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Communication

Change in dislocation configuration of deformed Fe-Ni-Nb-Ti-C-B alloy during stress relaxation

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Abstract: Transmission electron microscopy (TEM) was applied to investigate the evolution of dislocation configuration and strain induced precipitation behavior during relaxation process after deformation in Fe-Ni-Nb-Ti-C-B alloy. Experimental results indicate that the dislocation density is very high and distribute randomly before relaxation. As the relaxation time increasing, dislocation cells will form gradually by polygonization. The strain induced precipitation retards the progress. In the final relaxation stage, most dislocations get rid of pinning of precipitates and the cells have developed into subgrains with large size.

Key words: relaxation; dislocation cell; strain induced precipitation

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It is of great importance to study the interaction between the dislocations and precipitates in deformed crystals. The established works [1,2] have paid close attention to the recovery of dislocations and precipitation respectively while their interaction during stress relaxation has not been studied systematically. For this reason, an Fe-40%Ni (mass fraction) alloy containing Nb, Ti, C, B *etc.* was used to investigate the evolution of dislocation configuration and strain induced precipitation behavior during relaxation after deformation, emphasis was put on interaction between them.

1 Materials and experimental procedures

The alloy tested was melt in 5 kg vacuum induction furnace and cast in vacuum. Then the ingots were forged down to ϕ14 mm bar after heated to 1200℃. The chemical composition of the experimental material (mass fraction in %) is: Ni, 41.06; B, 0.0052; C, 0.032; Nb, 0.080; Ti, 0.094; and Fe balanced. To prepare samples for thermo-simulation test, the bars were machined into cylinders with 8 mm diameter and 12 mm length. Prior to the deformation, the samples were preheated at 1250℃ for 20 min, cooled at the rate of 2℃/s to 850℃, held for 1 min, and then deformed to true strain $\varepsilon = 0.25$. After that the samples were held for different time and followed by water quenching. The TEM samples were carefully grinded to produce a thin foil, followed by the electropolishing using a solution of 5% perchloric acid at −30℃ and a current of 50 mA.

2 Results and discussion

2.1 Measurement of stress relaxation curve

Stress changing with relaxation time is exhibited in **figure 1**. The stress relaxation curve will remain as straight line if without strain induced precipitation occurring [3]. It can be seen in figure 1 that the stress relaxation curve can been divided into three stages. The first stage immediately follows deformation and ends at about 10 s after deformation, in which stress decreases linearly with logarithmic time. After that, the curve turns and the second stage begins while stress decrease becomes obviously slower. This stage lasts for longer than 400 s. In the final stage, the curve turns and the curve slope of the stage is nearly the same as that of the first stage.

2.2 Evolution of dislocation configuration during relaxation

Figure 2 shows the dislocation configuration in specimens for different holding time after deformation. Figure 2(a) indicates that the dislocation density is very high and distribute randomly before relaxation. After relaxed for 30 s (figure 2(b)), the dislocation

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cells have started to appear, as marked by arrow. When the relaxation time increases to 60 s (figure 2(c)), nearly integrated dislocation cells have formed and the dislocations within the cells can be observed moving towards the cell walls. Figure 2(d) (relaxation for 200 s) shows that the dislocations display nearly same configuration as those in figure 2(c) (relaxation for 60 s). It demonstrates that the evolution of dislocation configuration during holding 60-200 s is relatively slow. As the relaxation prolonged to 1000 s (figure 2(e)), the dislocation cells have developed into perfect subgrains, whose size is larger than that of cells.

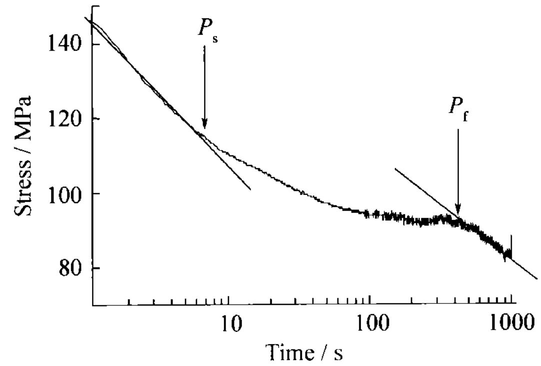

Figure 1 Stress relaxation curve of the tested alloy after predeformation for $\varepsilon = 0.25$ at 850℃.

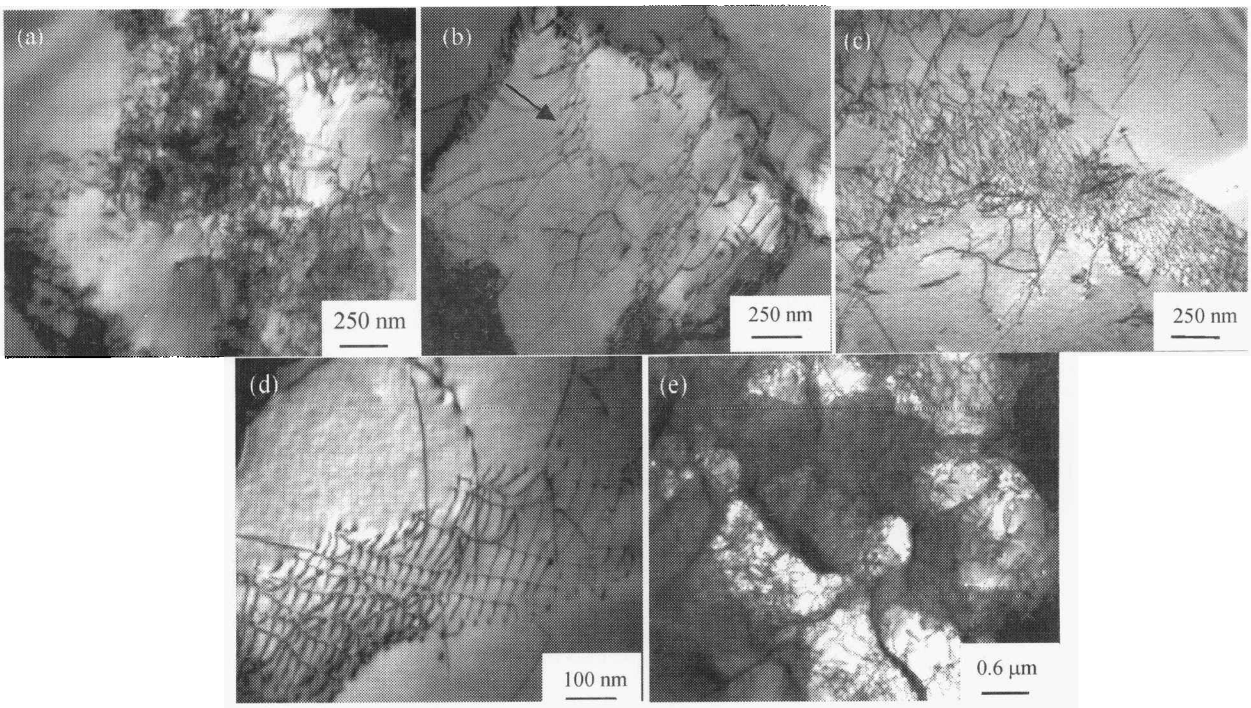

Figure 2 TEM micrographs showing dislocations configuration for speciments relaxing 0 s (a), 30 s (b), 60 s (c), 200 s (d), and 1000 s (e).

2.3 Interaction between the dislocations and strain induced nano-scale precipitates

Strain-induced precipitation of microalloying elements occurs during the same relaxation [4]. **Figure** 3(a) shows that in the specimens relaxed for 30 s, most dislocations are pinned by the particles whose size is under 10 nm. However, when the relaxation time reached to 200 s (figure3(b)), some dislocations are observed to get rid of pinning due to heat-exciting. It can be seen in figure 3(b) that a part of dislocation, as marked by arrow, is getting rid of pinning by way of Frank-Read source. Meanwhile, compared with the specimens relaxed for 30 s, the particles in specimens relaxed for 200 s have coarsened obviously and density of distribution has decreased, which makes the dislocations get rid of pinning easily.

2.4 Discussion

The experimental results indicate that: during the relaxation process in deformed Fe-40%Ni alloy, the denser and twisted dislocations will evolve into perfect dislocation cells gradually. Meanwhile, the dislocations are the preferred nucleation sites for strain induced precipitates [5]. Thus, the singular dislocation can be pinned at the early stage of precipitation, as shown in figure 3(a). When the dislocation network form, the pinned force becomes strong obviously and which makes the dislocation cells more stable for a longer relaxation time (during holding 60-200 s). On the contrary, after relaxed for 200 s, the dislocations can get rid of precipitates easily because the precipitates have coarsened. At this time, the progress of dislocation configuration will be accelerated obviously.

Furthermore, the Fe-40%Ni alloy can keep the fcc structure to room temperature and has a similar stacking fault energy to the austenite [6]. Thus, this paper can also presents the supportive evidence with the Fe-40%Ni alloy to simulate the deformed austenite in the steel.

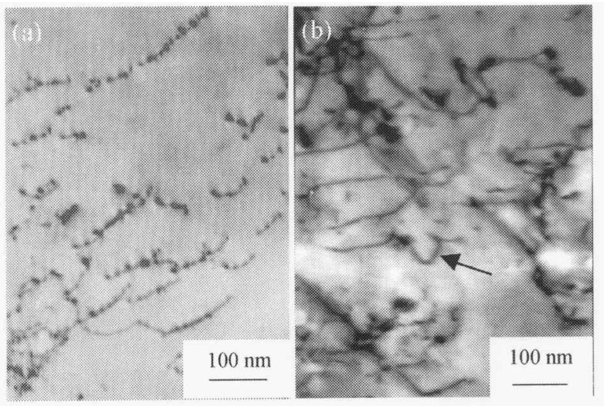

Figure 3 TEM Micrographs showing the precipitates pinned dislocations 30 s (a) and unpinned 200 s (b).

3 Conclusions

(1) During the relaxation process in deformed austenite, the denser and twisted dislocations will evolve into perfect dislocation cells gradually. For longer relaxation time, the subgrains would form due to the combination of dislocation cells.

(2) The evolution of dislocation configuration is retarded by the strain induced precipitation, which enhances the stability of deformed austenite.

References

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