In situ observation of austenite–ferrite interface migration in a lean Mn steel during cyclic partial phase transformations

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Abstract

High-temperature laser scanning confocal microscopy (HT LSCM) has been applied to investigate the austenite–ferrite interface migration during cyclic phase transformations in situ in a Fe–Mn–C alloy. It has been found that during the cyclic phase transformations the transformation proceeds via the migration of existing austenite–ferrite interfaces. The interfaces migrate in a retraceable way. For the first time, the so–Called stagnant stage has been observed directly. The new in situ observations show that the interface migration rates for interfaces in different grains are comparable with each other prior to soft impingement, while the equilibrium migration distances for different interfaces can be quite different, depending on the local grain size. The average interface velocities as measured by HT LSCM are in very good agreement with the velocities derived from dilatometric data, and those are predicted by a local equilibrium transformation model.

1. Introduction

The kinetics of austenite (γ)-to-ferrite (α) transformation and its reverse transformation remain of great interest because of their importance in the design of both conventional ferrite–pearlite and advanced multiphase steels. Hence they have been widely studied both experimentally and theoretically. Both surface techniques (e.g. optical microscopy [1–4], high-resolution transmission electron microscopy [5], high-temperature laser scanning confocal microscopy (HT LSCM) [6] and the decarburization technique [7,8]) and bulk techniques (e.g. calorimetry [9], dilatometry studies [10–13], X-ray diffraction [14,15] and neutron depolarization [16]) have been used to investigate the growth mechanism of this transformation. Numerous

numerical investigations based on chemical thermodynamics (see e.g. [17–28]) have been performed in order to describe the experimentally obtained results with very few fitting parameters. The progress in understanding austenite-to-ferrite transformation in the last decade has been systematically reviewed in Ref. [29].

In the past, experiments such as isothermal annealing followed by continuous cooling/heating or isothermal holding have been performed to study the growth mechanism of the austenite-to-ferrite transformations. In such experiments the transformation invariably starts from a fully austenitic sample, and proceeds via ferrite nucleation and growth. Only the overall transformation kinetics can be obtained from these normal experiments. As the effect of nucleation on the measured overall phase transformation kinetics cannot be determined with any accuracy [30–32], determination of fine details of the growth kinetics of phase transformations remains inaccessible.

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Recently, a new experimental procedure, the cyclic partial phase transformation concept [33], has been designed to study the growth kinetics of phase transformation in detail in the absence of an interfering nucleation effect. Furthermore, by staying within the two (ferrite–austenite) phase region, pearlite dissolution is avoided, which enables a more accurate investigation of the ferrite-to-austenite transformation kinetics.

When recording such partial cyclic transformation using dilatometry in Mn steels, two special features are observed [34,35]: (i) a stagnant stage [34,36], during which the degree of transformation does not vary while the temperature changes. Given the excellent qualitative agreement with prediction of a local equilibrium (LE) model [37–39], it was deduced that the stagnant stage is due to a growth mode transition from local equilibrium – negligible partitioning (LE-NP) to local equilibrium – partitioning (LE-P). While less likely, the stagnant stage could also be caused by renewed ferrite or austenite nucleation upon reversal of the heating/cooling cycle; and (ii) a growth retardation stage [35], which was found to be due to the interaction of the moving interface with the residual Mn spike created by prior interface passage. From an analysis of the phenomenon of growth retardation, it was deduced that the path of the moving interface during cyclic phase transformations should be retraceable. In situ observation of interface migration during cyclic phase transformations is required to directly prove this deduction.

In this work, HT LSCM is applied to directly observe the movement of austenite–ferrite interface during the cyclic partial phase transformations in a lean Mn–Containing steel, and to demonstrate the interfacial mobility during the stagnant stage as well as the retraceability of the interface during the cycling. Furthermore, the kinetics obtained from the in situ observation of migrating interfaces will be compared with a dilatometric study as well as the prediction for interfacial movement from an LE transformation model.

2. Experimental

The material investigated is a Fe–Mn–C alloy with a composition given in Table 1. The average ferrite grain size at room temperature was 50 μm. To measure the phase transformation kinetics during the cyclic partial phase transformations, two different techniques are used: dilatometry and HT LSCM. A Bähr 805A dilatometer is used to measure the dilation of the specimen (10 mm in length and 5 mm in diameter) during the cyclic experiments, and

the dilation signal can be translated into the average phase transformation kinetics within the bulk of the sample using the "rule of mixtures" (also called as "lever rule"). In addition to the temperature–Control thermocouple, a second thermocouple, placed at a distance of 4 mm from the first, was used to check the temperature gradient along the length of the specimen. The measured temperature gradient was always smaller than 5 °C. The dilatometer experiment is performed under a high vacuum.

A Yonekura VL 2000 DX high-temperature laser scanning confocal microscope equipped with an SVF 17 SP mirror furnace (Fig. 1) is applied to directly observe the local interface migration on the surface of the sample (5 mm in diameter and 1 mm in height) during the cyclic phase transformation experiment. The laser scanning confocal microscope was invented by Minski in 1961 [40], while the infrared furnace setup is based on the work by Cho et al. [41]. HT LSCM has been frequently applied in the study of phase transformations in metals (see e.g. [6,42]). To avoid oxidation on the surface of the sample, LSCM experiments are performed under a high-purity argon atmosphere.

A type H cyclic heat treatment involving extended hold times at both the lower and the upper cycling temperature
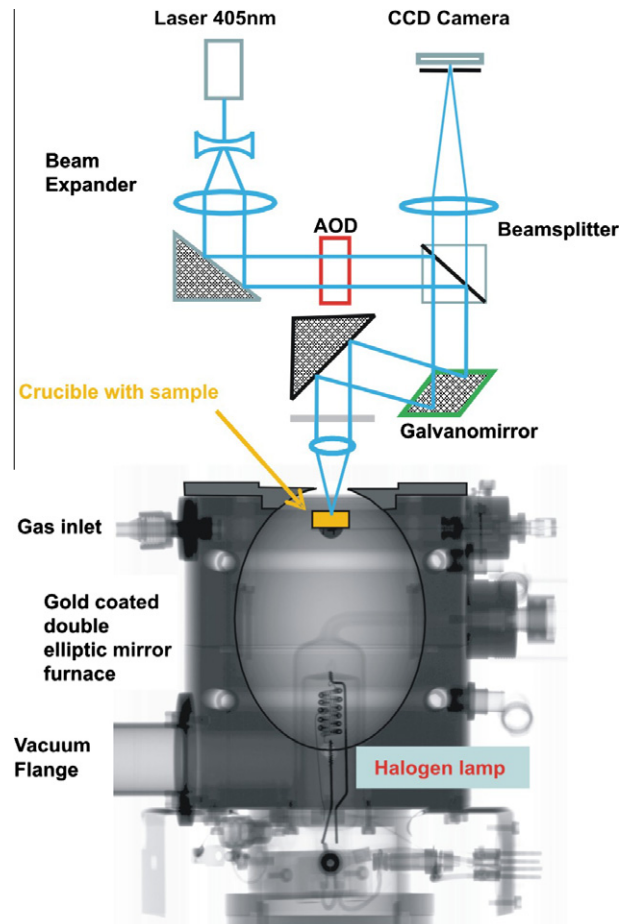

Fig. 1. Schematic sketch of HT LSCM Yonekura VL 2000DX and Mirror furnace SVF 17 SP.

Table 1
Chemical composition of the lean Mn steel (mass fractions of component i are denoted by w_i, mole fractions by x_i).

	C	Mn	Si
$w_i \cdot 100$	0.023	0.170	0.009
$x_i \cdot 100$	0.107	0.173	0.018