Effect of nonlocal elasticity on internal friction peaks observed during martensite transformation

ALİ DOĞAN
Fırat Üniversitesi, Fen-Ed. Fak, Fizik Bölümü, 23169, Elazıg Türkiye

ABSTRACT. The internal friction associated with martensite is calculated using elastic interaction energy between dislocations and solute atoms in nonlocal elasticity during low temperature aging process. The relaxation strength depends on the lattice parameter of the crystal as well as the temperature and the heating rate. The peak heights increase with increasing lattice parameter. The proposed model can demonstrate more realistically the shape of the change of internal friction versus temperature when nonlocal elasticity is included.

KEYWORDS. Internal friction; dislocation; solute atoms; solid state phase transformation; martensite.

PACS Nos 81.30; 62.20; 62.40

1. Introduction

In the last thirty years, internal friction associated with the martensite has been of interest to metallurgists to explain the aging and tempering process of martensite with subambient Ms temperature, i.e. martensite starting temperature [1–4]. There are three types of processes viz. relaxation, aging and tempering where the redistribution of solute atoms such as carbon can take place at temperatures as low as 230 K in virgin lenticular martensite having body-centered-tetragonal (b.c.t) lattice [4–16]. The low frequency internal friction evolution of Fe-28 Ni-0.2 C lenticular martensite during low temperature aging has been simulated by four peaks at different temperatures and a model has been proposed to describe the internal friction evolution of the process concerning with the diffusion of carbon atoms to dislocations at low temperature [4,17]. The classic (local) continuum theory of elasticity was used for computation of the internal friction peaks in the models in question. Therefore, the peak heights and shapes did not exactly fit the experimental results.

This paper determines the effects of nonlocal elasticity on the internal friction peak heights observed during the low temperature aging process considering the elastic interaction energy between a dislocation and a solute atom in nonlocal elasticity.

2. Nonlocal elasticity effect and internal friction model

The basic idea of nonlocal elasticity is that the theory takes into account long-range, i.e. nonlocal interactions in the determination of the elastic stresses originating from a displacement field, eliminating the stress singularities which appear in classic (local) elasticity. The theory is linear in strain, like the classical (local) continuum theory of elasticity. By considering the interaction due to the size effect of a solute atom as being
due to the effect of a dilatation centre, in a linear, isotropic, nonlocal elastic medium, the
elastic interaction energy between an edge dislocation and a solute atom in nonlocal
elasticity is obtained as [18, 19]

\[ V_m(r) = -\frac{\mu b (1 + \nu) A \Delta V \sin \theta}{3\pi (1 - \nu)} \left[ 1 - \exp\left(-\frac{k_0^2 r^2}{a^2}\right) \right], \tag{1} \]

where \( a \) is the lattice constant, \( k_0 \) is the attenuation factor, \( b \) is Burger’s vector of
dislocation and \( r, \theta \) represents the plane polar coordinates, \( \Delta V = V - V_0 \) is the volume
change due to an impurity defect which can be obtained from experimental data or
atomistic theories of the region surrounding the defect [20]. The shear moduli and
Poisson’s ratio of the slip system \{111\}, \langle 110 \rangle are determined by [21]

\[ \mu = 3C_{44}(C_{11} - C_{12})/[4C_{44} + C_{11} - C_{12}], \]
\[ \nu = C_{12}/2(C_{12} + C_{44}). \tag{2} \]

If \( a \) goes to zero, (1) reverts to the result of classical elastic theory [4, 22]

\[ V_c(r) = \frac{\mu b (1 + \nu) \Delta V \sin \theta}{3\pi (1 - \nu)} r. \tag{3} \]

Under a force \( F \) an atom migrating by thermal agitation acquires a steady drift velocity
\( v \) (in addition to its random diffusion movement) in the direction of \( F \), where \( D \) is
coefficient of diffusion. This velocity may be described by the equation which is called
Einstein’s formula

\[ v = DF/kT, \tag{4} \]

where \( k \) is Boltzmann’s constant and \( F \) is given by

\[ F = -\frac{d V_c(r)}{dr}. \tag{5} \]

This force attracts a solute atom to a dislocation. From (1), (4) and (5), a steady drift
velocity of an atom can be obtained as

\[ v = D \frac{\mu b (1 + \nu) \Delta V \sin \theta}{kT 3\pi (1 - \nu) r^2} \left[ 1 + \frac{2k_0^2 r^2}{a^2} \right] \exp\left(-\frac{k_0^2 r^2}{a^3}\right) - 1. \tag{6} \]

For small \( r \) the exponential term can be approximated to the first two terms of the series
expansion and (6) may be evaluated to give

\[ v = 2DA \frac{2\mu b (1 + \nu) \Delta V \sin \theta}{kT (k_0/a)^2}, \tag{7} \]

where \( A \) is the interaction potential constant and is given by [23]

\[ A = [\mu b (1 + \nu) \Delta V \sin \theta / 3\pi (1 - \nu)]. \tag{8} \]

The atoms originally at a distance \( r \) from the dislocation reach it in a time given
approximately by [23]

\[ t = 2\pi r/v \tag{9} \]