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Overview of the current issues in austenite to ferrite transformation and the role of migrating interfaces therein for low alloyed steels

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ABSTRACT

Solid state phase transformations in metals, and more precisely the science of transformation interfaces, is a key point to understand the formation of nano/microstructure, and thus, as a result, many physical properties such as mechanical properties, conductivity, thermoelectric and magnetic properties of materials.

Steels are by far the most widely used metallic alloys, and a deep understanding of their microstructure is essential to tailor their service properties. The transformation of high temperature parent austenite to ferrite is one of the main issues controlling the final microstructures, and for more than a century, this has driven metallurgists to investigate in detail this solid state transformation, and, particularly, the details of austenite to ferrite interface migration.

In this paper, we review the evolution of the different concepts and experiments developed in the last century to investigate this transformation mechanism.

After a brief introduction, most of the physical models developed, which reduce the α/γ interface into a mathematical body with its own properties, are reviewed and discussed with regard to experimental data. The increased availability of highly sophisticated experimental and modelling tools in recent decades has considerably clarified the perceptions of transformation interfaces. These recent advances are presented, and their contribution to the field of migrating austenite–ferrite interfaces are highlighted in a third section. In the fourth section, the latest developments in experimental methods, which now allow the quasi atomistic direct characterization of the interface chemistry, are presented. The observed conditions at the interfaces can be compared with model predictions, which is believed to be a critical step for the refinement of the theoretical concepts guiding the understanding of the interface migration. Finally, in the concluding section, the present situation of the field is summarized, and some perspectives regarding the expected future developments are sketched.

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1. Introduction

Solid state phase transformations, and more precisely the science of transformation interfaces, has been an active field of research for over a century. It draws attention and enthusiasm for many reasons. Firstly, from a theoretical point of view, it creates the wealth of knowledge of modern physical metallurgy and its contribution to domains such as thermodynamics, diffusion and crystallography is unquestionable. Secondly, from a practical point of view, it controls the nano/microstructure formation and their features. It therefore influences many properties such as mechanical properties, conductivity, thermoelectric and magnetic properties.

In steels, a large spectrum of mechanical properties can be achieved by controlling the microstructure features such as volume fraction, size distribution, topology and morphology of phases. Indeed, the allotropic transformation that iron exhibits at atmospheric pressure together with the capabilities of forming carbides provides an unequalled richness of microstructures resulting from combined phase transformations. In particular, the formation of bcc-ferrite from fcc-austenite is of particular interest because it is the basis for other closely related phase transformations occurring at lower temperature such as bainitic and martensitic transformations.

Recent advances in the field of phase transformation have made it possible to better understand and control both the microstructure formation and the mechanical properties of High Strength Steels (HSS) such as TRansformation Induced Plasticity (TRIP) and Dual-Phase (DP) steels with low manganese content (generally lower than 2 wt%) [1,2]. More recently, tremendous efforts were made to develop new advanced steels with very different alloying concepts than previously. For example, the medium manganese steels, with manganese contents between 4 wt% and 12 wt%, fall into this class [3,4]. The addition of these alloying elements leads to property improvements that can be traced to a large degree on their effect on phase transformations. However, the understanding of these mechanisms is not as advanced as it needs to be. From a scientific perspective, we are now at the exciting point that we have both experimental and modelling approaches that can provide insight into the atomistic mechanisms and the alloying element interactions with the bcc-ferrite/fcc-austenite interface [5]. As a consequence, it is certainly an appropriate moment to review the questions of highest priority and to put forward avenues for further researches in that field.

The theory and the models for ferrite growth under isothermal conditions in low alloyed steels have been extensively researched and documented over the last decades. We encourage the reader to study two excellent reviews on this topic [6,7]. The ferrite phase transformation process is dynamic and its kinetics results mainly from the interactions between diffusion fields in bulk phases and from the behaviour of -both carbon and alloying elements through the α-ferrite/γ-austenite interface [8].

The present review is concerned with the science of transformation interfaces in alloy steels, and more particularly, with the interactions between alloying elements (such as manganese and nickel) and the austenite to ferrite migrating interface. The discussion will be mainly restricted to the purely diffusive transformations in hypo-eutectoid steels involving both α-ferrite and γ-austenite at a temperature usually above 600 °C.

The structure of this paper is as follows. In Section 2, this contribution begins with a review of some long-standing fundamental issues, many of which are related to the various models of α/γ interface migration and to the crystallography of the α/γ interface. The simplest model reduces the interface into a mathematical surface following the pioneering work of Gibbs [9], assumes the interface to be sharp without any specific properties and considers a local equilibrium to be applied at the interface. Other more complex models such as the *free energy dissipation*, the *solute drag* and the *phase field models* have been developed to account for the observed deviation from Local Equilibrium in