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Texture Evolutions in Annealing Process for Medium Manganese Steel Sheets

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Abstract

High-strength medium-manganese steel sheets recrystallized in the alpha phase after cold-rolling have a good press formability due to the <111>//ND texture. If the A_3 temperature and the alpha-to-gamma transformation temperature are decreased, the addition of manganese affects the recrystallization and the formability. In this work, the annealing texture evolution of medium-manganese steel was investigated, carbon-free Fe-Mn sheets being used for preliminary research, and some temperatures around the T_0 temperature, at which ferrite and austenite have the same free energy, were selected for annealing. It was confirmed that the T_0 temperature is a key factor to control annealing texture, i.e., although evolving with progress of recovery and partial recrystallization at annealing temperatures below the T_0, the gamma fiber (<111>//ND) texture disappears at temperatures above the T_0. The texture memory effect during alpha-gamma-alpha transformation was not confirmed in this binary system.

Introduction

Due to environmental considerations, the high-strength steel sheets are needed for light-weighting of automotive bodies. Moreover, superior press-formability is required. TWIP (twinning induced plasticity) steel sheets are promising steel sheets [1] with an elongation of more than 50% and a tensile strength of more than about 1 GPa. However, since its manganese content is higher than 20 wt%, problems remain such as material cost, weldability, corrosion resistance, etc. Recently, medium manganese steel sheets containing 4-6% Mn, referred to as the third generation high-strength steel sheets, have been extensively studied and have attracted considerable attention due to their good strength-ductility relation [2]. However, it is assumed to be difficult to control the crystal texture by recrystallization annealing because the A_3 transformation temperature decreases with increasing Mn content and transformation to austenite easily occurs during annealing before recrystallization. So far, most research has been focused on control of the amount and quality of the retained austenite to improve the ductility but not the texture of the ferrite. In this study, texture control in medium manganese steel sheets was investigated with the aim of improving the press performance.

Experimental procedures

An Fe-5mass%Mn alloy ingot for this study was melted in an evacuated induction furnace. After forging, sheet bars were hot-rolled to a thickness of 3.5 mm with a finishing temperature of 900

˚C; coiling simulation was carried out at 600˚C for 1 hr, followed by furnace cooling to room temperature. They were then cold-rolled to a thickness of 1mm after grinding the surface to 3 mm. The rolled sheets were annealed at 650, 670, 695 and 800˚C, which were mainly located at around the T_0 temperature of 685˚C, for 60 min by using an infrared image furnace. The calculated Fe-Mn binary phase diagram including the T_0 temperature is shown in Fig. 1. The SEM-EBSD technique was employed to measure the crystal orientation, and *in situ* crystal orientation measurements also carried out using a heating stage during isothermal heat treatments at 670 and 695˚C.

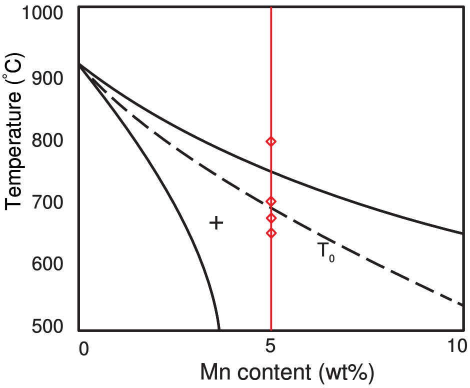

Figure 1. Calculated Fe-Mn binary phase diagram and T_0 temperature. The annealing temperatures for the experiments are also indicated by diamond-shaped marks.

Results and discussion

Inverse pole figure (IPF) maps obtained from hot-rolled (a), cold-rolled (b), and annealed sheets (c-f) are shown in Figure 2, where the crystal orientation parallel to the normal direction of the sheets is represented. It is seen that the hotband has a lath martensite structure with sub-structures and that the lath structure is elongated in the rolling direction by cold rolling. The elongated grain structures fully remain until annealing at 670˚C and partially remain at 695˚C. It was confirmed that the crystal orientation slightly changes at 695˚C and that the area fraction of near {100} oriented grains indicated by red color seems to increase, as shown in Fig. 2(e).

The area fractions of {111} and {100} grains ({hkl} plane parallel to the sheet plane) estimated from Fig. 2 are plotted as a function of annealing temperature in Figure 3, where the tolerance for an angle different from the ideal orientation is set to be ±15 degrees. It is seen that for {111} grains, the integrated intensity abruptly decreases at the T_0 temperature (685˚C), while increasing slightly for {001} grains.

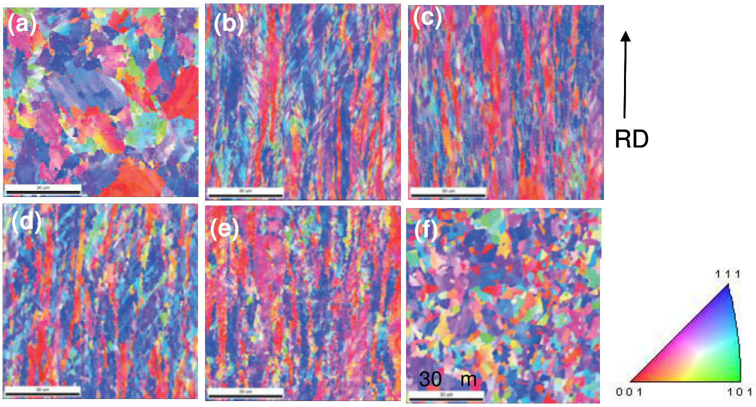

Figure 2. IPF maps of (a) hot-rolled, (b) cold-rolled and annealed sheets ((c) 650, (d) 670, (e) 695, (f) 800 °C) of Fe5%Mn.

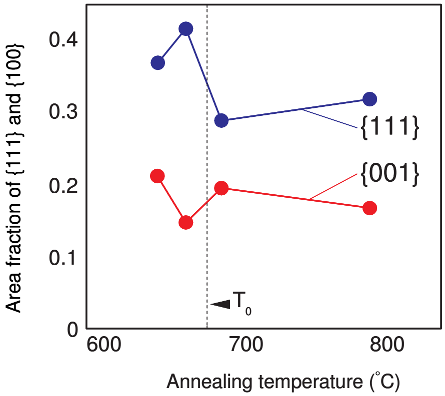

Figure 3. Effect of annealing temperature on the area fraction of {111} , {100} planes parallel to the sheet plane.

Figure 4 shows the characters of grain boundaries annealed at 670 and 695 °C. Inside the elongated grains in the sample annealed at 670 °C, sub-grain structures due to cold-rolling deformations are detected, which means that the sample is only at a recovery stage and that discontinuous recrystallization apparently does not occur. On the other hand, more greatly refined sub-structures were developed at 695 °C. Although 695 °C is just above the T_0 temperature and located in the two-phase region in the equilibrium condition, it is conjectured that transformation to the gamma phase occurred during the annealing.

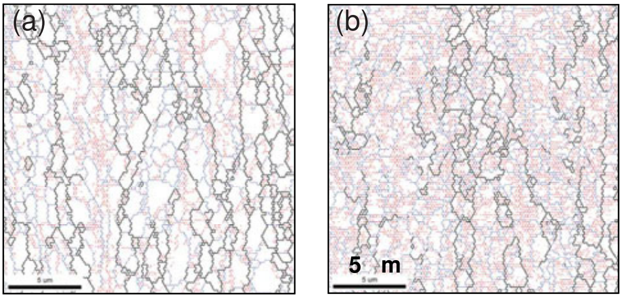

Figure 4. Characteristics of grain boundaries annealed at (a) 670 and (b) 695°C.

To confirm the recrystallization and transformation behavior, *in situ* EBSD measurements were conducted. Figure 5 shows the time evolution of IQ and IFP (ND) maps in *in situ* EBSD measurement for the sample isothermally annealed at 670°C, where the heating time up to the setting temperature was about 20 min. No phase transformation occurred within the measurement time to 80 min, whereas some sub-grains dissipated and coalesced as indicated by the arrow in Fig. 5. However, most high-angle boundaries stably remained.

Figure 6 shows the time evolution of IQ, IFP (ND) and phase maps in *in situ* EBSD measurement for the sample annealed at 695°C, just above the T_0 temperature. It is seen that some high-angle boundaries move in the initial stage up to 20 min and that at the holding time of 40 min, one austenite grain nucleates in the ferrite grains. The crystal orientation of the transformed austenite grain was confirmed to have a K-S relation with one of the surrounded ferrite grains as indicated by the arrow in Fig. 6(b). At 80 min, the transformation to austenite proceeded further and almost the whole area measured transformed to the austenite phase with coarse grains. Transformation would preferably occur in the vicinity of the preferred recrystallization sites with high dislocation energies. In the case of steel sheets including only low amounts of carbon and manganese, it has been reported that the texture memory effect [3] occurs during ferrite-austenite-ferrite transformation. In this research study, however, such a memory effect was not confirmed, as shown in Fig.3. This would be due to an abrupt transformation to the gamma phase. Moreover, austenite transformation from un-recrystallized ferrite grains may possibly affect the texture evolution during the transformation.

An attempt was made to simulate transformation behavior using DICTRA. Figure 7 shows the calculated manganese concentration profiles with various holding times at 695°C, taking manganese partition at the transformation interface into consideration. The transformation front does not easily progress at this temperature if the manganese partition is taken into consideration. In the present experiment, however, the manganese partition was not detected by EPMA analysis. This suggests that a massive-type transformation might abruptly occur at temperatures just above the T_0 point.

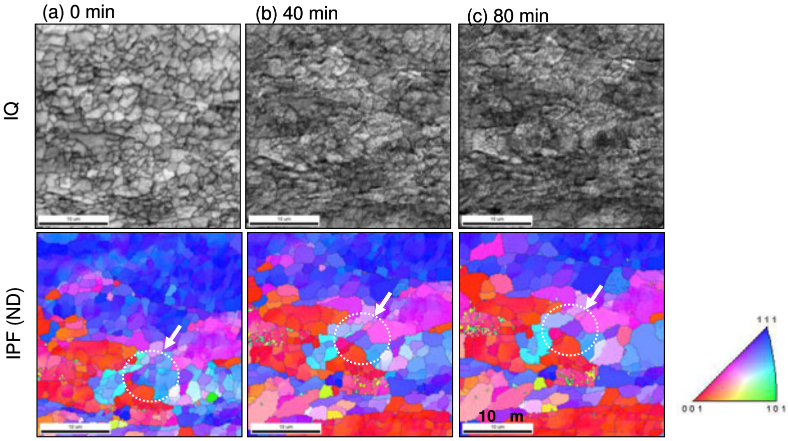

Figure 5. Time evolution of IQ and IFP (ND) maps in *in situ* EBSD measurement for the sample annealed at 670°C.

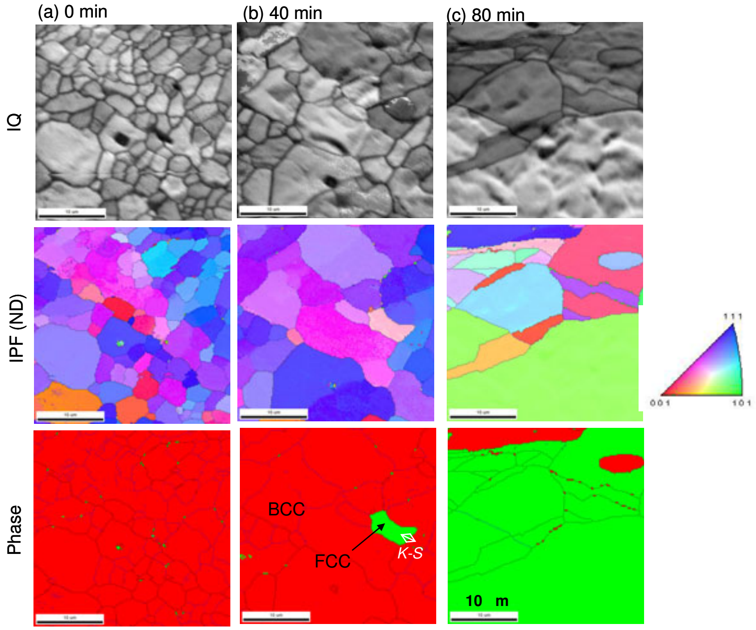

Figure 6. Time evolution of IQ, IFP (ND) and phase maps in *in situ* EBSD measurement for the sample annealed at 695°C.

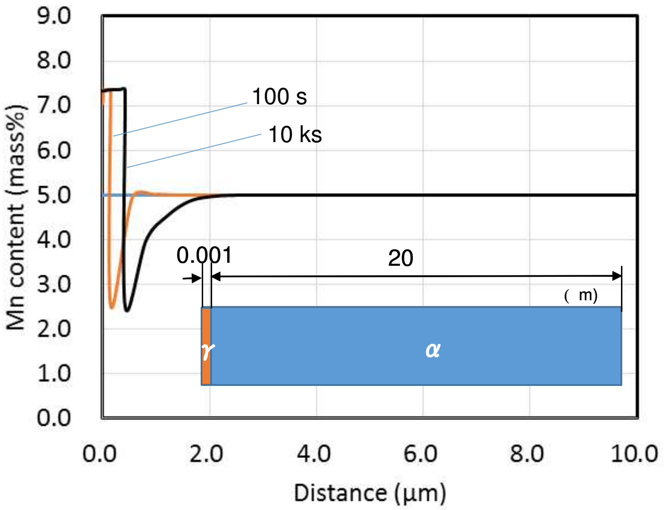

Figure 7. Manganese concentration profiles calculated by DICTRA. The simulation temperature is 695˚C.

Conclusion

In Fe-5%Mn binary alloy annealed at temperatures just below T_0, the gamma fiber (<111>//ND) evolved with progress of recovery and partial recrystallization. However, the texture was abruptly randomized at annealing temperatures above the T_0 temperature. The transformation to austenite occurring at temperatures just above the T_0 proceeded without partitioning of manganese. The texture memory effect in alpha-gamma-alpha transformation was not confirmed in this binary system.

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