bellows made of 316L stainless steel is presented. Bellows expansion joints belong to thin-walled structures of high flexibility. They are used to compensate for the relative motion of two adjacent assemblies subjected to the loads. The bellows expansion joints are crucial elements for systems working at cryogenic temperatures, where all structures contract significantly during cool-down process and the emerging displacement of components needs to be compensated. The choice of material is a crucial point for design of the bellows that are subjected to severe conditions. They have to resist cryogenic temperatures (down to 1.9 K), radiation and mechanical loading [2]. As an example, half convolution of a typical U-type bellows has been subjected to mechanical loading (axial displacements -16/+42 mm) at 4.2K.

Material	Thickness of ply t[mm]	Number of convultions	Outer diameter Do [mm]	Inner diameter Db [mm]	Convoluted lenght [mm]
SS 316L	0,15	15	90,15	82	78

Table 1. Basic geometrical parameters of the expansion bellows.

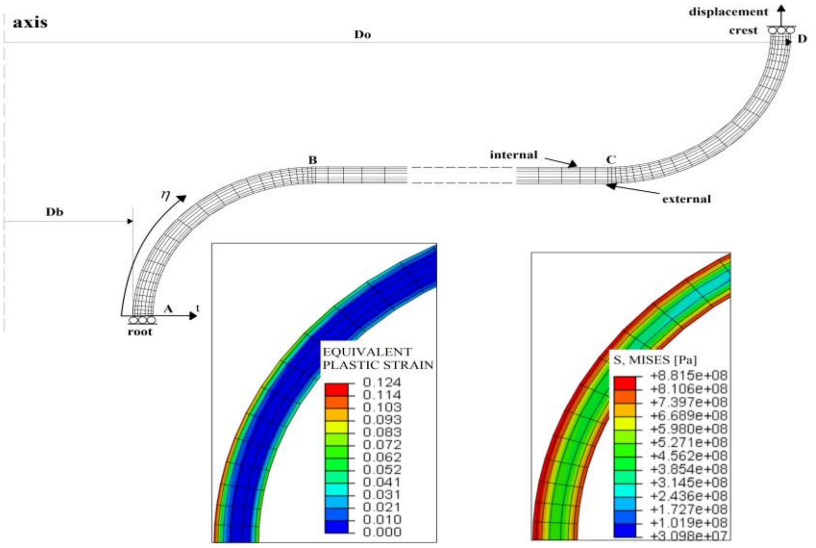

Figure 1. Boundary conditions and finite element mesh of expansion bellows, distribution of equivalent plastic strain and von Mises stress in the most deteriorated region after 300 cycles [3].

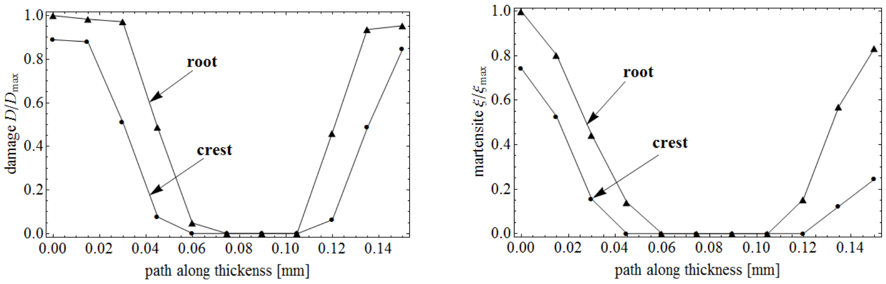

Figure 2. Distribution of damage (left) and martensite content (right) through thickness of the root and crest [3].

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6. References

[1] K. Saanouni, *Damage Mechanics in Metal Forming. Advanced modeling and numerical simulation,* ISTE/Wiley, London, 2012.

[2] B. Skoczeń, *Compensation Systems for Low Temperatures Applications*, Springer 2004.

[3] M. Ryś (2015). Modeling of damage evolution and martensitic transformation in austenitic steel at cryogenic temperature, *Arch. Mech. Eng.*, VOL. LXII, Number4.