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Effects of Hot Rolling on Microstructures and Magnetic Properties in 3% Si Grain Oriented Electrical Steels

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In grain oriented electrical steel process, hot band annealing has thought to be essential for obtaining good magnetic properties. New hot rolling method of heavy reduction in early hot rolling stage was applied to obtain good magnetic properties in GO process without hot band annealing. Hot rolling was carried out by varying hot rolling reduction distribution along hot rolling pass. The heavy hot rolling reduction in rear stand improves the magnetic flux density in the case of no hot band annealing. The hot band specimens of the heavy reduction in front stand shows the elongated hot deformed microstructures in the center layer and strong {001}<110> texture. On the contrary, the heavily reduced specimens in rear stand shows the recrystallization in the center layer of hot band and strong {111}<112> and {110}<001> textures.

Key words : grain oriented electrical steels, hot band annealing, hot rolling reduction, hot rolling texture

1. Introduction

Grain-oriented electrical steels are used as the core materials of transformer. Grain oriented electrical steels are produced with two different grades HGO (High Permeability Grain Oriented) and CGO (Conventional Grain Oriented). The preferable magnetic properties of grain oriented electrical steels are high magnetic induction and low core loss. These properties are related with grain orientation. Grain oriented electrical steels consists of the grains almost ideally oriented to {110}<001>, so called by "Goss texture".

The average deviation angle of <001>, easily magnetized axes from rolling direction of HGO is less than 3°. On the contrary, CGO is around 7° and not so strict comparing to HGO. Such grains are achieved by using fine precipitates as an inhibitor to the growth of the primary recystallized grains prior to secondary recrystallization. Traditionally, high slab reheating temperature is needed to fully dissolve precipitates. However, the extremely high temperature of slab reheating makes the hot rolling process very difficult and hence reduces productivity.

In last decade, the low slab reheating methods are reported in HGO [1-3]. In the conventional products of low sol-Al and Cu added compositions, slab reheating at low temperature 1250 °C also has been used for long times [4-6].

It is considered that omission of hot band annealing is the next effective way of cost saving. However, regardless of manufacturing methods, hot band annealing has known to be prerequisite for good magnetic properties. In the low sol-Al method, the effect of hot band annealing on the magnetic properties was reported [7]. The specimen without hot band annealing shows the fine and non-uniform AlN precipitates distribution and small primary recrystallization grain size comparing to the hot band annealed specimens. Due to these phenomena, in the specimen of no hot band annealing, the secondary recrystallization is developed at low temperature and poor magnetic induction is obtained.

In this study, the effects of hot rolling reduction distribution on texture and magnetic property were investigated in low slab reheating temperature process in the case of no hot band annealing.

2. Experimental Procedure

Vacuum melted ingot of composition (0.035% C; 3.1%

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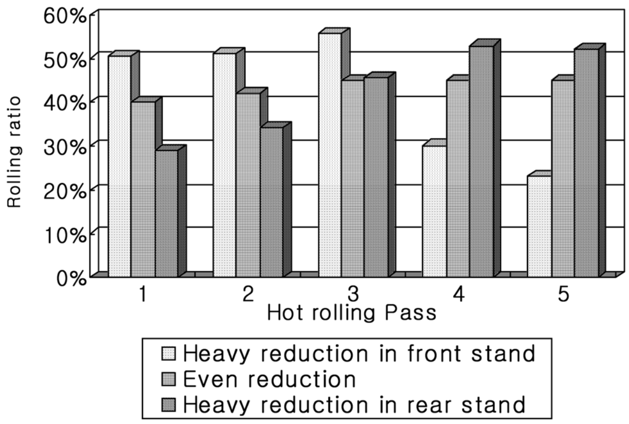


Fig. 1. Experimental hot rolling reduction distribution along hot rolling stand.

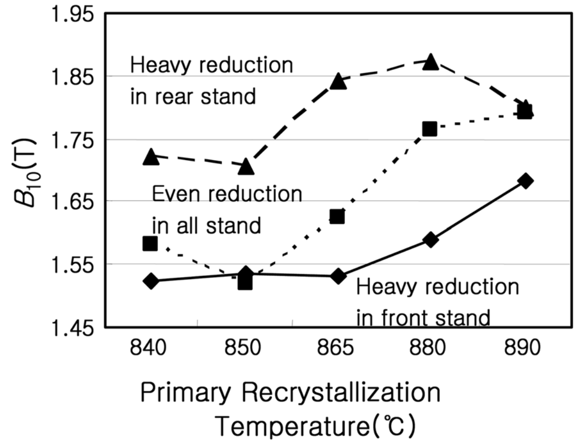


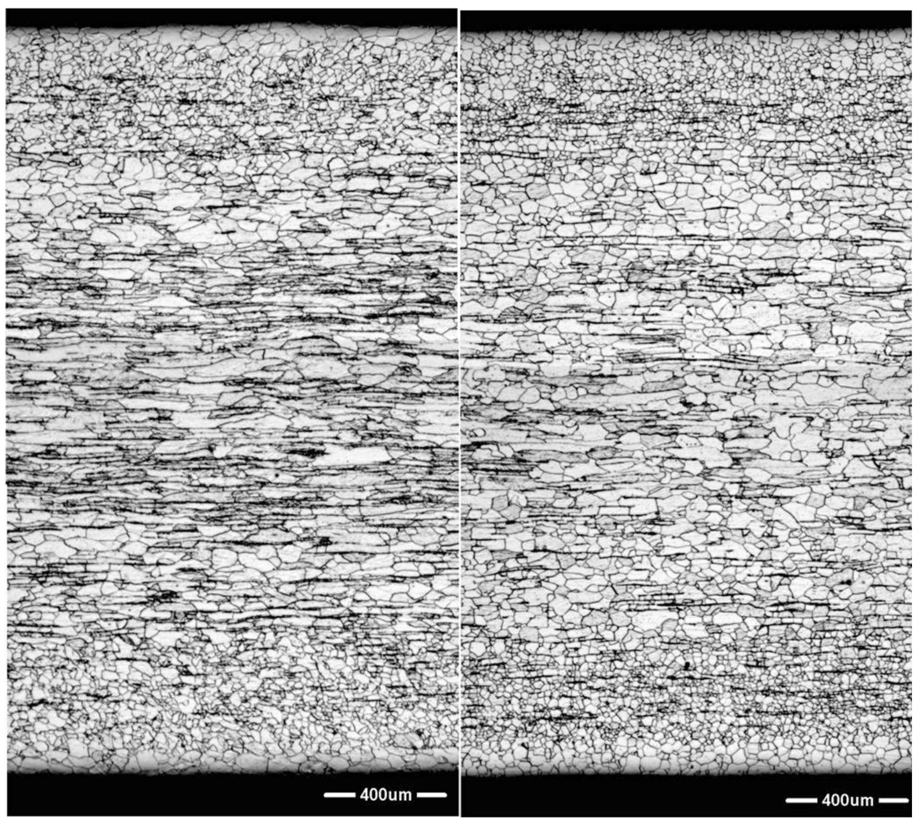
Fig. 2. Magnetic flux density B_{10} variation with hot rolling and primary recrystallization temperature.

Si; 0.3% Mn; 0.004% S; 0.02% sol-Al, 0.009% N, 0.4% Cu) was hot rolled to 40 mm thickness. It was heated for 1 hour at 1250 and hot rolled to 2.3 mm thickness. Hot rolling of 5 passes was carried out with three conditions, the heavy reduction in front stand, even reduction along each stand and the heavy reduction in rear stand using the experimental mill in laboratory. Pass schedule is shown in the Fig. 1.

These specimens were two stage cold rolled to 0.3 mm with intermediate annealing. Cold rolled specimens were annealed for primary and secondary recystallization.

3. Results and Discussion

Fig. 2 shows the magnetic flux density of the specimen with hot rolling reduction distribution. The effect of hot



(a) (b)

Fig. 3. Microstructures of hot bands; heavy reduction (a) in front stand, (b) in rear stand.

rolling reduction schedule on the magnetic flux density is large at the condition of no hot band annealing. The specimens with heavy reduction in front stand shows the poor magnetic flux density. The high reduction ratio shift from front stand to rear stand improves the magnetic flux density in large scale. The best property is achieved at 880 primary recrystallization temperature.

Fig. 3 shows the hot band microstructures with different hot rolling reduction distribution. The specimen with heavy reduction in rear stand shows the recrystallization in the center layer comparing to heavy reduction in front stand.

Fig. 4 shows the hot rolling texture of the hot bands with reduction distribution at 1/4t and 1/8 t depth from surface. {110}<001>, so called as Goss texture is stronger at the surface and at the condition of heavy reduction in rear stand. Maximum intensity of {001}<110> and {111}<112> is almost same at the surface. At 1/4t depth, the heavy reduced specimen in rear stand shows the weaker {001}<110> and stronger {111}<112> intensity than the heavy reduced specimen in front stand. It is known that {111}<112> is easily consumed by Goss grains and {001}<110> is not in secondary recrystallization [8, 9]. In that sense, the heavy hot rolling reduction in rear stand is thought to render the good magnetic property.

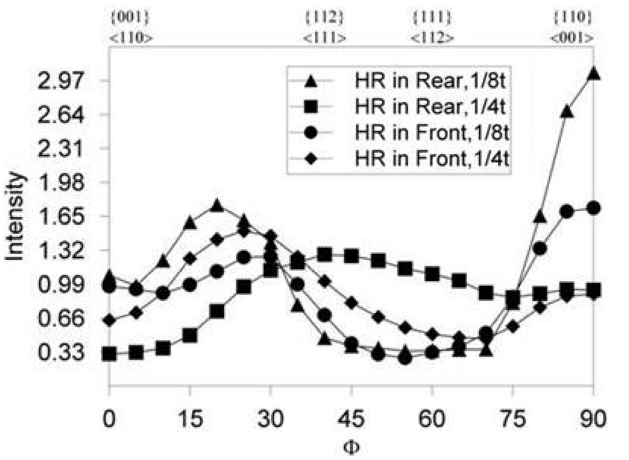


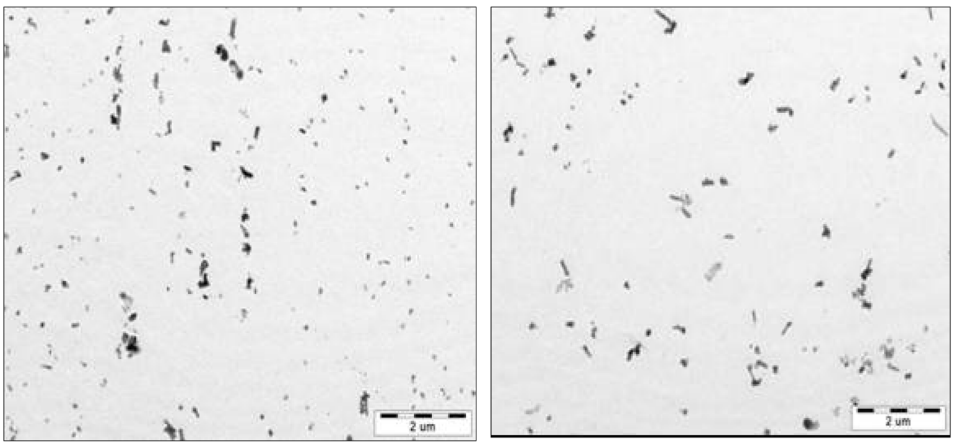
Fig. 4. Maximum intensity profile of ε-fiber with hot rolling condition and depth.

Fig. 5 shows the precipitates distribution after primary recrystallization. The specimen with heavy reduction in rear stand shows the more uniform precipitates distribution. The specimens with heavy reduction in front stand shows the wide range of precipitates size. Small size precipitates are easily disappeared and diffuse into large precipitates. Therefore, it is thought that the specimens with non-uniform distribution lose the inhibiting strength of primary recrystallization grain growth and it leads poor magnetic properties.

4. Conclusion

In GO fabrication process, hot band annealing has thought to be prerequisite to obtaining good magnetic properties. New method of shifting hot rolling reduction from front stand to rear stand showed the high magnetic induction in no hot band annealing process.

The heavy reduction in rear stand shows the weak {001}<110> and strong {110}<001>texture in hot band specimens and uniform precipitates distribution in primary recrystallization. The hot band specimens of the heavy reduction in rear stand also shows the more recrystallized microstructures in the center layer. Due to these, the heavy hot rolling reduction in rear stand improves the magnetic induction in the case of no hot band annealing.



(a) (b)

Fig. 5. Precipitates distribution of primary recrystallized specimen; heavy reduction (a) in front stand, (b) in rear stand.

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