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A MODEL FOR EUTECTOID STEEL SUBJECTED TO HEAT TREATMENT AND ITS FINITE ELEMENT SIMULATION

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ABSTRACT

This work presents a thermodynamic model for phase transformations occurring during steel heat treating. The focus is on an eutectoid steel, where three phases have to be accounted for: Austenite, which is stable at high temperature; Pearlite, stable at low temperature and coming from a diffusive transformation; Martensite, a low temperature stable phase which originates through a displacive transformation. A Ginzburg-Landau framework is proposed [1], similarly to the approach described by Brokate and Sprekels [2] and followed by Bouville and Ahluwalia [3] among others. Thus, a convenient form for the free energy, as a function of one or more variables, named *order parameters* , is assumed, together with some evolution laws. Additionally, the model must obey the principles of thermodynamics.

The existing literature shows the importance of the choice of the order parameters, which mark the phase change. Commonly adopted order parameters force the model to a microscopic scale [4]-[5]. The novelty of this work is in developing a higher scale model. This leads to a different choice of the order parameters and of the evolution equations. The choice of the scale is determined by the necessity to model practical applications. Thus, for example, the model may be useful to predict the microstructure obtained during a heat treatment of a machine part.

Focusing on an eutectoid steel model, two order parameters need to be introduced. One marks the transition from Austenite to Pearlite, and the other the transition from Austenite to Martensite. Referring to the latter, existing literature makes use of an order parameter depending on the cristallografic texture orientation (thus frame dependent). In order to develop a macroscopic scale model, it is necessary to remove the frame-dependence of the order parameter. This is possible by assuming a quantity which is related to one of the strain tensor invariants.

Regarding the free energy function, due to the additivity property, it is possible to split the total amount into the sum of three contributions: one dependent on the order parameter describing the Austenite-to-Martensite tranformation; one dependent on the order parameter describing the Austenite-to-Pearlite transformation and a gradient term, which accounts for non-locality properties. The free energy formulation must satisfy the second law of thermodynamics, and an energy balance must be provided as well.

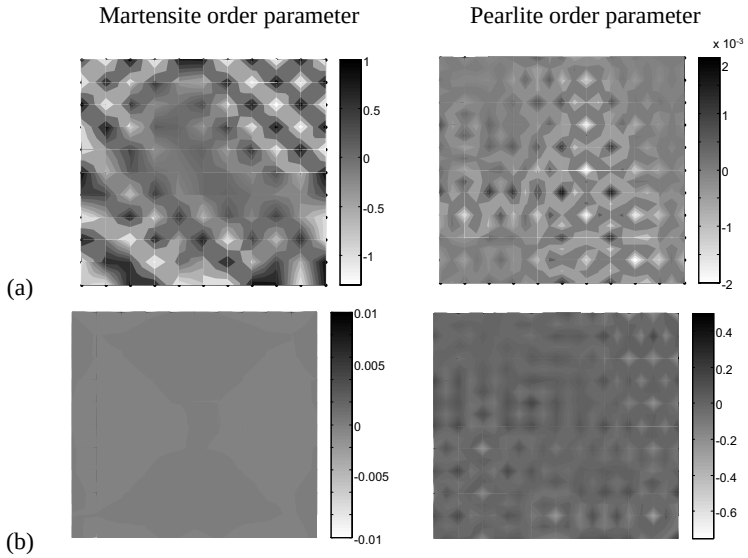

Figure 1: (a) Quenching test. (b) Normalising test.

In addition, two other equations are needed: one is the linear momentum equation; the second is the Cahn-Allen equation [6], an evolution law for non-conserving order parameters. The Cahn-Allen equation accounts for the evolution of the order parameter which drives the transformation from Austenite to Pearlite.

The outlined problem is non linear, time dependent and involves deformation gradient. A variational formulation is cast and a finite element simulation is carried out showing the effectiveness of the model. The framework is able to predict the microstructure resulting from two commonly used heat treatments such as Quenching (rapid cooling from a high temperature) and Normalising (moderate rate cooling from a high temperature).

Figure 1(a) shows the results for a Quenching test: Martensite is obtained at the boundaries while in the domain core, where the cooling rate is less rapid, Pearlite results. On the other hand, Figure 1(b) shows a Normalising test: only Pearlite is obtained within the whole domain. These results are consistent with experimental observations.

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