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

ON THE TRANSFORMATION TOUGHENING OF A CRACK ALONG AN INTERFACE BETWEEN A SHAPE MEMORY ALLOY AND AN ISOTROPIC MEDIUM

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Key Words: *Phase transformation, Shape memory alloys, Fracture mechanisms, Finite elements, Transformation toughening.*

ABSTRACT

Shape memory alloys (SMAs) have received much attention in recent years, especially as a result of their various applications in smart structures, actuators, medical devices, space and aeronautics. These materials exhibit extremely large, recoverable strains (of the order of 10%), resulting from transformation between austenitic and martensitic phases. This transformation may be induced by a change, either in the applied stress (stress-induced transformation), the temperature (temperature-induced transformation), or a combination of the two. From a macroscopic point of view, one may separate the observable behavior of SMAs into two major phenomena. The first one is known as *pseudo-elasticity* (PE), in which nonlinear elastic behavior is observed. Here, very large strains upon loading occur, but full recovery is achieved in a hysteresis loop upon unloading. When an SMA experiences the *shape memory effect* (SME), it exhibits a large residual strain after loading and unloading. This strain may be fully recovered simply by raising the temperature of the body.

With the increasing use of SMAs in recent years, it is important to investigate the effect of cracks. Theoretically, the stress field near the crack tip is unbounded. Hence, a stress-induced transformation occurs, and the martensite phase is expected to appear in the neighborhood of the crack tip, from the very first load step. For a crack that propagates quasi-statically, the near tip stress field is governed by near tip stress intensity factors, rather than far field stress intensity factors as in classical linear elastic fracture mechanics. This behavior implies transformation toughening or softening.

Shape memory alloys appear in many applications as layers in laminated composites, or as fibers that are embedded in a polymeric or metallic matrix, see for example [1-3]. These are usually called *active laminates*, since the SMA fibers or layers may assist in controlling the bending, buckling or post-buckling behavior of the composite [4]. Although these studies describe the essential phenomena of smart laminated composites, in none of them is the behavior determined for a crack slowly propagating along the interface between an SMA and a linear elastic or elasto-plastic medium. Hence, the main objective of this investigation is to obtain the transformation toughening behavior of a slowly propagating crack along this interface. This is achieved by means of a cohesive zone model. Since the energy dissipation caused by the inelastic

transformation strains in the vicinity of the crack tip depends upon crack advance, the outcome of this approach is a crack growth resistance curve.

The present study is a continuation of a recent investigation [5]. In that study, by means of a cohesive zone model, mode I crack growth resistance curves were obtained for a slowly propagating crack in a homogeneous shape memory alloy under plane strain conditions. Here, this approach was extended for the case of an interface crack where mixed mode behavior is expected. Specifically, two interface crack problems were considered: the behavior of a crack propagating quasi-statically along the interface between (1) a shape memory alloy and a linear elastic, isotropic medium and (2) a shape memory alloy and an elasto-plastic, isotropic medium.

For the first material pair, the size and shape of the transformation zones in the vicinity of the crack tip were derived from the asymptotic solution of an interface crack, using the assumption of small scale transformation zones for a stationary crack. Upon isothermal loading, three distinct zones are generally observed in the examined body: the fully and partially transformed martensite zones in the vicinity of the crack tip and an austenite region at a distance from the crack tip. Hence, a crack along the interface is characterized by a varying mismatch oscillatory parameter ε, and consequently, three phase angles. These angles, ψ, ψ_s and ψ_f, describe the mode mixity at a distance L from the crack tip, the interface between the austenite and the partially transformed martensite, and the interface between the near tip martensite field and the partially transformed region, respectively.

The transformation toughening behavior of an interface crack was numerically obtained by means of a cohesive zone model with resistance curves presented. It was observed that for a fixed cohesive energy, the resistance curves depend upon the maximum traction t_0 of the cohesive elements. This results from a relatively large transformation zone and significant energy dissipation. Consequently, a higher applied load is required for crack propagation. In addition, increasing values of applied mode mixity $|\phi|$ results in increasing steady state resistance values. Similar analyses were carried out for the case of an interface crack between a shape memory alloy and an elasto-plastic material.

REFERENCES

[1] D.C. Lagoudas, D. Moorthy, M.A. Qidwai and J.N. Reddy, "Modeling of the thermomechanical response of active laminates with SMA strips using the layerwise finite element method", *J. Intell. Mater. Sys. Struc.*, Vol. **8**, pp. 476-488, (1997).

[2] Z.G. Wei, R. Sandsrom and S. Miyazaki, "Shape memory materials and hybrid composites for smart systems. Part II shape-memory hybrid composites", *J. Mater. Sci.*, Vol. **33**, pp. 3763-3783, (1998).

[3] J. Aboudi and Y. Freed, "Two-way thermomechanically coupled micromechanical analysis of shape memory alloy composites", *J. Mech. Mater. Struc.*, Vol. **1**, pp. 937-955, (2006).

[4] R. Gilat and J. Aboudi, "Thermal buckling of activated shape memory reinforced laminated plates", *Sm. Mater. Struc.*, Vol. **15**, pp. 829-838, (2006).

[5] Y. Freed and L. Banks-Sills, "Crack growth resistance of shape memory alloys by means of a cohesive zone model", *J. Mech. Phy. Sol.*, Vol. **55**, pp. 2157-2180, (2007).