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Effects of external electric field on recrystallization texture and microstructure of 08Al killed steel sheet

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The effects of electric field annealing on recovery and recrystallization in a cold-rolled 08Al killed steel sheet were investigated. Results show that, with the application of a DC electric field, the recovery and recrystallization processes are retarded and the recrystallization γ-fiber texture is strengthened. Those retardation effects are attributed to a decrease of the driving force for recrystallization caused by electric field, which would hinder grain nucleation and growth on the whole. Possible reason for the intensification of the recrystallization γ-fiber texture through electrical annealing is briefly discussed.

1. Introduction
Deep-drawing steels have been widely used in the automobile manufacture industry. Their good deep-drawability is generally attributed to well-controlled microstructures with a strong γ-fiber (ND//⟨111⟩) recrystallization texture formed during annealing. There has been an increasing interest in developing high grade and low cost deep-drawing steels through microstructure and texture modification.

In recent years, annealing in an electric field has been shown to exert some considerable influences on the structure and properties of materials. It is accepted that external electric fields affect the mobility of atoms and dislocations in metals [3, 4], and in turn microstructural evolution. For instance, the imposition of an electric field may retard the recovery and recrystallization of Al and Cu [1, 2]. In the present work, a DC electric field was applied when annealing a cold-rolled deep-drawing 08Al killed steel sheet, and its effects on the microstructure and recrystallization texture development were investigated.

2. Experimental
The experimental specimens were cut from a 73% cold-rolled 08Al killed steel sheet of 1.1 mm thickness, with chemical composition of (wt%): 0.009 C, 0.004 Si, 0.50 Mn, 0.04 P, 0.04 S, 0.06 Al. They were subjected to isothermal annealing at different temperatures ranging from 500°C to 700°C for 120 min, with or without a DC electric field, E, of 300 V/mm. The annealing treatments were done in a nitrogen atmosphere and at a heating rate of 10°C/min to the desired temperature. The electric field was applied by placing the specimens (positive electrode) in the middle of two parallel stainless steel sheets (negative electrode) that were 20 mm apart. The experimental arrangement is shown in Fig. 1.

The microstructures of the annealed specimens were examined by optical microscopy and transmission electron microscopy (TEM). The X-ray textures of the specimens were derived from three incompletely measured {110}, {200} and {211} pole figures with the two-step method [5], and the results were presented in terms of constant $\phi = 45°$ section of the orientation distribution function (ODF).

3. Results
The TEM micrographs of the specimens annealed at 500°C for 120 min are shown in Fig. 2. It is seen that the ordinarily annealed specimen presents many polygonized structures and flat boundaries with no or few dislocation tangles (Fig. 2a), whereas the electrically annealed specimen shows more cell structures with dense dislocation tangling in the cell boundaries and within the cells (Fig. 2b). This might indicate that the imposition of the electric field has lowered the mobility of dislocations, postponed the process of polygonization, and restrained the subgrain formation and recovery.

Figs 3 and 4 show the optical micrographs of the specimens annealed at 600°C and 700°C for 120 min, without and with electric field, respectively. After annealing at 600°C, new recrystallized grains appeared in the ordinarily annealed specimen (Fig. 3a), but there

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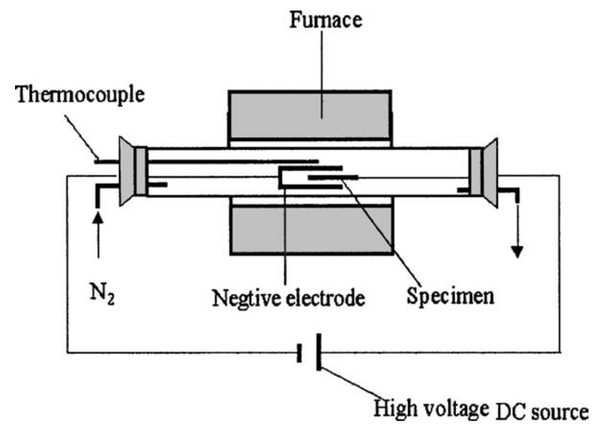

Figure 1 Experimental arrangement.

was no obvious recrystallization in the specimen annealed with the electric field (Fig. 4a). When the annealing temperature was increased to 700°C, both the ordinarily and electrically annealed specimens exhibited fully recrystallized microstructures (Figs 3b and 4b, respectively) with average grain sizes of 10.0 μm and 7.9 μm. Obviously, the progress of recrystallization in the electrically annealed specimen dropped behind that of the ordinarily annealed specimen.

Figs 5 and 6 show the constant $\phi = 45°$ sections of the ODFs for the specimens annealed at 600°C and 700°C. With the increase of annealing temperature, the recrystallization α-fiber texture was weakened and the recrystallization γ-fiber texture was strengthened, which follows the general law for the recrystallization texture evolution in a low carbon steel sheet [6]. However, the electrically annealed specimens exhibit higher average intensity of the γ-fiber texture, as compared with the ordinarily annealed specimens.

The above results have suggested that the external electric field retards the recovery and recrystallization and enhances the recrystallization γ-fiber texture for a cold-rolled 08Al killed steel sheet.

4. Discussion

Up to now, the exact mechanism as to how the electric field affects the recrystallization and texture

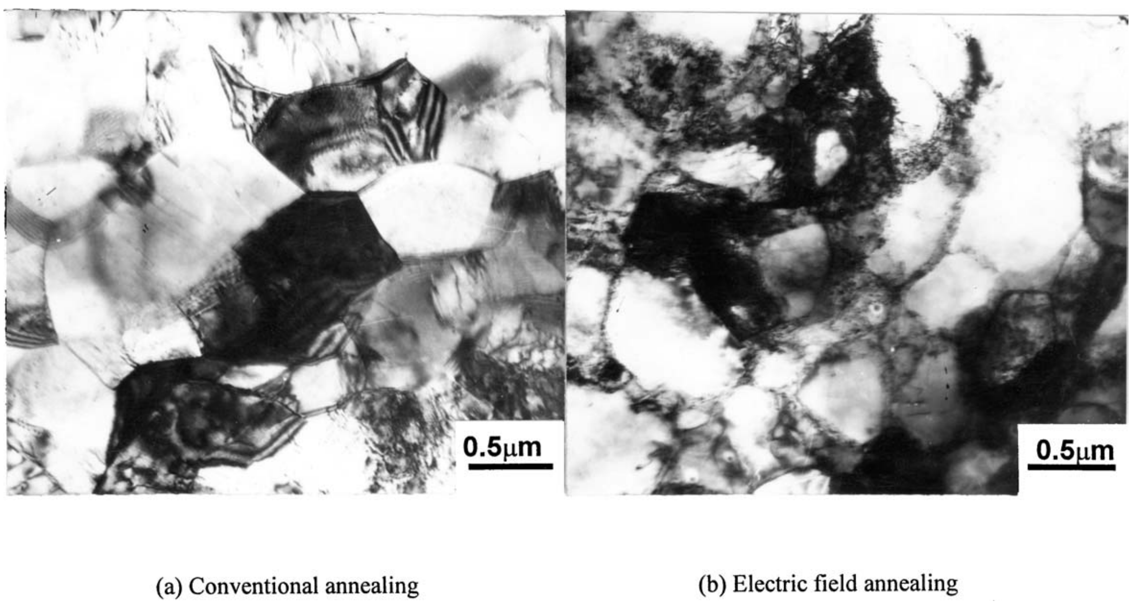

Figure 2 TEM micrographs of the specimens annealed at 500°C for 120 min without (a) and with an electric field of 300 V/mm.

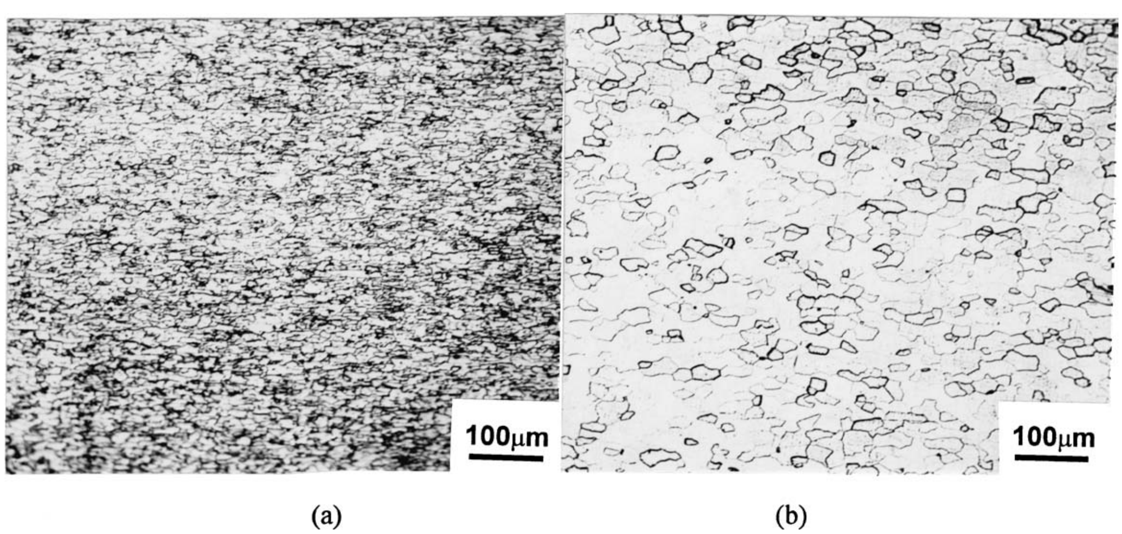

Figure 3 Optical micrographs of the specimens annealed at (a) 600°C and (b) 700°C for 120 min.

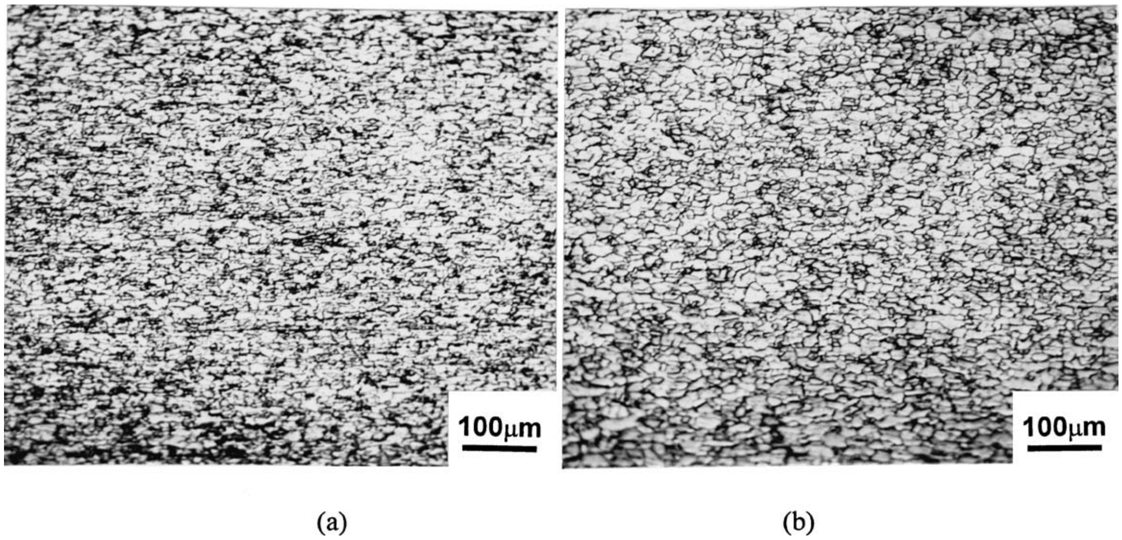

Figure 4 Optical micrographs of the specimens annealed at (a) 600°C and (b) 700°C for 120 min with an electric field of 300 V/mm.

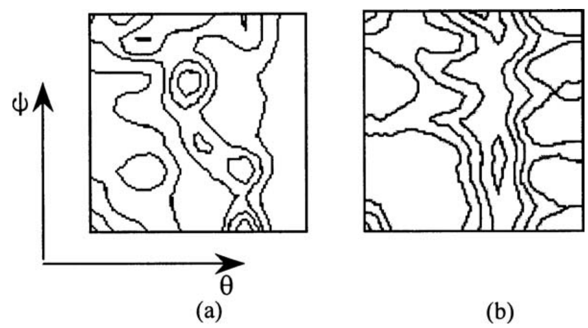

Figure 5 Constant $\phi = 45°$ sections of the ODFs (levels: 1, 2, 3, 4 . . .) for the specimens annealed at (a) 600°C and (b) 700°C for 120 min.

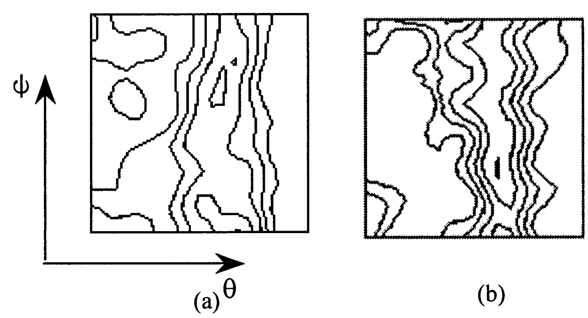

Figure 6 Constant $\phi = 45°$ sections of the ODFs (levels:1, 2, 3, 4. . .) for the specimens annealed at (a) 600°C and (b) 700°C for 120 min with an electric field of 300 V/mm.

development in metals has remained unclear. It is known that, during cold-working of a metal, a small fraction of the energy of deformation is stored in crystals in the form of lattice defect energy, which provides a driving force for recovery and recrystallization. According to the electron theory of metals [7], a vacancy is electronegative, and the lattice defect energy is considered as a kind of electrostatic energy caused by a thin layer made up of negative charges shielding the positive charge [3]. When specimens are annealed as an anode in a DC electric field, the shielding effect would be lowered. Consequently, the lattice defect energy, i.e. the driving force for recovery and recrystallization is decreased in the case of electric field annealing.

Quantitative electron microscopy analysis and X-ray measurements have shown that grains with different orientations may store different amounts of energy after deformation, e.g. the {111} oriented grains receive relatively high energy in a deep-drawing steel sheet [8]. With the advantages in nucleation rate and size, the {111} oriented nuclei preferentially form and grow further in the deformed matrix with the same orientations, which may result in a well developed recrystallization γ-fiber texture [9, 10]. As discussed above, the external electric field generally reduces stored energy of deformation and lowers the driving force for grain nucleation and growth. Thus, it is reasonable to presume that the nuclei with random orientations are further restrained and nuclei with the {111} orientations are more favored during electric field annealing, which leads to a relatively strong γ-fiber texture. Such an enhancement of γ-fiber texture with electric field annealing may contribute to the deep-drawability improvement for 08Al killed steel sheets.

5. Conclusions

A DC electric field of 300 V/mm was applied during annealing of a 08Al killed steel sheet. The electric field annealing did not change the mechanisms of the development of recrystallization and recrystallization texture, but restrained considerably the recovery and recrystallization processes. The intensification of the recrystallization γ-fiber texture with the applied electric field may be of benefit in deep-drawing operations.

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