TEXTURE DISTRIBUTIONS THROUGH THE THICKNESS OF AN ELC-BH SHEET WITH VERY HIGH $\bar{r}$ -VALUE PRODUCED BY A NEW TECHNOLOGY

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Effects of a new technology which made $\bar{r}$ -value increase remarkably on the distributions of the cold rolling and annealing textures through the thickness of an extra low-carbon and high strength bake-hardening sheet steel have been researched by means of the method of ODF. The results are expressed as follows: (1) γ -fiber axis texture in the ELC-BH sheet obtained by the new technology develops so strongly and purely, especially within the sheet. This is the essential cause why $\bar{r}$ -value of the sheet remarkably increases. (2) The very strong γ -fiber axis texture of being completely different from conventional one is closely related to the cold rolled sheet supplied by the new technology which benefits to develop $\{1\ 1\ 1\}$ annealing texture strongly. The inside of the cold rolled sheet is far more favorable than its surface to the development of the γ -fiber axis texture.

Keywords: Texture distribution; New technology; Extra low-carbon steel;
High strength; Bake-hardening

INTRODUCTION

Adding a procedure of texture pretreatment between hot- and cold-rolling process of conventional producing technology for extra low-carbon and high strength bake-hardening sheet steel (for short, hereafter called ELC-BH sheet) could make $\{1\ 1\ 1\}$ annealing texture

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develop still more strongly so that $\bar{r}$ -value of the finished sheet reached the same level as IF steel (Guan, 1993). This method benefits to eliminate harmful action of the deep drawability decrease brought by adding phosphorus into the ELC-BH sheet, and also supplies a feasible technological way for developing extra low-carbon and high strength sheet steel with super extra-deep drawability. Some effects of the new technology on the microstructures and properties of the ELC-BH sheet have been researched, especially with respect to its textures (Guan *et al.*, 1995a,b). However the effects on the cold rolling and annealing texture of the ELC-BH sheet obtained by this new process are only limited within the layer whose center was 1/4 sheet thickness from the sheet surface. The researches on the change law of the textures through sheet thickness of the ELC-BH sheet have not still been carried out so far. Therefore it is necessary that based on the past researches, the whole distribution of the textures through the sheet thickness are further analyzed in order to discover the mechanism of the remarkable increase of $\bar{r}$ -value caused by the new technology accurately.

EXPERIMENTAL MATERIALS AND METHODS

Experimental sheets selected for the investigation were from the same furnace steel and produced by conventional and the new technology, respectively. The composition of the steel is shown as follows (mass%): 0.0021% C, 0.0039% N, 0.026% Si, 0.24% Mn, 0.098% P, 0.008% S, 0.011% Al, 0.041% Nb, 0.024% Ti and trace RE. The steel was melted in a 50 kg vacuum-induction furnace in our laboratory. The slab forged for hot rolling was hot rolled to 8 mm thickness after being reheated to 1150°C for 1 h, followed by coiling at 750°C for 2 h. Then the hot rolled sheet was treated to two kinds of sheets of 0.8 mm thickness by conventional and the new technology, respectively. The cold reductions of the two kinds of finished sheets were about 90%. Soaking temperature was 910°C and soaking time was 120 s during annealing.

Texture samples for testing were obtained from the cold rolled and annealed sheet corresponding to two kinds of different technologies, respectively. All of their sizes were 25 mm length and 20 mm width. Considered the texture distribution in experimental sheets of taking their center section as symmetrical plane, the textures at surface,

section of 1/4 sheet thickness from surface, and center of the sheets were only determined by the method of testing texture at individual plane separately.

Testing the textures was carried out on a Rikaku-3014 type X-ray diffractometer using Mo K_α radiation at 40 kV and 20 mA. And the results were given by the figures of the orientation distribution functions (that is, ODFs). At first, two incomplete pole figures of (100) and (200) were determined by reflection method within $\alpha = 30^\circ - 90^\circ$. Then the ODFs were calculated and drawn based on the pole figures through a texture analysis program system invented by Prof. H. J. Bunge. The samples were ground to suitable sheet thickness corresponding to different testing plane by sand paper, followed by chemical polishing.

EXPERIMENTAL RESULTS

The Comparison between Two Kinds of Cold Rolling Textures

It is shown in Figs. 1 and 2 that the texture distributions through the thickness of the cold rolling sheets obtained by two kinds of technologies respectively are basically alike, but still there exist some differences. As shown in Fig. 1, ODF figure corresponding to the cold rolling texture gained through conventional technology is fundamentally similar, that is, the characters of cold rolling textures through the sheet thickness are basically the same. All the textures consist of more strongly partial α -fiber axis texture and $\{001\}\langle\bar{1}00\rangle$ and their near components as well as weaker γ -fiber axis texture. And the difference between the intensities of two main components of γ -fiber axis texture, that is, $\{\bar{1}11\}\langle\bar{1}\bar{1}0\rangle$ and $\{\bar{1}11\}\langle\bar{1}\bar{1}2\rangle$, is little. But the intensities of $\{001\}\langle\bar{1}\bar{1}0\rangle$ and $\{001\}\langle\bar{1}00\rangle$ and their adjacent components decrease a little from the surface to the center of the sheet. While average intensity of γ -fiber axis texture is not fundamentally related to every section through the sheet thickness. The difference is connected with touch friction between roll surface and sheet bar during cold rolling.

As shown in Fig. 2, compared with conventional one, the characters of texture through the thickness of the cold rolled sheet produced by the new process display obvious differences, especially at the sheet surface. ODF figures at 1/4 sheet thickness and central section are

(a)

FIGURE 1(a)

basically the same. Both of them show the same character that consists mainly of stronger γ -fiber axis texture and weaker α -fiber one. The character is completely different from that of conventional cold rolling texture. And intensity of every texture component at 1/4 sheet thickness section is slightly higher than that at central one. While ODF figure of the cold rolling texture at the sheet surface is absolutely different from that at the two sections mentioned above. It still remains the character of conventional cold rolling texture. It is known from the

(b)

FIGURE 1(b)

comparison of Figs. 1 and 2 that the changes for making α -fiber axis texture weaker and the γ -fiber one stronger take place in the whole of cold rolled sheet obtained through the new technology. But the change of α -fiber axis texture is even larger than that of γ -fiber one, especially within the range from $\{001\}\langle\bar{1}\bar{1}0\rangle$ to $\{223\}\langle\bar{1}\bar{1}0\rangle$ component. These changes gradually strengthen from the surface to the center of the cold rolled sheet to cause the differences of the texture characters mentioned

(c)

FIGURE 1(c)

FIGURE 1 ODF figures of the cold rolling textures obtained by conventional technology (a) at the sheet surface (b) at 1/4 thickness section of the sheet (c) at central section of the sheet.

above. It can be seen that the intensity of γ -fiber axis texture is always higher than that of α -fiber one within a certain range under the sheet surface, that is, the character of the cold rolling texture produces qualitative change.

(a)

FIGURE 2(a)

The Comparison between Two Kinds of Annealing Textures

It is shown in Figs. 3 and 4 that the texture distributions through the thickness of annealed sheets obtained by two kinds of technologies respectively still contains some differences. All the textures through the thickness of conventional annealed sheet display fundamental character as that had in ELC-BH sheet generally, that is, it consists of

(b)

FIGURE 2(b)

stronger γ -fiber axis texture, in which the intensities of $\{\bar{1}11\}\langle\bar{1}\bar{1}2\rangle$ components are the highest and that of $\{\bar{1}11\}\langle\bar{1}\bar{1}0\rangle$ are second placed (Guan and Wang, 1993; 1995). But the intensities of the two kinds of fiber axis textures change with the place of testing section. Generally speaking, the intensities at 1/4 thickness section is the strongest and that at sheet surface is the weakest among the textures at the three kinds

(c)

FIGURE 2(c)

FIGURE 2 ODF figures of the cold rolling textures obtained by the new technology (a) at the sheet surface (b) at 1/4 thickness section of the sheet (c) at central section of the sheet.

of sections, especially with respect to γ -fiber axis texture. It is obvious that these changes are actually related to original state of cold rolling texture through the sheet thickness and the mechanism of prior nucleation and continuous development for $\{111\}$ annealing texture.

(a)

FIGURE 3(a)

As shown in Fig. 4, the major characters of textures through the thickness of annealed sheet produced by the new technology are the same. All the textures consist basically of γ -fiber axis texture whose intensity is even stronger than that of conventional annealing one and the strongest components have transformed from $\{\bar{1}11\}\langle\bar{1}\bar{1}2\rangle$ to $\{\bar{1}11\}\langle\bar{1}\bar{1}0\rangle$. The annealing textures at 1/4 thickness and central section have the same character, and compared with that at the sheet

(b)

FIGURE 3(b)

surface, their γ -fiber axis textures are far stronger, while their α -fiber ones change little. This shows that the texture uniformly distributes inside the annealed sheet gained by the new technology, while conventional annealing texture does not possess this character by comparison. The differences between the texture characters at the surface and the inside of the sheet are also related to the distributions of its original cold rolling texture as conventional annealing texture.

(c)

FIGURE 3(c)

FIGURE 3 ODF figures of the annealing textures obtained by conventional technology (a) at the sheet surface (b) at 1/4 thickness section of the sheet (c) at central section of the sheet.

DISCUSSIONS

As mentioned above, compared with the annealing texture obtained by conventional one, qualitative change of the texture takes place in the whole of the annealed sheet produced through the new technology, that

(a)

FIGURE 4(a)

is, γ -fiber axis texture is far stronger and purer, and the strongest components transform too. The qualitative change of annealing texture is the essential cause with respect to improving $\bar{r}$ -value of the sheet produced by the new technology remarkably. Thus it can be known that the research results on the texture at 1/4 thickness section also suit the other sections of the sheet. It should be pointed out that the differences between the textures at the surface and the inside of the sheet

(b)

FIGURE 4(b)

show that strengthening γ -fiber axis texture at the sheet surface may benefit the increase of $\bar{r}$ -value further. It is seen from the comparison with the cold rolling and annealing texture obtained by the new technology, as shown in Figs. 2 and 4, that the change of the annealing texture is closely related to the original state of the cold rolling one. At the sheet surface, the cold rolling texture does not have essential

(c)

FIGURE 4(c)

FIGURE 4 ODF figures of the annealing textures obtained by the new technology (a) at the sheet surface (b) at 1/4 thickness section of the sheet (c) at central section of the sheet.

difference from conventional cold rolling one, while within the sheet, the cold rolling one shows the same character as conventional annealing texture and its γ -fiber axis texture is far stronger. According to the mechanism of prior nucleation and continuous development for

$\{111\}$ annealing texture in ELC-BH sheet (Guan and Wang, 1993), two kinds of different texture changes take place in the sheet during the annealing under the same condition. On the one hand, the grains of $\{111\}$ orientation which are dominant in quantity within the cold rolled sheet first recover and form subgrains, followed by nucleating and growing prior to grains of the other orientations so that γ -fiber axis texture develops so strongly. On the other hand, the development of γ -fiber axis texture is definitely hindered so that its intensity is much weaker than that within the sheet for the α -fiber one to occupy dominant place at the surface of the cold rolled sheet. At the same time, uniform texture distribution within the cold rolled sheet produced through the new technology results in the same texture character inside corresponding annealed sheet. Thus it is seen from the experimental results and discussions mentioned above that the new technology supplies a good cold rolled parent state which benefits to develop very strong $\{111\}$ annealing texture, in which texture distributions are not uniform and its inside is far more favorable than its surface to the development of $\{111\}$ annealing one.

CONCLUSIONS

1. γ -fiber axis texture in an ELC-BH sheet obtained by the new technology develops so strongly and purely, especially within the sheet. This is the essential cause why $\bar{r}$ -value of the sheet remarkably increases.
2. The very strong γ -fiber axis texture being completely different from conventional one is closely related to the cold rolled parent state supplied by the new technology which benefits to develop $\{111\}$ annealing texture strongly. The inside of the parent state is far more favorable than its surface to development of the γ -fiber axis texture.

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