Fracture control parameters for NiTi based shape memory alloys

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In this paper new fracture control parameters for Nickel–Titanium (NiTi) based shape memory alloys (SMAs) are proposed, based on a recent literature analytical model on fracture mechanics of SMAs. In fact, the stress induced martensitic transformation, occurring in the crack tip region of NiTi alloys, causes a complex and unusual stress distribution with respect to common engineering materials. For this reason two different stress intensity factors (SIFs) have been defined to describe the stress distribution in both transformed and untransformed regions, i.e. in the martensitic and austenitic phases, respectively. Systematic studies have been carried out to analyze the effects of the main thermo-mechanical parameters of NiTi alloys on the two proposed SIFs, i.e. on the crack tip stress distribution, and comparisons with linear elastic fracture mechanics have been illustrated. Finally, the proposed model was used to analyze different loading conditions of a commercial superelastic NiTi alloys, which demonstrated a marked effect of the temperature on the crack tip stress distribution.

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1. Introduction

Nickel–Titanium (NiTi) based shape memory alloys (SMAs) have seen increasing number of applications in many fields of engineering and medicine in the last years (Otsuka and Wayman, 1998) and, consequently, a great interest has been devoted from the scientific community to this class of materials. In fact, many research reports have been published on SMAs in the last decades which demonstrate the intense activities from many researchers, mainly operating in the field of engineering and material science. In particular, many aspects related to the mechanical and functional behavior of NiTi alloys have been deeply analyzed, as well as the effects of thermo-mechanical treatments and of micro-structural properties (Otsuka and Ren, 2005). These results are of great interest as functional behaviors of NiTi alloys are affected by their thermo-mechanical history, therefore great attention should be devoted during production of NiTi components, and proper design criteria must be used for a long-term functional and structural life. To this aim, several numerical models have been developed (Paiva and Savi, 2006) which are able to predict both the mechanical and functional properties of NiTi based components, and they can be used as effective design tools. Furthermore, the great interest from medicine, and in particular from cardiovascular surgery, has given a great impulse to analyze the mechanical performances of NiTi alloys under severe loading and environmental conditions. For these reasons, some recent studies have been carried out to analyze the structural life of NiTi alloys under fatigue loading conditions, as well as to investigate the effects of micro and macro flaws on the mechanical strength. From a material science point of view these topics are of great interest and much research must be carried out to develop analytical and/or semi-empirical models, which allow reliable and safe design of NiTi based components, especially in the field of cardiovascular surgery where a failure could represent a dramatic and irreparable event. In fact, the well known theories to predict the evolution of cracks in common engineering materials as well as the failure modes, under static or variable loading conditions, cannot be applied to NiTi alloys due to their unique features and constitutive behavior. In particular, the high value of local stresses arising near geometric discontinuities or cracks causes microstructure modifications, i.e. martensite reorientation or stress-induced martensitic transformation (SIM). As a result, it is widely accepted from the scientific community that SIM plays an important role on fracture properties of NiTi alloys, as it significantly changes the crack tip stress distribution with respect to common engineering metals. To better understand the role of SIM on crack tip stress distribution some numerical studies have been carried out (Maletta et al., 2009b; Wang, 2006; Wang et al., 2005, 2010), by using commercial finite element codes, and the effects of various thermo-mechanical parameters and loading conditions have been investigated. In addition, a cohesive zone model has been developed by Freed and Banks-Sills (2007) to analyze the effects of the SIM on crack growth resistance in NiTi alloys, as well as to simulate the effects of the wake of the crack, which is mainly associated with the reverse martensitic transformation occurring during crack propagation. This latter mechanism was...