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A preliminary in-situ TEM study of martensite/austenite interface migration in an Fe-20Ni-5.4Mn alloy

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Abstract

We report an in-situ TEM investigation of a reverse martensite transformation in an Fe–Ni–Mn alloy at temperature ranging from 400 °C to 600 °C. Two modes, normal and ledge motions, have been observed during retreating migration of the broad interfaces (~habit plane) between austenite and martensite. A large number of dislocations nearly perpendicular to the interface were observed in the volume swept by a fast normal motion of the interface, while few dislocations are left behind in the fresh austenite transformed by a ledge motion. During the ledge motion, concurrent displacement of the interfacial dislocations along both ledge riser and terrace plane is evidently detected. The normal displacement component for the dislocations in the broad interface is small and this is associated with a slow normal motion of the interface.

Keywords: In-situ TEM; lath maternsite; austenite/martensite interfaces; dislocations; ledges

1. Introduction

Lath martensite is a typical microstructure in high strength structural steels. There is an increasing trend towards its use. For example, it replaces or partly replaces the traditional ferrite + pearlite microstructure in automotive sheet steels to upgrade the strength of the steels [1]. Considerable efforts in understanding lath martensite have been made especially in the last century. Nevertheless, as concluded in the third edition of the well-known book by Christian [2],

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"There is at present no successful theory of crystallography of lath martensite". In contrast to the twinned martensite, the lath martensite, containing dislocations both inside and in the interfaces, cannot be interpreted with the original phenomenological theory of martensite crystallography (PTMC)[3, 4].

The Fe–20Ni–5.4Mn (wt.%) alloy serves as a good model alloy for an investigation of lath martensite, since a considerable amount of austenite remains to facilitate the analysis of martensite/austenite interfaces using transmission electron microscopy (TEM). A pioneer study of this alloy was made by Sandvik and Wayman [5, 6], who observed one set of dislocations in the habit plane. More recent progresses on interfacial structures have been obtained mainly by Japanese researchers, e.g., [7-9]. The dislocation structures between lenticular martensite and austenite are claimed to be similar to that of lath martensite [9]. A high resolution TEM investigation of the interfaces suggests that the interfaces should contain two sets of near screw dislocations [9]. How the interfacial dislocations move during the martensitic transformation remains unclear. A direct observation of the interface motion during the transformation is desirable, but this was proved to be impossible for the Fe–20Ni–5Mn alloy with the available facilities. Therefore, an in-situ hot-stage TEM was used to examine the migration of the existing interfaces during a reverse transformation of pre-existing martensite to austenite [10], to provide direct evidence on the possible migration modes of the habit plane. According to this study, the austenite/martensite interfaces were found to move by a ledge mechanism, in contrast to the classic picture of uniform normal motion of the interface during a lath martensitic transformation. The present investigation is the continuation of the previous study [10]. More locations of the martensite lath were carefully examined, and richer migration modes were observed.

2. Experimental

The alloy and specimen preparation are the same as that for the previous study [10]. Only the final treatment is briefly described below. An alloy Fe–20.2Ni–5.4Mn (wt.%) was austenized at 1200 °C for 1 h before being quenched in water. The specimens were then placed at -80 °C for 2h in order to form a sufficient amount of martensite to study. Standard TEM samples were obtained by mechanical polishing and electropolishing (using a 4% perchloric acid–ethanol solution at -35 °C with an applied current of 10 mA). In situ TEM experiments were performed in a JEOL 2010 microscope operated at 200kV using a GATAN heating holder. Samples were heated first at a high heating rate (several °C/min) up to 400 °C. The temperature was then increased by increments of 5 °C following long periods of observation (several minutes). The interface motions were recorded using a MEGAVIEW III camera operated at 25 fps and a DVD recorder. Over twelve hours recording were obtained from various locations in two samples. Still images were then extracted from video sequences. The overall microstructure was examined prior heating using conventional bright field imaging. Electron diffraction patterns were used frequently during heating to identify the phases.

3. Results

During heating, a reverse transformation of martensite was observed at different temperatures in the range from 450 °C to 600 °C. The transformation occurs either by retreating the existing interfaces between martensite and residual austenite or by nucleation and growth of fresh austenite from martensite. The migration of interfaces exhibits various modes, clearly indicating anisotropic mobility of interfaces. In some locations, normal motion of interfaces is possible, but in the other locations, the interfaces migrate via lateral motion of ledges. These two modes were observed operating either at the lath tip (possibly the lath edge) or along the lath side (possibly the habit plane). The interface motion is evidently associated with generation and migration of dislocations. In general, the volume swept by normal motion of an interface tends to contain high density of dislocations, while ledge mechanism does not cause an obvious increase of dislocations behind the interfaces. There is no obvious link between the transformations temperatures and different modes of interface migration in individual cases. It is uncertain whether all reverse transformation is martensitic type. The observations may not represent the reverse transformation in a bulk material, since relaxation of the transformation strain is different in bulk and in thin foils (~a few hundreds of nm). However, the observed interfacial migration modes especially in the existing interfaces between lath martensite and austenite may be helpful for one to suggest a possible interface migration mode in a lath martensite transformation in a bulk material. Therefore, this is short paper mainly focuses on the retreating motion of the existing broad interfaces, which presumably represent the habit plane. Two typical examples of different migration modes are given below.

3.1 Normal motion

Figure 1 shows a series of bright field images extracted from a video sequence taken at 500 °C just after a temperature increase, with the time for Fig. 1a being arbitrarily set at t = 0. A narrow band of austenite (A) can be seen between two martensite laths (M). The interface between austenite and martensite is almost edge-on. The original austenite far from the interface can be recognized due to a sudden drop of dislocation density. The upper interface was observed clearly to migrate in its normal direction, leading to the growth of fresh austenite and the shrinkage of martensite. The interface migration is accompanied by generating a large number of dislocations in the volume swept by the interface. A sudden dislocation (marked by d in Fig. 1c) nucleation event presumably from the interface was detected. The migration rate can be measured with respect to a fiducial marker X indicated in the images. From Fig. 1a to 1b, the interface has moved at a rate of ~1.5nm/s. The interface continues to migrate at an increasing speed (~3 nm/s). The overall interface migration can be measured in Fig. 1e, which gives the image difference between Fig. 1a and Fig. 1d. It clearly shows the overall interface migration (marked by m in Fig. 1e) using the fixed point X as a reference. The average migration speed is about 2 nm/s. The dislocations behind the interface are found attached to the interface at one end, e.g. d' in Fig 1c, while their other ends probably terminate at the surface. The interface virtually pulls the dislocations during its migration. As a result, the dislocations are nearly perpendicular to the interface and its length increases with the displacement of the interface. Each inner dislocation is likely attached to a particular defect in the interface, such a dislocation node, where two interfacial dislocations meet. This is possible since the interface may contain two sets of dislocations [9]. However, how the dislocations are generated with the normal motion of the nodes requires further investigations. It would be interesting to link the generation mechanisms of the dense inner dislocations in Fig. 1 and in a usual martensite lath.

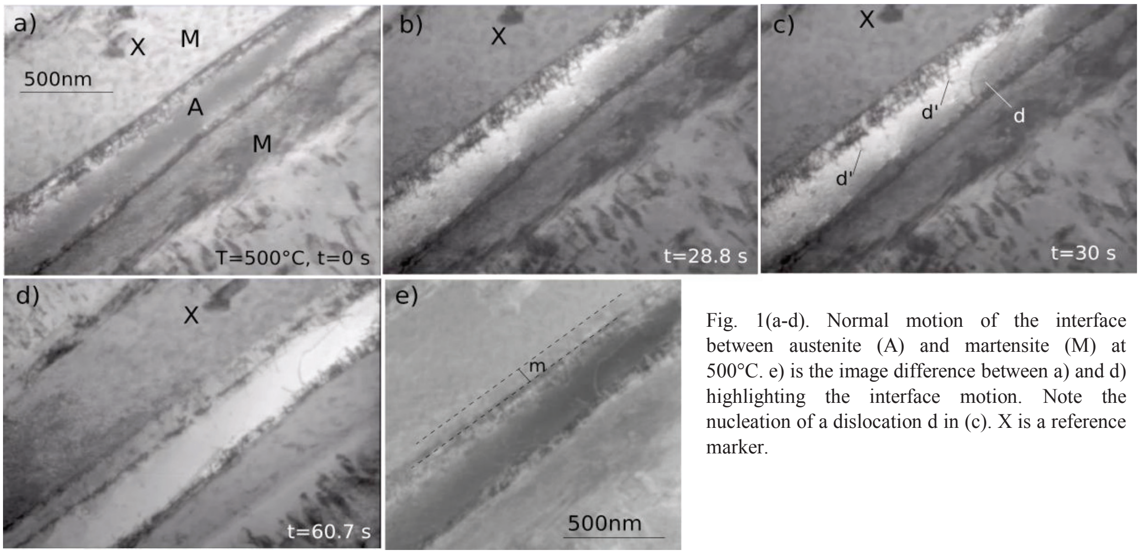

Fig. 1(a-d). Normal motion of the interface between austenite (A) and martensite (M) at 500°C. e) is the image difference between a) and d) highlighting the interface motion. Note the nucleation of a dislocation d in (c). X is a reference marker.

3.2 Ledge motion

Figures 2 show a typical ledge motion at 560 °C. The image difference between Fig. 2a and Fig. 2e is given in Fig. 2f to demonstrate the migration process. Although the ledge motion (LM) (average speed ~0.6nm/s) is clearly evidence, a normal motion (NM) (average speed of ~0.2nm/s) of the terrace plane can be also detected. Interfacial dislocations are clearly seen in the broad interface, with two of them (1, 2) indicated in Figs. 2a and 2b. Concurrent glide of the interfacial dislocations along the terrace plane has been detected, as seen from the image difference between Fig. 2a and Fig. 2b shown in Fig. 2c. The motion of dislocations is accompanied with a component normal to the broad interface, and hence it is associated with the interface normal motion. The ledge riser exhibits a flexible shape as it moves. An intermediate smaller step (l) appeared in the course of ledge motion (Fig. 2d), probably when the ledge motion experienced a local obstacle. It straightened once the obstacle is passed as seen in Fig. 2e. Interfacial dislocations can also be observed in the ledge riser, as highlighted more clearly in the insert of Fig. 2e. These dislocations, which exhibit a similar contrast to those in the habit plane, are probably of the same type. However, these dislocations move faster when they are located in the ledge riser than in the terraces.

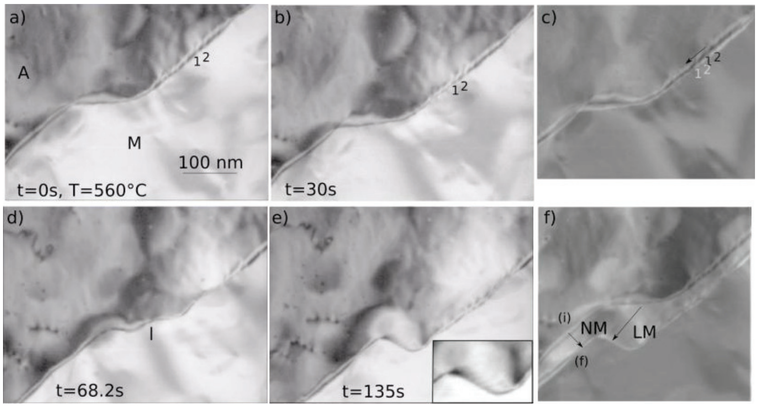

Fig.2. Ledge motion of the austenite/martensite interface. Displacement of interfacial dislocations are seen (1, 2) (a-c). f) is the image difference between a) and e) showing both ledge motion (LM) and normal motion (NM).

4. Summary

In situ TEM was used to observe retreating migration of broad interfaces between austenite and martensite in a Fe-20Ni-5.4Mn alloy. It revealed the existence of different modes of motions, including normal motion and ledge mechanism, associated with fast and slow migration rate, respectively. Irrespective to the modes of migration, these observations show that the habit plane is glissile and the concurrent motion of the interfacial dislocations is possible, in agreement with the assumption of the PTMC [3, 4]. The fresh austenite transformed by fast normal motion of the habit plane contains high density of dislocations, nearly perpendicular to the interface. The austenite transformed by the ledge mechanism usually contains dilute dislocations. The interfacial dislocations can move with both the ledge riser and the terrace. While the broad interface migrates mainly via lateral motion of ledges, the terrace plane itself is not completely immobile. The displacement direction of the dislocations in the broad interface is obviously inclined to the interface, with a minor normal component associated with slow normal motion of the board interface.

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