Grain refinement mechanism of prior austenite during reversion after cold rolling in medium Mn steel

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The microstructure formation of Fe-5Mn-0.1C-1.2Si (mass%) steel during and after reversion from martensite to austenite were observed by SEM/EBSD method, and then, the grain refinement mechanism by annealing after cold rolling in medium Mn steel was discussed from the viewpoint of the crystallographic characteristics of the reversed austenite grains. In the specimen without cold rolling, a crystallographic restriction, so-called “austenite memory”, was appeared during the intercritical annealing at 923 K, so that the austenite with the same orientation (same variant) as the prior austenite grains nucleated and grew. In addition, these austenite grains coalesced with each other after annealing at 973 K in the austenite single phase region, leading to the coarse austenite grains of 50 μm (almost the same as that of the prior austenite). In contrast, in the cold-rolled specimen, the extremely fine austenite grains of below 5 μm were formed after annealing at 973 K. This would be because the cold rolling suppressed the strict variant selection owing to the reduction of anisotropic internal local residual stress in martensite, and this prevented the austenite memory. Furthermore, the orientation rotation of the martensite due to the cold rolling had dispersed the orientations of the resulting reversed austenite grains, which is considered to be one of the factors that suppressed the formation of coarse grains.

Keywords: *grain refinement;reversed austenite;EBSD;austenite memory;medium manganese steel.*

1. Introduction

Multi-phase steels, such as DP (Dual Phase) steel and TRIP (TRansformation-Induced Plasticity) steel, are mainly used as high strength steels for automobiles, but in recent years, medium Mn martensitic steel containing 3-10 mass%Mn is attracting attention as one of the third generation AHSS (advanced high strength steels). This type of steel has excellent strength-ductility balance because the stable retained austenite enriched with Mn and C is formed by the intercritical annealing at the ferrite and austenite dual phase region, and it transforms into a hard deformation-induced martensite during deformation[1)]. To further increase the strength of this steel, it is effective to generate an ultrafine grained ferritic and austenitic dual-phase structure by cold rolling before intercritical annealing[2)]. However, the effect of cold rolling on the nucleation and growth behaviors of reversed austenite during intercritical annealing, i.e. the grain refinement mechanism by cold rolling, have remained unclear. In this study, the microstructure formation of 5%Mn-0.1%C steel during and after reversion from martensite to austenite were observed by SEM/EBSD method, and then, the grain refinement mechanism by annealing after cold rolling in a medium Mn steel was discussed from the viewpoint of the crystallographic characteristics of the reversed austenite grains.

2. Experiment

The chemical composition of the steel used in this study is shown in Table 1. The specimens were quenched in water after austenitization at 1023 K for 1800 s and cold-rolled to 0-30%. After that, two kinds of heat treatments were applied to the specimens (Fig. 1):

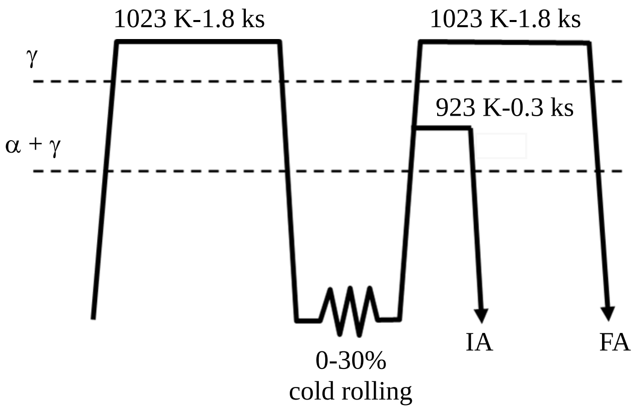

Fig.1 Schematic diagrams of mechanical heat treatment.

(I) Full annealing (FA)

The specimens were austenitized at 1023 K in the austenite single-phase region for 1.8 ks and then quenched in water to room temperature to observe the microstructure of martensite transformed from reversed austenite.

(II) Intercritical annealing (IA)

The specimens were annealed in a salt bath held at 923 K in the ferrite and austenite dual phase region. Then, the specimens were kept there for 300 s to observe the microstructure formation of reversed austenite.

For observation of the distribution of retained austenite, an electron backscattering diffraction (EBSD) method was applied using an orientation image microscope mounted on a field-emission scanning electron microscope (Carl Zeiss Microscopy SIGMA500)

3. Results

Figure 2 shows the inversed pole figures (IPF) of

Table 1. Chemical composition of the steel used in this study (mass%).

C	Si	Mn	P	S	Al	N	O	Fe
0.10	1.19	5.0	0.003	0.002	0.017	0.0013	0.0010	Bal.

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specimens that were fully annealed at 1023 K. In the figures, the prior γ grain boundaries are shown as black lines: they are obtained based on the Kurdjumov-Sachs (K-S) relationship((111)fcc//(011)bcc, [0-11]fcc//[1-11]bcc), which is the crystal orientation relationship between α'/γ. In the case of the specimen without cold rolling, the prior γ grain size is approximately 40 μm, which is the same as that before austenitization. On the other hand, it is difficult to identify the prior γ grain boundaries and packet grain boundaries in the cold rolled specimen, and the crystallographic analysis revealed that the prior γ grain size has been reduced to about 5 μm, and that the aspect ratio of the block has decreased. In order to investigate the mechanism of grain refinement of prior γ grains by cold rolling, the specimens were annealed at 923 K for 0.3 ks, which is in the (α+γ) dual phase region, and the crystallographic characteristics of the reverse γ nucleated during the intercritical annealing were investigated.

Fig. 3 shows the (001)γ pole figure in one of the packets of the specimen without and with cold rolling annealed at 923 K. In the specimen without cold rolling, the specific variant of the reverse γ (Variant 1) occupies the majority in the packet, and the analysis using the pole figure shows that this reverse γ has a K-S relationship with all the α' in the prior γ grains. This indicates that austenite memory (a phenomenon in which the reverse γ variant with the same orientation as the prior γ grains is generated[3]) is occurred. On the other hand, in the specimen with cold rolling, the multiple variants of reverse γ nucleated in the packet, indicating that austenite memory was suppressed. In addition, the orientation distribution of each variant becomes larger for the cold-rolled specimen (b) than for the specimen without cold rolling (a). The orientation distribution for each variant in the specimen without cold rolling was about 6 degrees, while that in the cold-rolled specimen had an orientation distribution of up to 30 degrees. Since the orientation difference of the high angle grain boundary is about 15 degrees, it is expected that the coalescence of the reverse γ is less likely to occur in the cold-rolled specimen.

4. Discussion

Nakada et al.[4] reported that when γ nucleates from a packet of α', two types of variants with a twinning relationship can be generated due to the variant restriction by habit plane and lath boundaries. In addition, they also reported that internal local residual stress is introduced during α' transformation to reduce the transformation strain, and the specific variant is selected during the γ reverse transformation, resulting in the preferential growth and coalescence of austenite grains with the same crystallographic orientation as the prior austenite grains (Variant 1). The reason why austenite memory did not develop in the cold-rolled specimen is thought to be that the internal local residual stress in α' was disturbed by cold rolling, allowing that the two variants could be generated in the packet in equal proportion.

In addition, the orientation distribution of the matrix-phase (a') in the cold-rolled specimen was found to have orientation distribution of up to 30 degrees, suggesting that the orientation distribution of reverse γ in the cold rolled specimen would be also broadened due to the rotation of the crystallographic orientation of the matrix-phase (α') by cold rolling.

Therefore, the grain refinement by cold rolling in this study is explained by the suppression of austenite memory by internal local residual stress relaxation and grain coalescence by orientation rotation of α'.

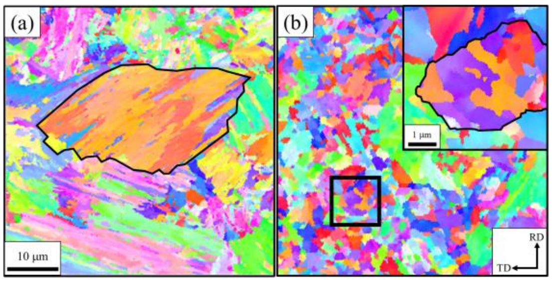

Fig.2 Inverse pole figures (IPF) of med-Mn steel heat-treated at 1023 K (a) without and (b) with cold rolling.

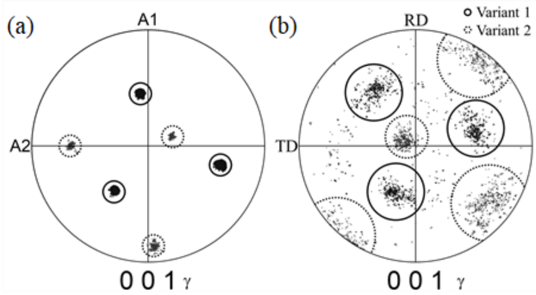

Fig.3 (001)$_\gamma$ pole figure for each packet (a) without and (b) with cold rolling.

5. Conclusion

(1) By cold rolling, the prior γ grain size was reduced from 40 μm to 5 μm.

(2) In the specimen without cold rolling, austenite memory caused coarsening of the prior γ grains.

(3) In the cold-rolled specimen, the internal local residual stress generated during α' transformation is weakened, and the crystallographic orientation rotation of the matrix-phase (α') occurred, which is considered to be the factors that suppressed the formation of coarse grains.

6. References

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