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Short communication

Effect of thermal cycling on martensitic transformation and mechanical strengthening of stainless steels – A phase-field study

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ABSTRACT

A 3D elastoplastic phase-field model is used to study the effect of thermal cycling on martensitic transformation as well as on mechanical strengthening of both austenite and martensite in stainless steel. The results show that with an increasing number of thermal cycles, martensite becomes more stable. Increase in strain, plastic strain and strain hardening lead to strengthening of austenite.

1. Introduction

Phase transformations play an important role in enhancing the mechanical properties of stainless steels. The solid state phase transformation of austenite to martensite, known as martensitic transformation, occurs during quenching and imparts significant strength to steels. Reverse phase transformation of martensite to austenite occurs during intercritical annealing and has been reported to improve the yield strength, by grain refinement, and the ductility of steels [1–3].

Reversion of martensite can occur either by a shear mechanism or a diffusion-controlled mechanism. During reversion by a shear mechanism, dislocations from martensite are inherited into reversed austenite and thereby increase the ductility of steels [1,4]. Morevoer, reversion of martensite leads to grain refinement [1,2,5,6] and grain boundary strengthening [7], which are reported to be effective strengthening mechanisms. Grain refinement can lead to reduction of M_s temperature [8], increased retained austenite [9,10] and dislocation density [11].

Owing to the importance of martensite formation, reverse phase transformation and grain refinement in enhancing the mechanical properties of steels, several thermo-mechanical processing methods have been developed [1,6,12]. Thermal cycling, i.e. repeated quenching and subsequent heating, has proved to be an effective way of grain refinement and strengthening of steels [10]. Durlu reported an increase in dislocation density and strength after thermal cycling of Fe-Ni-C single cystals [13]. Alaei et al. have recently showed that dislocations are inherited from martensite to reversed austenite and that the dislocation density as well as the yield strength increase with increasing number of thermal cycles in an Fe-Ni-C TRIP steel [14]. Although the experimental studies showed that thermal cycling leads to strengthening of steels [10,13,14], it is essential to study the role of austenite and martensite in mechanical strengthening due to thermal cycling.

Several constitutive and phenomenological models have been proposed to study martensite formation and the relation between phase transformation and plasticity [15–17]. The phase-field approach [18,19] has been successfully applied to study martensitic transformation and other solid state phase transformations [20–28] as well as the reversion of martensite to austenite by a shear mechanism [27,29–31]. In the present work, the effect of thermal cycling on martensite formation and reversion of martensite by a shear mechanism as well as on mechanical strengthening of stainless steel is studied, by using a 3D elastoplastic phase-field model [20,29].

2. Phase-field model

The phase-field equation governing the microstructure evolution is given by:

$$\frac{\partial \eta_p}{\partial t} = -\sum_{q=1}^{q=v} L_{pq} \frac{\delta G}{\delta \eta_q} \tag{1}$$

where η_q is the phase field variable that tracks the evolution of martensite, v is the total number of martensite variants and L_{pq} is a matrix of kinetic parameters. Martensite variants (laths), which form in 24 different crystallographic orientations according to the Kurdjumov-

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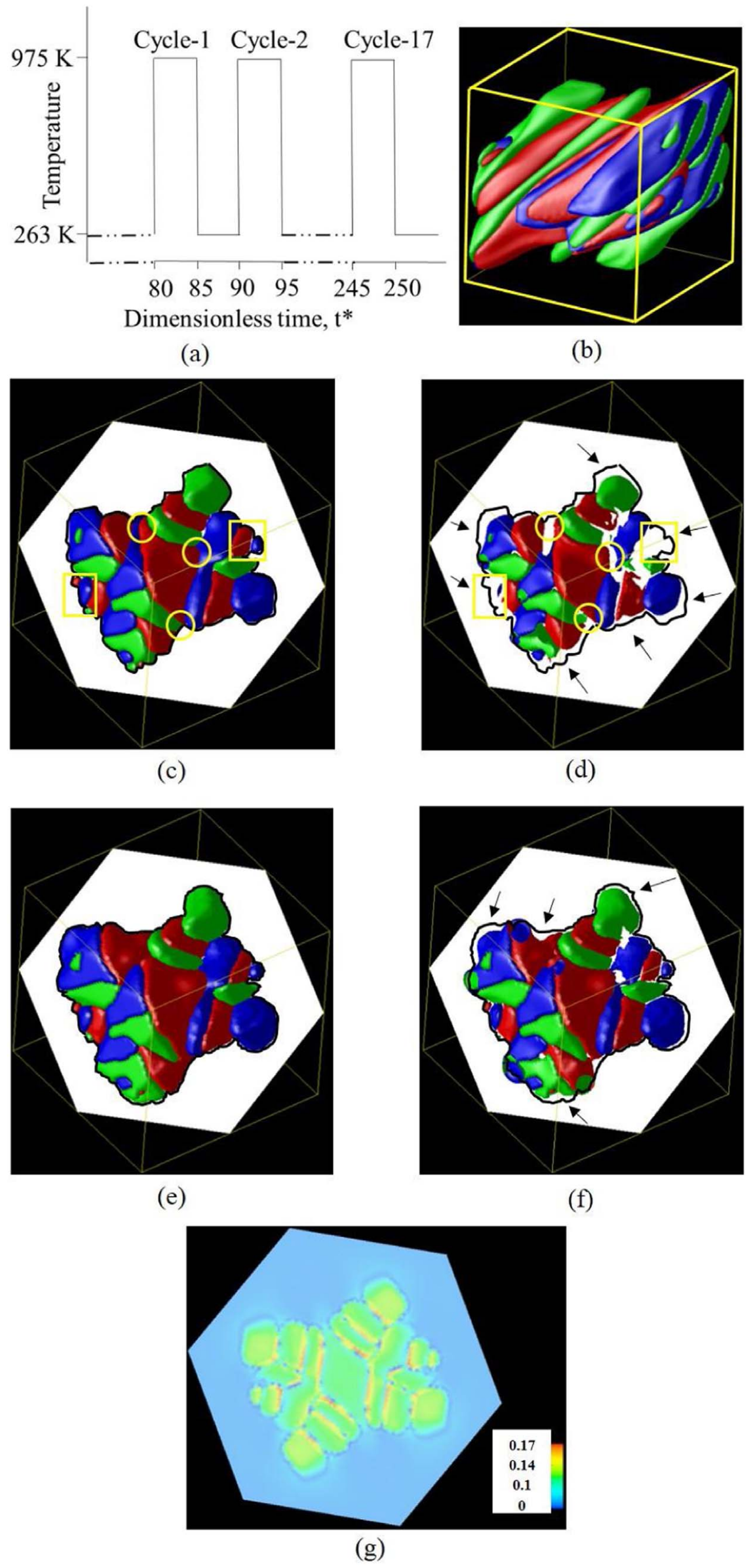

Fig. 1. (a) Schematic of the simulated thermal cycling process. Microstructures at (b) t^*=80 (side view) (c) t^*=80 (top view) (d) t^*=85 (e) t^*=190 and (f) t^*=195 and (g) von Mises equivalent plastic strain plot of the microstructure in (d). Martensite variants -1,2 and 3 are shown in red, blue and green, respectively. Austenite on the $(111)^{\gamma}$ plane is shown in white. Arrows point towards the areas where reversion occurs.