DEPENDENCE OF THE ENERGY RELEASE RATE ON THE PROPAGATION SPEED OF MARTENSITIC TRANSFORMATION IN MATERIALS

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ABSTRACT

Martensitic transformation process is a dynamical process. The well-known experimental fact is: once the nucleation barrier has been overcome, the excess free energy becomes so large that the martensite plate grows rapidly until it hits a barrier such as another plate, or a high angle grain boundary. In the present paper, the dynamic energy release rate was derived. To obtain the analytical expression of the energy release rate, two simple cases were considered: one is a semi-infinite one-dimensional bar under the action of an impact load, and the other example is a spherical martensite inclusion expanding along its radial direction. From the two examples, it can be found that the dynamic energy release rate decreases with increasing the propagation speed of transformation, and when the speed reaches some critical value, the deriving force becomes zero. That means that the propagation speed of martensitic transformation has an upper limit.
KEYWORDS: Energy Release Rate, Martensitic, Transformation

INTRODUCTION

Martensitic transformation process is a dynamical process even though most researchers have taken the quasistatic assumption in their analysis. The well-known experimental fact is this: once the nucleation barrier has been overcome, the excess free energy becomes so large that the martensite plate grows rapidly until it hits a barrier such as another plate, or a high angle grain boundary. A single plate of martensite in steel grows in 10^{-5} to 10^{-7} s to its full size, at velocities approaching the speed of sound. Using resistivity changes to monitor the growth of individual plates of martensite in, e.g. Fe-Ni alloys, researchers have measured speeds of 800-1100 m/s (Nishiyama, 1978). In fact, such a dynamic propagation process of the martensite is always observed in practice even if the applied load is quasistatic. Under impact, or other dynamic loading, the propagation of martensite becomes even more difficult to analyze. Because of the great speed of martensite growth, it is extremely difficult to study this transformation experimentally.
There have been extensive analytical, experimental and numerical investigations of static and quasistatic behaviors of martensitic transformations. On the other hand, the existing study of dynamic behaviors of martensitic transformation is rather limited. Escobar and

Q.P. Sun (ed.), IUTAM Symposium on Mechanics of Martensitic Phase Transformation in Solids, 111–120.

Clifton (1993) carried out pressure-shear plate impact experiments on Cu-14.44Al-4.19Ni single crystals to study the kinetics of the stress-induced phase transformation. By using the experimental data obtained in their work, Abeyaratne and Knowles (1997) determined the values of phase boundary velocity and driving force, as well as the kinetic law which relates these two quantities. Chen and Lagoudas (2000) carried out a dynamic analysis of the impact induced phase transformation in a shape-memory alloy rod, with a special focus on the propagation of stress waves and phase transformation fronts in the rod. Wang et al. (1999) considered the dynamic growing spherical inclusion, and they obtained the analytical solution for the elastodynamic problem based on the work of Willis (1965) and Mikata and Nemat-Nasser (1988). Ball and James (1987) and James (1981, 1986) considered the equilibrium shock problems.

The Gibbs free energy of the system will be reduced during the martensitic transformation process, and the released energy will serve as the driving force for the phase transformation. The Gibbs free energy of the system can be divided into the chemical free energy, the interfacial free energy and elastic energy. The elastic energy is the most complicated part to evaluate. In dynamic fracture mechanics, generally speaking, the energy release rate associated with crack propagation will decrease with the velocity of crack propagation. And when the velocity of crack propagation reaches some critical value, the energy release rate becomes zero. Since we know that energy dissipation is inevitable in the crack propagation process, crack propagation at velocities exceeding the critical velocity is impossible in the continuum model. Using basic ideas of dynamic fracture mechanics, we can reason that released elastic energy associated with the formation of martensitic phase should also depend on the propagation speed of martensitic transformation. By setting the energy release rate equal to zero, one can find a maximum limiting velocity for martensitic transformation in materials.

Therefore in this investigation, we will derive the elastic energy release rate of the martensitic transformation as a surface integral. Two examples are considered to calculate the energy release rate as a function of the transformation speed; one is a one-dimensional bar under impact loading, the other is a spherical transformation domain expanding along the radial direction. For such simple cases, we did find the energy release rate decreases with increasing propagation speed of the transformation domain.

DRIVING FORCE FOR THE PROPAGATION OF MARTENSITIC TRANSFORMATION

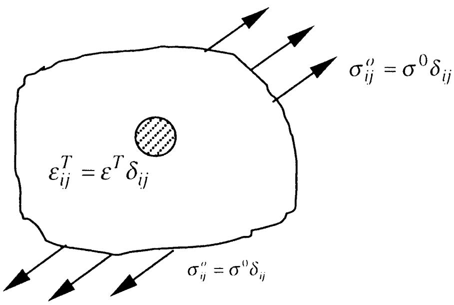

Figure 1. A finite elastic body containing a spherical transformation inclusion with a dilatational eigenstrain