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EFFECTS OF ALLOYING ELEMENTS AND HOT-ROLLING TEMPERATURE ON TEXTURES AND $\bar{r}$ VALUES OF CONTINUOUS-ANNEALED EXTRA LOW CARBON STEEL SHEETS

W. C. JEONG, J. C. SHIN, AND J. H. CHUNG

Research Institute of Industrial Science and Technology,
P. O. Box 135, Pohang, Korea

ABSTRACT

The effects of hot rolling temperature and alloying elements on the textures and $\bar{r}$ values of cold rolled and annealed extra low carbon steel sheets have been investigated. The steels examined were one extra low carbon Al-killed steel and two Ti-IF (Interstitial Free) steels with or without phosphorus. (200) pole figures and relative intensities of various reflections from the rolling plane were determined for hot bands and annealed sheets. The hot rolled textures are found, when finish-rolled at about 900°C, random regardless of the steels tested. When the finish rolling temperature is lowered to the ferrite region temperature of 750°C, however, the principal preferred orientation of (100)[011] is developed. $\bar{r}$ values of annealed sheets are decreased with decreasing the finish rolling temperature. This could be related to the presence of the stronger (100)[011] component, which is originated from the texture inhomogeneity in the through thickness direction of the hot bands at 750°C. The steel having the lower $\bar{r}$ value revealed the higher yield point elongation which is closely related to the solute carbon content in the steels. The major component of the recrystallization texture was near {554}<225> irrespective of the steels tested, but the intensity of (100)[011] component was increased with decreasing the finish hot rolling temperature.

I. INTRODUCTION

Numerous investigations of texture formation during cold rolling and subsequent recrystallization have been carried out with a view to producing cold rolled sheets with high $\overline{r}$ values. Recently, there has been increased interest in extra low carbon steels (1-3) which can yield materials with high $\overline{r}$ values by hot rolling in the high ferrite range with or without a subsequent recrystallization anneal.

The present investigation was undertaken to study the effects of hot rolling temperature and alloying elements on the textures and $\overline{r}$ values of cold rolled and then continuous annealed extra low carbon steel sheets.

II. EXPERIMENTAL PROCEDURE

Three kinds of steels were employed and their chemical compositions are given in Table 1. Steel C is known as high strength

Table 1. Chemical compositions of steels(wt%)

Steel	C	Si	Mn	P	S	Al	N	Ti
A	0.0011	0.01	0.20	0.013	0.0046	0.018	0.0024	-
B	0.0011	0.01	0.20	0.013	0.0046	0.017	0.0030	0.033
C	0.0012	0.01	0.21	0.074	0.0046	0.039	0.0033	0.037

cold rolled steel with extra-deep drawability. This steel is solid solution hardened by adding more phosphorus than steel B, well known as the best formable cold rolled steel.

Each ingot was hot forged to 30 mm thick plate. The forged plates were reheated at 1250°C for one hour, and then hot rolled to 3.2 mm thick hot bands by 3 passes. The finish hot rolling temperatures were varied from 900°C to 750°C by the interval of 50°C. The hot rolled sheets were then kept at 700°C for one hour, followed by furnace cooling to simulate coiling process.

The hot-rolled sheets were pickled and cold-reduced 75 % to the nominal thickness of 0.8 mm. To simulate the continuous annealing cycle, the cold-rolled sheets were heated to 850°C at a rate of 5°C/sec, held at the temperature for 40 seconds, then slowly cooled down to 650°C at 5°C/sec, and then rapidly cooled to room temperature at a rate of 40°C/sec.

The textures of hot bands and annealed sheets were examined. Both (200) pole figures and relative intensities of various reflections from the rolling plane were determined. The plastic strain ratio, $\bar{r}$, was determined by measuring the width and thickness change after 15 % tensile strain.

III. RESULTS AND DISCUSSION

The relative intensities of (222), (200), (211), and (110) reflections of the surface and the half-thickness plane of hot rolled strips as a function of the finish hot rolling temperature are shown in Figure 1(a) and (b). All the intensities at the surfaces were more or less constant irrespective of the hot rolling temperature for the steels examined. The intensities of (222), (200), and (211) reflections of the half-thickness plane are increased with decreasing the finish hot rolling temperature, while the intensity of (110) reflection decreased with decreasing the finish rolling temperature.

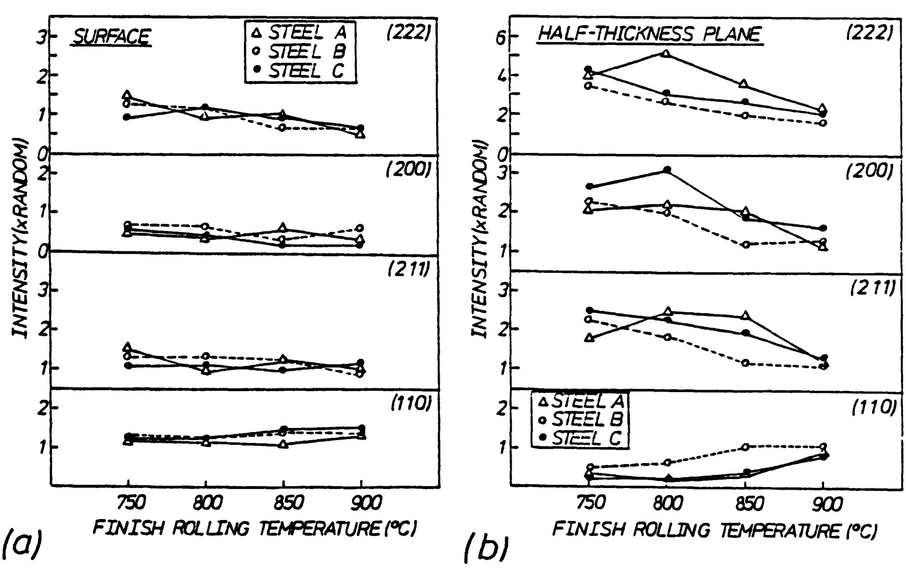

Figure 1 Relative intensities at (a) the surface plane and (b) the half-thickness plane of hot rolled strips as a function of finish hot rolling temperature.

When the hot rolling was finished at 900°C, there was only a little difference between the pole intensities of the surface and the half-thickness plane of the hot rolled strips. When hot rolled at 750°C, however, the intensities of (222), (200), and (211) reflections increase and the (110) intensity decreases toward the center of the sheet thickness. This texture inhomogeneity through the thickness direction is often pointed out as a major problem associated with hot rolling in the ferrite region.

The (200) pole figures were determined from the half-thickness plane for the hot bands rolled at 750oC and 900oC. Figure 2 shows the (200) pole figures for steel B. When the steel was finish rolled at 900oC, its intensities were nearly random as expected from the pole intensities of Figure 1. When the hot rolling temperature was lowered to the ferrite region temperature of 750oC, the principal preferred orientation of (100)[011] appeared and the (112)[$\bar{1}$10] orientation became stronger. This tendeny was commonly observed for all the three steels.

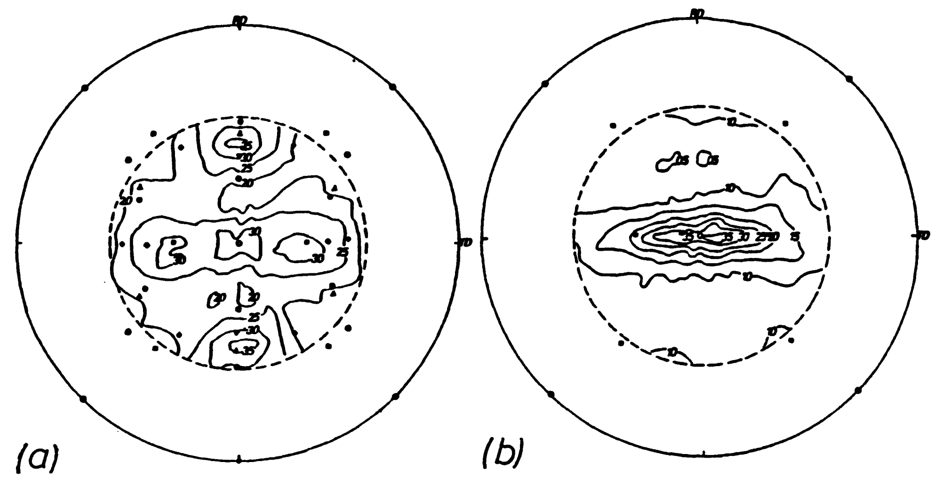

Figure 2 (200) pole figures determined from the half-thickness plane of steel B after hot rolling at (a) 900oC and (b) 750oC.

On the other hand, little difference was observed in the pole figures of steel A and steel B hot rolled at 900oC. The texture of steel C containing both titanium and phosphorus, however, showed the stronger (100)[011] orientation and the weaker (111)[$\bar{1}\bar{1}$2], (111)[10$\bar{1}$], and (554)[22$\bar{5}$] than the steels, A and B.

The variations in the $\bar{r}$ value and yield point elongation for continuous annealed steel sheets with the finish hot rolling temperatures are shown in Figure 3(a) and (b). For the three steels examined, with decreasing the hot rolling temperature, the $\bar{r}$ value decreased.

The (200) pole figures of continuous annealed sheets were measured in the half-thickness plane, as shown in Figure 4. Irrespective of the hot rolling temperatures, the major orientations are (554)[22$\bar{5}$], (111)[$\bar{1}\bar{1}$2], and (111)[10$\bar{1}$]. This result is similar to the other's work (1) that the major orientation of interstitial free steel is near{554}<225>. The (100)[011] orientation is increased, however, with decreasing the hot rolling temperatures. It is clear that the increase of the (100)[011] component is originated from the (100)[011] orientation, the

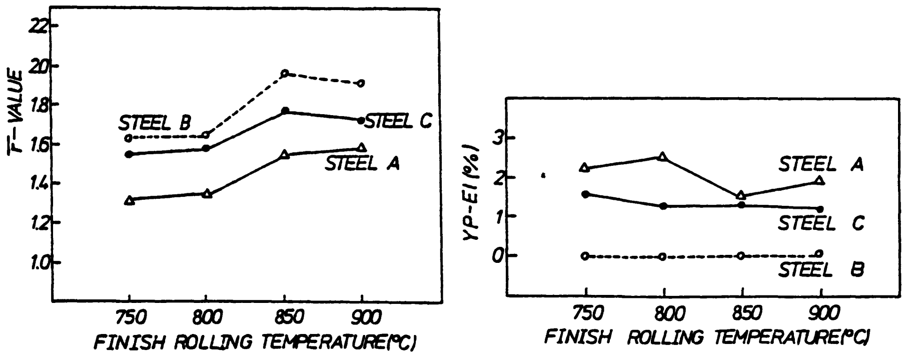

Figure 3 Effect of finish hot rolling temperature on $\overline{r}$ value and yield point elongation of the continuous annealed steel sheets.

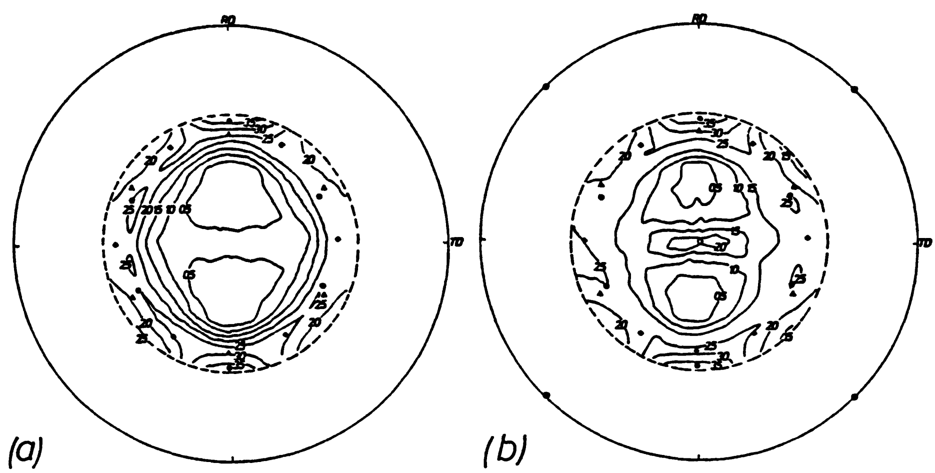

Figure 4 (200) pole figures determined from the half-thickness plane of steel B cold-rolled and continuous-annealed after hot rolling at (a) 900°C and (b) 750°C.

principal orientation of the hot rolled strips. The deterioration of $\overline{r}$ value with decreasing finish rolling temperature is thought to be caused by the existence of the strong (100)[011] component produced as a consequence of the texture inhomogeneity in the through thickness direction.

The $\overline{r}$ value was highest in the Ti-added extra low carbon steel and the lowest $\overline{r}$ value was obtained for the extra low carbon steel without titanium, a strong carbide former, for all the annealing temperatures employed. This could be explained as follows. The existence of solute carbon prior to the recrystallization is well known to deteriorate the deep drawability of annealed steel sheets. The effect of solute carbon on the $\overline{r}$ value is evaluated by correlating the solute carbon content after the anneal to the amount of yield point elongation (YP-El). As shown in Figure 3, the amount of YP-El was almost constant over the finish hot rolling temperatures, while the more YP-El was observed in the order of steels A, C and B. This order is exactly opposite to the order of the $\bar{r}$ value. This result appears to confirm the deteriorating effect of the solute carbon on the $\bar{r}$ value. It is important to note that the steel C containing titanium content enough to scavenge all the solute carbon in steel showed 1-2% YP-El. This could be because the extensive precipitation of titanium in (Fe,Ti)P resulted in the decrease of effective titanium content enough to scavenge the solute carbon (5).

IV. CONCLUSIONS

The effects of hot rolling temperature and alloying elements on the textures and $\bar{r}$ values of cold rolled and annealed extra low carbon steel sheets have been investigated. $\bar{r}$ values of annealed sheets are decreased with decreasing the finish rolling temperature. This could be related to the presence of the stronger (100)[011] component, which is originated from the texture inhomogeneity in the through thickness direction of the hot bands at $750^{\circ}C$. The steel having the lower $\bar{r}$ value revealed the higher yield point elongation which is closely related to the solute carbon content in the steels. The major component of the recrystallization texture was near $\{554\}\langle 225\rangle$ irrespective of the steels tested, but the intensity of (100)[011] component was increased with decreasing the finish hot rolling temperature.

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