

Texture Improvement in High-Permeability Nonoriented Electrical Steel by Antimony Addition

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Keywords
electrical steel, magnetic, Sb additions, steel texture

1. Introduction

IT has long been known that magnetic properties, particularly permeability, can be improved by adding a small amount of antimony to nonoriented electrical steel and subjecting it to a hot band annealing. The effect of the antimony addition on magnetic properties was first studied by Shimanaka et al.[1] As shown in Fig. 1, the addition of a small amount of antimony produces higher permeability in nonoriented electrical steel with a high silicon content.

Later, Komatubara[2] ascertained that antimony was also effective in low-silicon steel (Fig. 2). It was found that the effect of antimony on magnetic properties was significant at the higher annealing temperature of the hot band.

An increase in the (100) and (110) components and a decrease in the (111) component due to the antimony addition resulted in an improvement in magnetic properties. Figure 3 schematically shows the mechanism of texture improvement by antimony additions explained by Shimanaka. Hot band annealing increases grain size and enhances antimony segregation to grain boundaries. It was reported that antimony prevented the nucleation of recrystallization near the original grain boundaries and decreased the (111) component.

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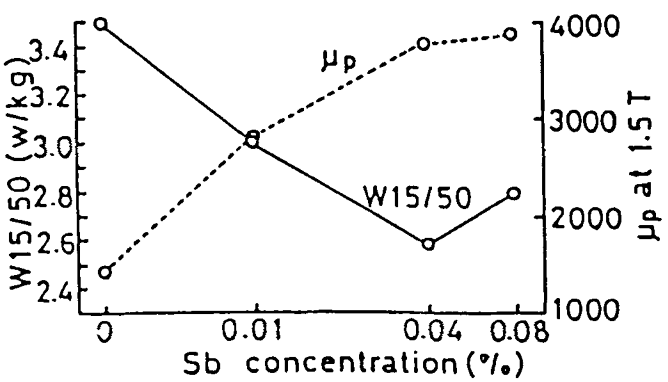

Fig. 1 Effect of antimony additions on magnetic properties of 1.85Si-0.20Mn-0.30Al (wt%).[1]

The purpose of the present investigation is to examine the effects of antimony on texture change during recrystallization and grain growth and to clarify the mechanism of the significant effect of antimony additions on texture improvement.

2. Experimental Procedure

Vacuum-melted ingots with the chemical composition shown in Table 1 were used. Ingots were hot rolled, and some hot bands were heat treated to produce large grains. Hot bands and heat treated hot bands were cold rolled and then annealed at various temperatures from 580 to 850 °C (Fig. 4).

The heating pattern of annealing after cold rolling is shown in Fig. 5. An infrared furnace was used to perform this heat cycle. The heating rate was 5 °C/s. After these treatments, hardness measurements, microstructure observations, and texture measurements were performed.

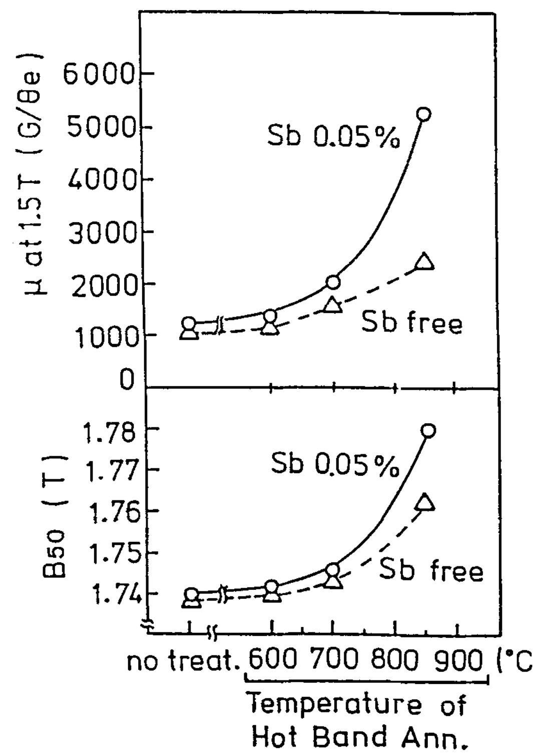

Fig. 2 Effect of antimony additions and hot band annealing on magnetic properties of 0.60Si-0.30Mn-0.22Al (wt%).[2]

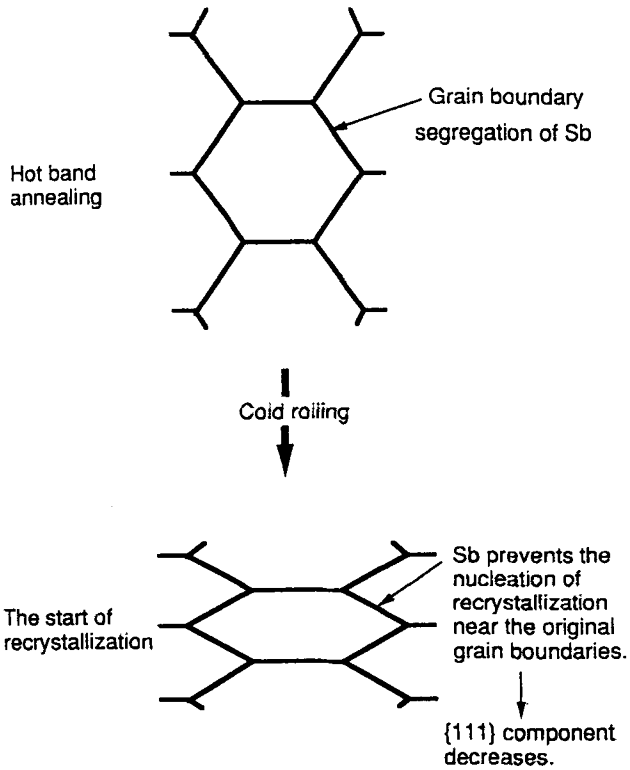

Fig. 3 Mechanism of texture improvement by addition of antimony.[1]

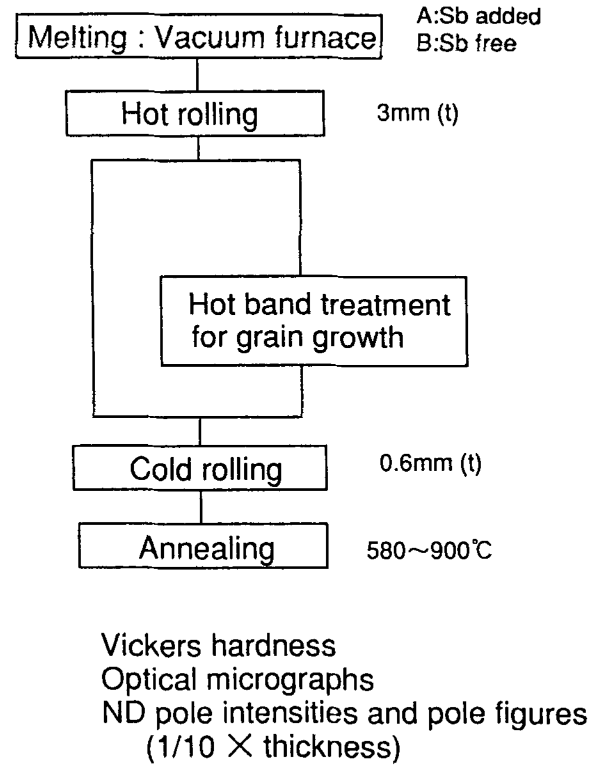

Fig. 4 Experimental procedure.

Table 1 Chemical composition of steels

	Composition, wt%					
Specimen	C	Si	Mn	P	S	Sb
A	0.005	0.10	0.25	0.08	0.004	0.05
B..............	0.005	0.11	0.26	0.08	0.004	Trace

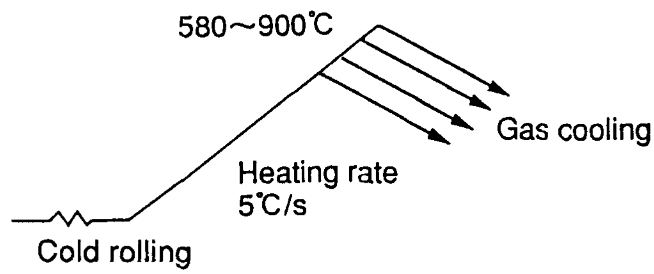

Fig. 5 Heat pattern of annealing after cold rolling (infrared furnace in N_2).

Figure 6 shows the microstructures of hot bands before cold rolling in the as hot rolled condition (a and b) and after hot band annealing. Hot band annealing increased the grain size, but the antimony addition did not change the grain size.

3. Experimental Results

3.1 *Hot Bands with Small Grains As Hot Rolled*

The changes in Vickers hardness during recrystallization and grain growth are shown in Fig. 7. Antimony addition increased hardness slightly. The changes in hardness and in microstructures showed that the recrystallization started at 620 °C and completed at 680 °C in both the antimony additions and antimony-free steels.

The changes in pole intensities are shown in Fig. 8. (110) intensities increased in the recrystallization stage and decreased in the grain growth stage. The antimony addition retarded a decrease in the (110) component in the grain growth stage, as shown in Fig. 8(a).

In the antimony-free specimen, the (222) component decreased in the recrystallization stage and increased in the grain growth stage. On the other hand, in the specimen containing antimony, the (222) component did not change during grain growth. The antimony addition retarded the (111) texture formation in the grain growth stage, as shown in Fig. 8(b).

The (200) component decreased in the recrystallization stage and did not change during grain growth. A difference in the (200) component change between the specimen containing antimony and the antimony-free steel was not observed (Fig. 8c).

3.2 *Heat Treated Hot Bands with Large Grains*

The changes in Vickers hardness during recrystallization and grain growth are shown in Fig. 9. From hardness measure-

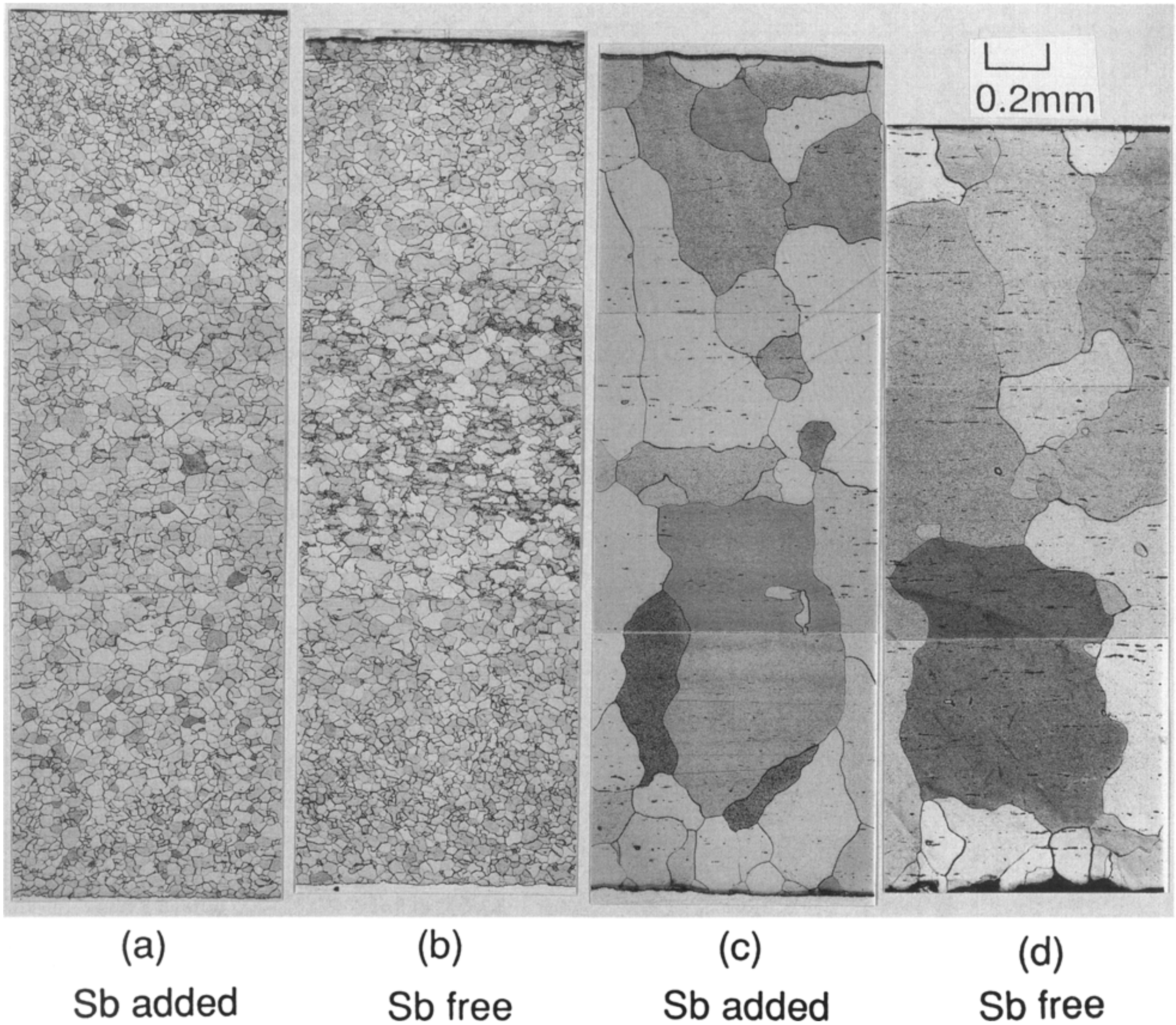

Fig. 6 Optical micrographs of hot bands. (a) and (b) As hot rolled. (c) and (d) Heat treated.

ments and microstructural analysis, recrystallization was found to start at 620 °C and reach completion at 720 °C in both antimony-free and antimony-modified specimens. The recrystallization temperature of these specimens were slightly higher than those of specimens with small grains.

The changes in pole intensities during recrystallization and grain growth are shown in Fig. 10. The (110) intensities of specimens containing antimony increased rapidly at the early stage of recrystallization, and they were always significantly higher than those of the specimens without antimony additions (Fig. 10a).

The (222) component decreased in the recrystallization stage and did not change during grain growth (Fig. 10b). The (200) ND pole intensities decreased monotonously during annealing (Fig. 10c). Changes in the (222) and (200) component between antimony-containing and antimony-free specimens were not observed.

4. Discussion

It is well known that antimony additions increase the (110) component and decrease the (111) component of an oriented steel. However, it has not been clear when the difference in texture between antimony-containing and antimony-free specimens developed. In the present experiments, the effects of grain size prior to cold rolling and antimony addition on texture were studied, respectively, to clarify the mechanism of texture evolution.

When the grain size before cold rolling was small, the (110) texture developed, and the (222) texture formation was suppressed at the stage of grain growth. In this case, it is anticipated that antimony effectively controlled grain boundary migration during grain growth.

When the grain size before cold rolling was large, the (110) texture increased even at the beginning of recrystallization.

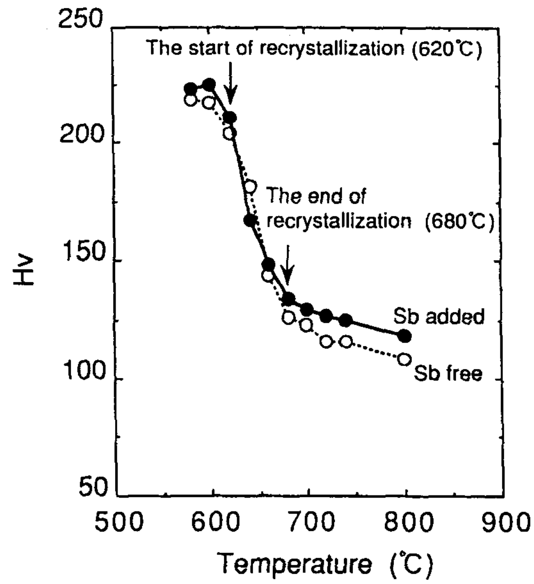

Fig. 7 Change in Vickers hardness during recrystallization and grain growth. Grain size before cold rolling was small.

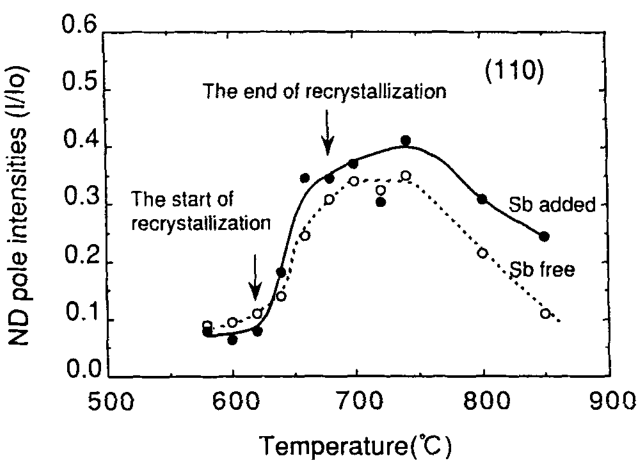

Fig. 8(a) Change in (110) ND pole intensities during recrystallization and grain growth. Grain size before cold rolling was small.

The (222) component did not increase in both antimony-containing and antimony-free steels. The (200) component decreased in both steels. Figure 11 shows optical micrographs of the early stage of recrystallization in antimony-containing and antimony-free steels. Deformation bands developed easily in the interior of grains when the grain size before cold rolling was large. The (110) grains often preferentially nucleated at deformation bands, and hence, the (110) component increased significantly in the early stage of recrystallization. Additions of antimony accelerated the formation of deformation bands, and thus the (110) component increased. In large sized grains, the effects of deformation bands are quite significant, and the other effects become minimal.

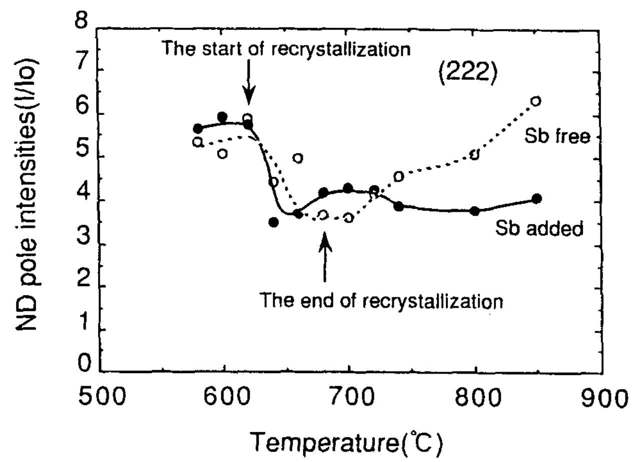

Fig. 8(b) Change in (222) ND pole intensities during recrystallization and grain growth. Grain size before cold rolling was small.

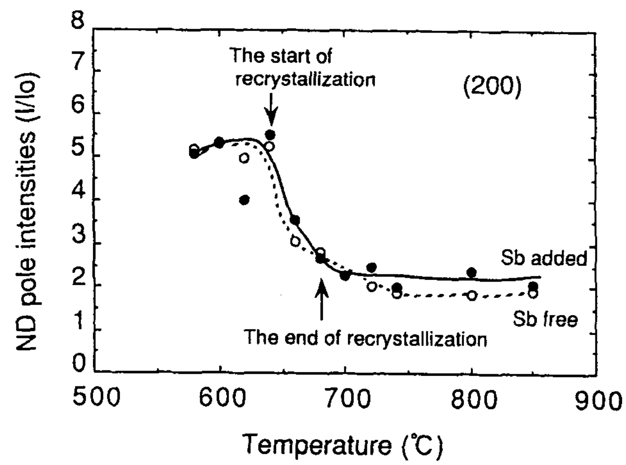

Fig. 8(c) Change in (200) ND pole intensities during recrystallization and grain growth. Grain size before cold rolling was small.

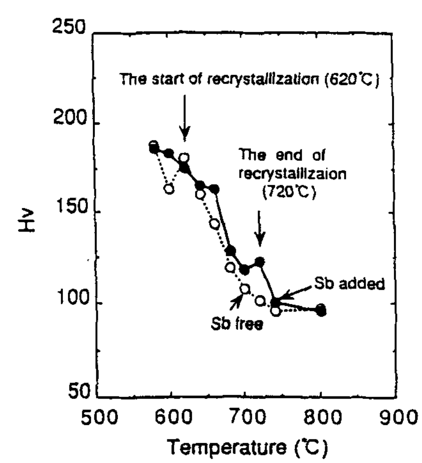

Fig. 9 Change in Vickers hardness during recrystallization and grain growth. Grain size before cold rolling was large.

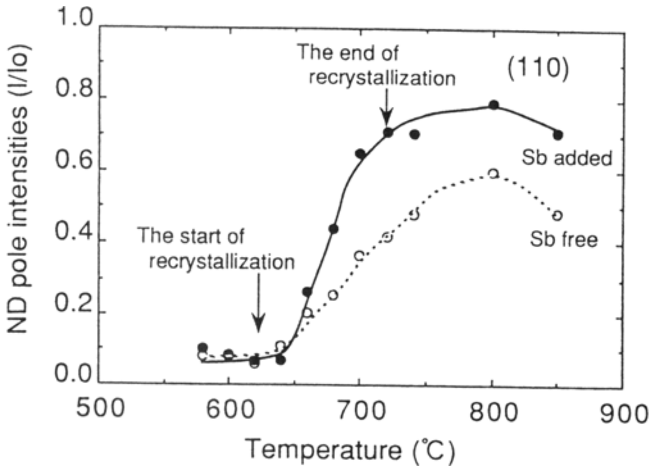

Fig. 10(a) Change in (110) ND pole intensities during recrystallization and grain growth. Grain size before cold rolling was large.

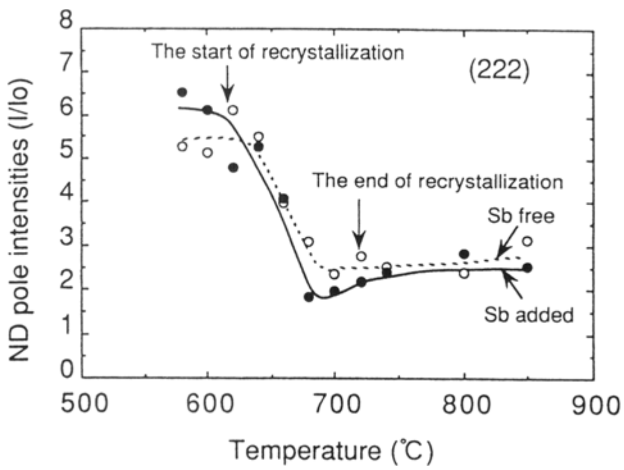

Fig. 10(b) Change in (222) ND pole intensities during recrystallization and grain growth. Grain size before cold rolling was large.

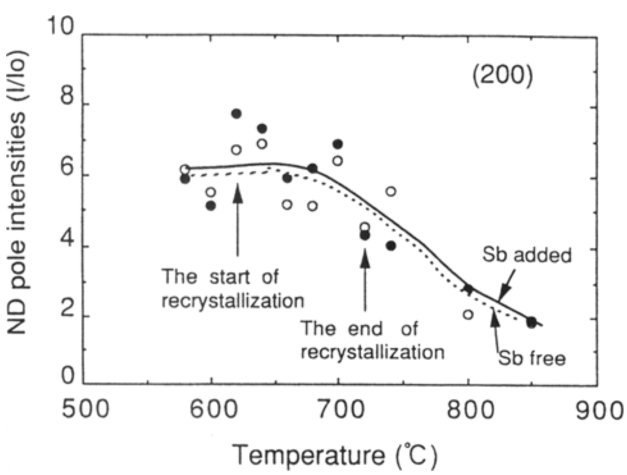

Fig. 10(c) Change in (200) ND pole intensities during recrystallization and grain growth. Grain size before cold rolling was large.

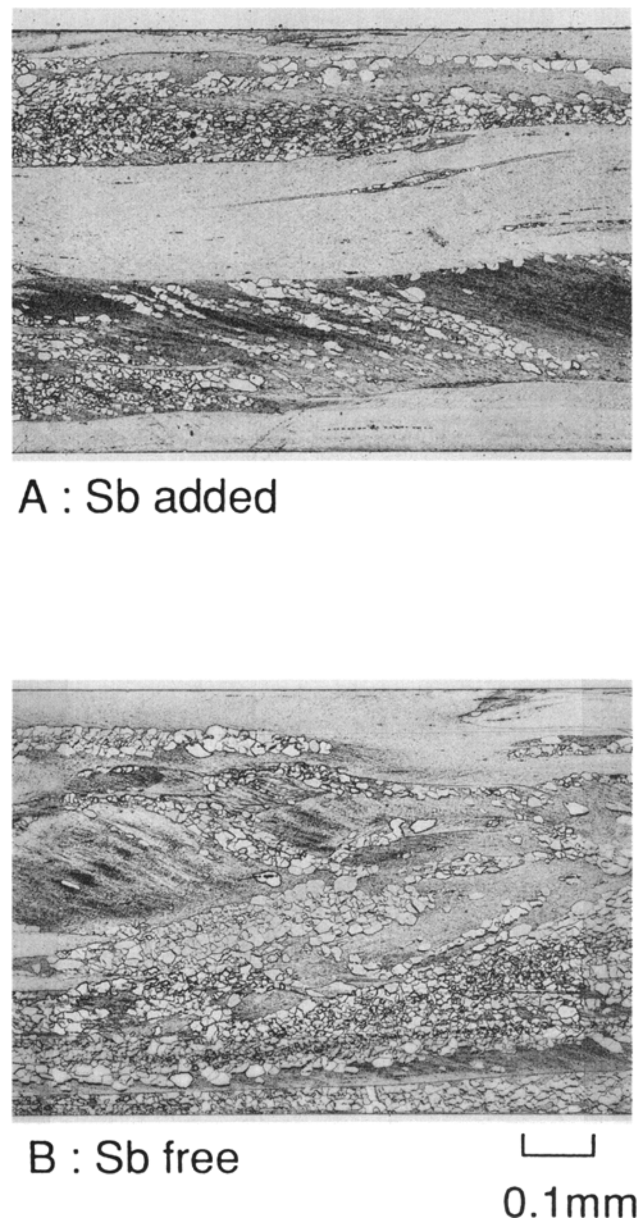

Fig. 11 Optical micrographs taken in the early stage of recrystallization in antimony-containing and antimony-free steels. Annealing temperature; 640 °C.

In the case of small grain sizes, the deformation band is hardly produced due to the grain boundary effects, and then the effect on the grain growth stage becomes significant.

Thus, the effects of antimony additions change depending on the grain size before cold rolling. Based on these effects, processing conditions in antimony-containing steels should be optimized.

5. Conclusion

The mechanism of the significant effect of antimony additions on texture improvement was studied, and the results are as follows. When grain size before cold rolling was small, the antimony addition retarded {111} texture formation in the grain growth stage. When grain size before rolling was large, the {110} component increased in the early stage of recrystallization in the antimony-containing specimens because of the dense formation of deformation bands. Based on these effects of antimony additions on preferential texture formation, high-permeability nonoriented electrical steel has been produced at Kawasaki Steel Corporation.

References

1. H. Shimanaka et al., *J. Magn. Magn. Mater.*, Vol 19, 1980, p 63
2. M. Komatubara et al., *CAMP-ISIJ*, Vol 2, 1989, p 1935