research note

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Detailed Microstructural Evolutions of TWIP Steel During Tensile Straining: In situ SEM Observations

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Abstract

Microstructural evolutions of twinning induced plasticity (TWIP) steel during tensile straining were investigated by in situ SEM observations. The results indicated that slip lines and mechanical twins as well as surface relief were increased with increasing strain, resulting in a stepped surface. Additionally, these deformation mechanisms could change the shape of each grain via shear and rotation. Non-uniformly distributed strain within grains led to change in the misorientation or banding of deformation markings with further straining.

Keywords: TWIP steel, Slip, Mechanical twinning, Surface relief.

1. Introduction

Recently, microstructural evolutions and mechanical properties of low stacking fault energy (SFE) twinning induced plasticity (TWIP) steels with chemical compositions close to Fe-30Mn-3Al-3Si (wt. %) have been investigated [1-3]. TEM observations have indicated that mechanical twins appear in the deformed structure after a certain plastic strain [2]. It means that the initiation of mechanical twinning happens at a critical dislocation density and slip is necessary before mechanical twins are formed.

In low SFE metals and alloys such as TWIP steels, it is clearly expected that increasing the applied strain can increase the volume fraction of mechanical twins until saturation. Several experimental observations have confirmed this behavior [3-7]. For example, the volume fraction of mechanical twins versus true strain was approximated by fitting the twinned area fraction data obtained from the SEM analyses. This curve is usually used as the mechanical twinning kinetic in the physical modeling of strain hardening behavior of TWIP steels [3-5]. However, these observations were conducted interruptedly, i.e., the structure of deformed samples was observed by stopping tensile tests at different strain levels. Because of the inhomogeneous behavior of the mechanical twinning and also, deformation and rotation of grains associated with strain distribution in the deformed structure, the mechanical twinning kinetic obtained via the interrupted observations may not be accurate. The aim of this study was to present a better microstructural evolution of TWIP steels during deformation processes. Therefore, a detailed microstructural evolution of TWIP steel, including rotation and distribution of strain as well as mechanical twinning, was analyzed using in situ SEM observations during tensile straining.

2. Experimental Procedure

TWIP steel was selected with a chemical composition of Fe-30Mn-3Al-3Si. Tensile test specimens with a geometry shown in Fig. 1 were punched out from the cold rolled and annealed TWIP steel plate with the thickness of 1.1 mm and the average grain size of 10µm. In situ SEM observations were conducted to investigate the surface relief of the samples during tensile testing. Surface of the specimens were polished and etched with 5% Nital solution by employing the standard metallography procedure. Then, specimens were examined in a Leica Stereo scan SEM equipped with a tungsten 260 filament with a voltage up to 30 kV.

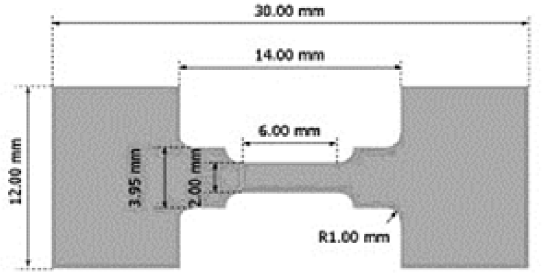

Fig. 1. The geometry of the tensile test specimen.

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3. Results and Discussion

The stress-strain curve obtained from in situ SEM straining experiment showed a similar behavior as the ones presented by Dini et al.[2]. SEM micrographs of particular zones at regular intervals of true strain (ε) are shown in Fig. 2 and 3. In Fig. 2, the evolutions of a multigrain area (view along the normal direction (ND)) at ε=0.05 and ε=0.40 are represented whereas the change of a particular grain can be seen in Fig. 3 with the true strain varying from 0.02 to 0.40.

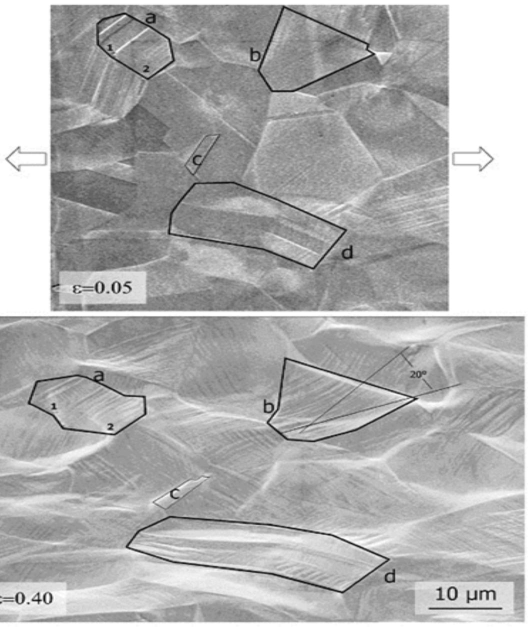

Fig. 2. The evolution of a particular multigrain area from ε=0.05 to ε=0.40.

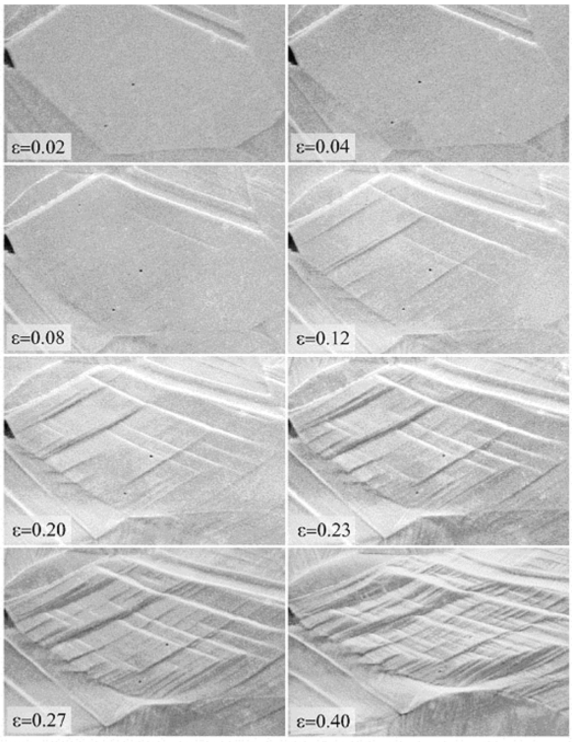

Fig. 3. The evolution of a particular grain (50 μm in width) from ε=0.02 to ε=0.40.

From these figures, some general features could be seen. First, the surface relief was detected due to the induced strain. The roughness of the surface was increased with increasing strain because of the slip by dislocation glide and twinning shear. The more the strain applied, the more were the dislocations and mechanical twins generated, thereby resulting in a stepped surface observed as parallel lines. It was seen that these deformation markings were mostly inside the grains. Moreover, it seemed that each grain was popping out of the surface, probably to indicate that a substantial part of the strain was accommodated at grain boundaries.

The second observed feature was grain rotation, e.g. the region marked with **c** in Fig. 3. This grain was ~20° clockwise rotated when analyzing the long grain boundaries. Both surface reliefs could be attributed to slip and mechanical twinning, i.e., shear and grain rotation could completely change the shape of a grain as seen in all marked grains.

It is interesting to notice that the total strain or the strain accommodated by a grain was not uniformly distributed within that grain. Some parts of a grain were strained more than the others. This led to misorientation or crystal lattice bending as shown in grain **b** (Fig. 2). A strain and/or rotation gradient was developed because of the bending of the parallel slip/twin lines. The misorientation reached ~20° when looking at the tangent of the slip/twin lines at the two grain boundaries where the lines stopped.

Many individual slip and twinning lines were visualized within grains as shown in regions **a** and **d**. These regions showed the evolution of the annealing twins. Although both parent phase and annealing twin had a common {111}-plane [7], the strain was not accommodated everywhere on this common plane. This was only true for the parent (region **a2**) and not for the annealing twin (region **a1**, where the slip/twin lines were perpendicular to the ones in the parent).

Even though a majority of the grains only activated slip/twin systems on one {111}-plane, some grains had an orientation favoring systems on two {111}-planes (figure 3). They appeared on the surface at the same strain and more and more lines, at more or less regular distances, came out of the surface as strain was increased. Much bending of the slip lines was not observed.

However, this did not exclude the rotation of the grain because the inspection of the evolution of the angle between the two types of slip lines could be an indication of the rotation of the grain (with the rotating axis not parallel to the normal direction). The angle varied from 57° at ε=0.02 to 44° at ε=0.40.

4. Conclusion

In situ SEM investigations of TWIP steel during tensile straining revealed that both slip and mechanical twinning could result in a stepped surface. Additionally, grain rotation, shear and non-uniformly distributed strain within grains could change the shape of each grain and misorientation. These phenomena, as well as the content of mechanical twinning, should be considered in the evaluation of TWIP steel microstructural evolutions.

References

[1] S. Vercammen, B. Blanpain, B.C. De Cooman and P. Wollants: Acta. Mater., 52(2004), 2005.

[2] G. Dini, A. Najafizadeh, R. Ueji and S.M. Monir-Vaghefi: Mater. Des., 31(2010), 3395.

[3] G. Dini, R. Ueji, A. Najafizadeh and S.M. Monir-Vaghefi: Mater. Sci. Eng. A., 527(2010), 2759.

[4] M.N. Shiekhelsouk, V. Favier, K. Inal and M. Cherkaoui: Int. J. Plas., 25(2009), 105.

[5] S. Allain, J.P. Chateau and O. Bouaziz: Mater. Sci. Eng A., 387-389(2004), 143.

[6] P.H. Adler, G.B. Olson and W.S. Owen: Metall. Trans. A., 17A(1986), 1725.

[7] S. Asgari, E. El-Danaf, S.R. Kalidindi and R.D. Doherty: Metall. Mat. Trans. A., 28A(1997), 1781.