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Effect of Deformation Temperature on Deformation Mechanism of Fe-6.5Si Alloys with Different Initial Microstructures

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Abstract: Deformation behaviors and mechanisms under different temperatures for columnar-grained Fe-6.5Si (mass%) alloys fabricated by directional solidification and equiaxed-grained Fe-6.5Si alloy fabricated by forging were comparatively investigated. The results showed that, with increasing the deformation temperature from 300 ℃ to 500 ℃, the elongation increased from 2.9% to 30.1% for the equiaxed-grained Fe-6.5Si alloy, while from 6.6% to about 51% for the columnar-grained Fe-6.5Si alloy. The deformation mode of equiaxed-grained Fe-6.5Si alloy transferred from nearly negligible plastic deformation to large plastic deformation dominated by dislocation slipping. Comparatively, the deformation mode of the columnar-grained alloy transferred from nearly negligible plastic deformation to plastic deformation dominated by the twining, and finally to plastic deformation dominated by dislocation slipping. Meanwhile, compared with the alloy with equiaxed grains, it was found that ultimate tensile strength and elongation could be increased simultaneously, which was ascribed for the twinning deformation in columnar-grained Fe-6.5Si alloy. This work would assist us to further understand the plastic deformation mechanism of Fe-6.5Si alloy and provide more clues for high-efficiency production of the alloy.

Key words: Fe-6.5Si alloy; deformation behavior; microstructure control; mechanical property; tensile deformation

Compared with the common electrical steels, Fe-6.5Si (mass%) alloy exhibits excellent soft magnetic properties[1-3], which has a wide application prospects in high frequency electromagnetic fields[4,5]. However, it is difficult to fabricate sheets using conventional casting-rolling process due to their long-lasting brittleness and hard-processing problems, which seriously impedes the development of the alloy[6,7]. Therefore, it is urgent to improve the plastic deformation properties of the Fe-6.5Si alloy.

It is widely acknowledged that the key factors dominating the plastic deformation behaviors and mechanisms of metals were deformation conditions[8,9] and initial microstructures[10,11]. For example, Qin et al.[8] found that the main deformation mechanism switched from twinning to dislocation slipping in Fe-Mn-Al-C alloy as the temperature increased from −60 ℃ to 600 ℃, due to the increasing stacking fault energy with the rise of deformation temperature. Peaks can be observed in tensile strength and elongation when the deformation is processed at 300 ℃. Zhao et al.[10] found that the initial microstructure dramatically influenced the warm deformation behavior of the 45 steel. The flow stress of the quenched specimens with martensite was higher than that of the annealed ones with ferrite and pearlite at 550 ℃, while at 600 ℃ to 700 ℃ the whole flow curves of quenched specimens were below those of annealed ones. Further microstructure examination proved that the tempering and dynamic recrystallization easily occurred in the specimens with martensite during deformation.

Therefore, to understand the plastic deformation mechanism of Fe-6.5Si alloy and provide more

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clues for high-efficiency production of the alloy, the effects of deformation temperature and initial microstructure on plastic deformation behaviors of Fe-6. 5Si alloys were comparatively investigated in this study.

1 Materials and Methods

A Fe-6. 5Si alloy with the compositions (mass%) of C 0. 0032, Si 6. 42, Mn 0. 028, S 0. 0024, P 0. 0081, Al 0. 005, B 0. 048, and the balance of Fe was first induction melted and casted in a vacuum furnace. The as-cast ingots were then homogenized and forged at the temperature ranging from 850 to 1000 ℃. The Fe-6. 5Si alloy rods cut from the forged ingot were directionally solidified with the solidification rate of 1 mm/min[12] to obtain columnar grains with <100> orientation, denoted as the "columnar-grained (CG) alloy". The forged specimens were denoted as the "equiaxed-grained (EG) alloy".

The microstructure and crystallographic orientation of the specimens were detected by optical microscope (OM) and electron backscattered diffraction (EBSD) detector equipped on a ZeissAuriga scanning electronic microscope (SEM), respectively. Specimens for EBSD were electrolytically polished at a voltage of 20 V in the electrolyte of 25 vol. % $HClO_4$ and 75 vol. % C_2H_5OH for 10 s. Fig. 1 shows the microstructure and grain orientation of the EG and CG alloys. Many equiaxed grains with the average size of 300—500 μm and random grain orientation can be observed in the EG alloy as shown in Fig. 1(a); while in the CG alloy, columnar grains are distributed homogeneously with the width of 500—800 μm with paralleled straight grain boundaries, as shown in Fig. 1(b).

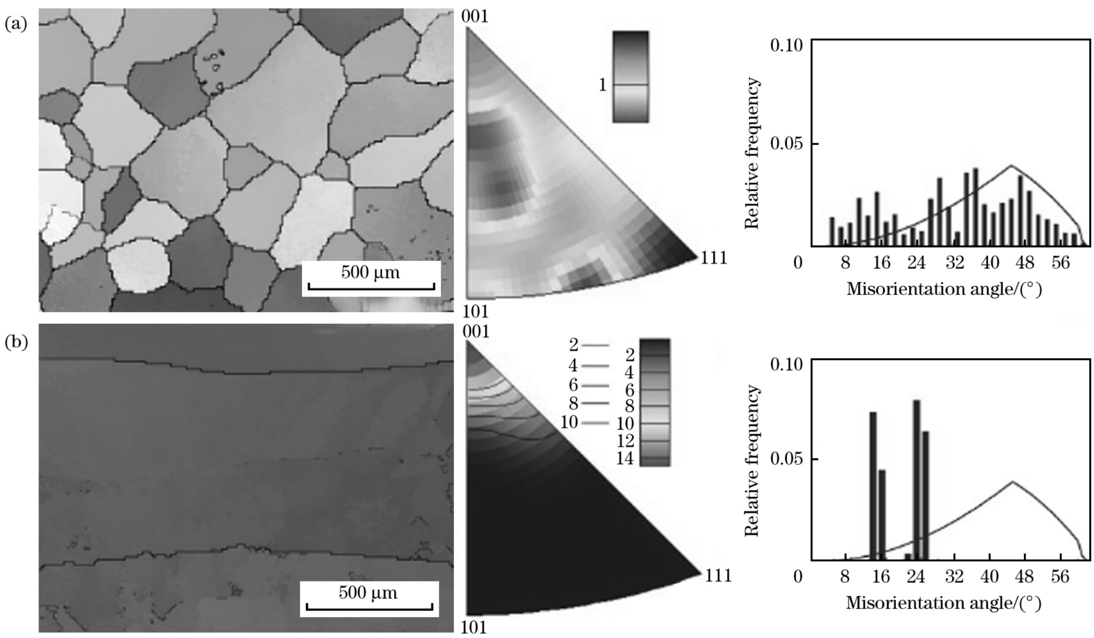

Fig. 1 Microstructure, grain orientation and grain boundary misorientation of EG (a) and CG (b) alloys

The specimens were heat treated at 900 ℃ for 1 h[13] followed by oil quenching, and tensile tests of the Fe-6. 5Si alloy specimens were conducted along the solidification direction of the specimens at the stress rate of 0. 5 mm/min and the deformation temperature range of 300—500 ℃ by a MTS experiment machine. The specimens for tensile tests were dog-bone-shaped with the gauge diameter of 4 mm and length of 10 mm. No less than three specimens were tested for each experimental condition with good reproduction. Detailed microstructural observations were performed by a JEOL 2010 high resolution transmission electron microscope (TEM).

2 Results

2.1 Effect of deformation temperature on tensile deformation behavior of EG alloy

Fig. 2 depicts the typical tensile load-displacement curves of EG alloys at 300 ℃, 400 ℃ and 500 ℃, respectively. When the deformation temperature is 300 ℃, the alloy fractured with negligible elongation. As the deformation temperature increased to 400 ℃, the plastic deformation improved obviously. At 500 ℃, longer necking section was observed, indicating its more obviously local deformation. Fig. 2(b) shows the tensile properties at various deformation