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Application of the generalized linear elastic fracture mechanics to NiTi catheter

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Abstract – The contribution presents a procedure for the determination of the direction of crack initiation from a rectangular notch in the shape memory alloy (SMA) sensors mounted on SMA backbone used as an active catheter. The problem is solved as the homogeneous case of the bi-material rectangular notch. The solution is based on the knowledge of the strain energy density distribution which follows from the evaluation of the two existing singular terms.

SMA sensor for position feedback in active catheters - Catheter-based interventions are becoming increasingly popular in intracardiac procedures, but existing manual catheters lack the precision and dexterity needed to reach the desired locations inside the heart efficiently and effectively. These challenges can be overcome by the development of a robotic or “active” catheter, which on the other hand needs sensory informations for precise control and force feedback. Because of the large force to volume ratio, SMA sensors are an ideal candidate for minimally invasive tools. Unfortunately, there are stress concentrators in the design of the studied SMA sensors, see e.g. [1], that needs the analysis focused on particular type of concentrator, e.g. homogeneous rectangular notch as the special case of the bi-material one, see Fig. 1.

Stress distribution in the vicinity of a bi-material notch - The expressions for the singular stress distribution referring to plane problems in the vicinity of a bi-material notch are based on the solution of the Airy stress function. The singular character of the stress field at the notch is usually investigated by a combination of analytical and numerical approaches, see e.g. [2]. As a result, the singular stress distribution is found in the form

$$\sigma_{m,ij} = \sum_{k=1}^{2} H_k r^{-p_k} F_{ij,km}(p_k, \theta)$$

where p_k correspond to stress singularity exponents, H_1 and H_2 refer to the generalized stress intensity factors (GSIFs), the subscript m refers to material 1 or 2, the subscripts i, j refer to the polar coordinates (r,θ) and $F_{ij,km}$ are known functions, see e.g. [2]. The values of GSIFs result from a numerical solution for a given construction with the notch and with given boundary conditions, see [2].

Determination of the direction of initial crack propagation - Following the basic assumption of the stress energy density theory (SED) [2], it is supposed that the direction θ_0 of crack initiation will be identical with the direction of the local minimum of the strain energy density $w(r,\theta)$ and the value of the crack propagation angle θ_0 is then given by

$$\left.\frac{\partial w}{\partial \theta}\right|_{\theta=\theta_0} = 0, \quad \left.\frac{\partial^2 w}{\partial \theta^2}\right|_{\theta=\theta_0} = 0$$

Numerical results - There are evaluated directions of crack initiations θ_0 for the rectangular bi-material notch for a varying ratio of Young’s moduli E_1/E_2 and GSIFs in the Fig. 2. The case of the homogeneous notch, which corresponds to the notches designed in the SMA sensor, is highlighted in red color.

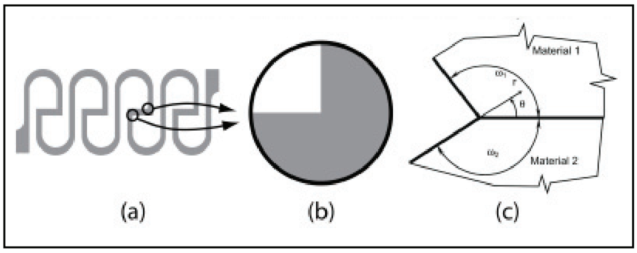

Figure 1: Geometry of SMA sensor (a), detail of analyzed notch (b) as a special case of the general bi-material notch (c).

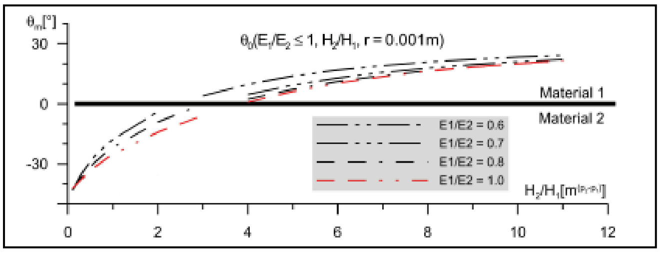

Figure 2: Directions of crack initiations.

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