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INVESTIGATION ON THE TEXTURE OF AN ELC-BH SHEET WITH VERY HIGH $\bar{R}$-VALUE PROCESSED BY NEW TECHNOLOGY

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The texture of an extra low-carbon and high strength bake-hardening sheet steel (i.e. ELC-BH sheet) processed in our laboratory through a new invented technology has been investigated by means of ODF method, so that the cause of the very high $\bar{r}$-value of this sheet has been discovered. Experimental results are shown as follows: ① The $\bar{r}$-value of the experimental sheet treated by the new process is as high as 2.67 and this is the highest $\bar{r}$-value published so far for phosphorus – added high strength and deep drawing sheet steels. At the same time, the contradiction between deep-drawability and strengthening is successfully solved too. ② A nucleus of the new technology is supplying a good cold rolled parent state which benefits to the development of {111} annealing textures through controlling texture, while strong development of {111} annealing textures can cause very high $\bar{r}$-value. ③ The cold rolling and annealing texture obtained by the new technology are quite different as compared with that of conventional process. New cold rolling texture has stronger {111} components and weaker {100} components than conventiopnal cold rolling texture. The concentrations of {111} components of new annealing texture are not only distinctly general increase but also the crystal orientations corresponding to the peak values of orientation concentrations of the texture have been also changed from conventional $(\bar{1}11)$ $[1\bar{1}2]$ orientations to $(\bar{1}11)$ $[0\bar{1}1]$ orientations.

KEY WORDS: Drawing sheet steel, plastic strain ratio, texture, extra low-carbon steel, high strength, bake-hardening.

INTRODUCTION

It is well known that ELC-BH sheets is one of automobile sheet steels with best combined properties in the world of today (Wang and Guan). However, because strengthening caused by adding phosphorus makes drawability be damaged so that $\bar{r}$-value of ELC-BH sheet is lower than that of interstitial-free steel (i.e. IF steel), this is not beneficial for widening its applying range and raising its strength level without the decrease of drawability. Based on the close relation between average plastic strain ratio ($\bar{r}$-value) and {111} annealing textures as well as the hereditability of texture development in the sheet during process, we invented a new technology in order to solve the problem (Guan) Experimental sheet produced by the new technology had even higher $\bar{r}$-value than that through conventional process, while its strength and

Table 1 The chemical composition of experimental sheets (wt.%).

C	*N*	*Si*	*Mn*	*P*	*S*	Al_s	*Nb*	*Ti*	*RE*
0.0021	0.0039	0.026	0.24	0.098	0.008	0.011	0.041	0.024	trace

bake-hardenability weren't damaged. In present work, the reason why $\bar{r}$-value of the sheet processed through the new techno-logy was markedly raised is discovered according as our investigation on the textures of two sheets obtained by conventional and new technology respectively.

EXPERIMENTAL PROCEDURE

Two ELC-BH sheets selected for investigation were produced from a Nb+Ti-treated steel which was melted in a 50 kg laboratory vacuum-melted heats. The chemical composition of the steel is shown in Table 1. The ingot was rolled to 8 mm thickness through conventional hot rolling process in laboratory. Then the hot strip was treated to two sheets of 0.8 mm thickness by conventional and new technology respectively.

The mechanical and forming properties were tested on MTS type material test machine. The inspection and manufacture of samples were conducted according to Chinese Standars GB228-76, GB3076-82, GB5027-85 and GB5928-85.

Texture analysis was conducted on Rigaku-3014 type X-ray diffraction instrument. The target material is Molybdenum and testing conditions were: tube voltage = 40 kv, and tube current = 35 mA. First, two whole pole figures of (110) and (200) were determined by the method of combining transmission with reflection. Then, the values of the orientation distribution function (ODFs) were calculated based on the data of pole figures. Last, the analysis results were given through $\varphi = 45°$ sections of ODFs, α- and γ-fiber axis textures, and ODF figures drawn according as an equal concentration line on which orientation concentrations were equal to 4. The texture samples which had 15×15 mm^2 size and 70μ thickness were cut from cold rolled and annealed sheets respectively. Because the texture of surface in the sheet may be different to some extent from that of center, all samples were only tested within the thickness layer whose center was 1/4 sheet thickness from the surface of sheet.

EXPERIMENTAL RESULTS AND DISCUSSIONS

The comparison between the properties of two ELC-BH sheets treated by conventional and the new technology respectively is shown as Table 2 and Figure 1. It is clearly seen that the $\bar{r}$-value of the sheet obtained by the new technical method is distinctly raised, that is, its $\bar{r}$-value increases from 1.92 of conventional process to 2.67, and increase extent is 39%. And other main properties such as strength and bake-hardenability aren't damaged. It points especially out that the $\bar{r}$–value gained by the new process is as high as 2.67, which if is the highest $\bar{r}$-value among documents published so far for phosphorus – added drawing sheets. Hence, the new technology solves successfully the contradiction between deep drawability and strengthening, and supplies beneficial condition to manufacture more drawing sheets with even higher strength and better drawability.

Table 2 The comparison between properties of the sheets treated by two technologies respectively.

technology	*YS* (*MPa*)	*TS* (*MPa*)	*YS/TS*	EL_{10}	$\bar{r}$	$\bar{n}$	Δr	*AI* (*MPa*)	*BH* (*MPa*)
conventional	200.0	355.0	0.565	45.0	1.92	0.231	0.246	22.6	29.0
new	198.0	345.0	0..574	40.0	2.67	0.222	0.901	23.0	32.8

The reason why the $\bar{r}$-value obtained by the new method is markedly enhanced is closely connected with the effect of this method on texture. The comparison of two annealing textures acquired by conventional and new technology respectively are shown in Figure 2 to Figure 4. As these figures show, the annealed sheet treated by the new process has even stronger γ-fiber axis textures (i.e. {111} textures) than that through conventional process, while its {100} texture disappears completely. It is well established that excellent deep drawability (high $\bar{r}$-value) is occasioned by texture which contains high concentrations of {111} planes parallel to the sheet plane and low concentrations of {100} planes (Held). Therefore, it is strong {111} annealing textures that make the $\bar{r}$-value of sheet treated by the new method be obviously improved. It should be noted that the orientations corresponding to the peak values of orientation concentrations for the new process have changed from $(\bar{1}11)[1\bar{1}2]$ orientations of conventional technology to $(\bar{1}11)[0\bar{1}1]$ orientations as Figure 3 shows. It shows that the viewpoint that high $\bar{r}$-value is usually corresponding to strong $(\bar{1}11)[1\bar{1}2]$ annealing texture components should be discussed again.

Strong {111} annealing textures caused by this new process relate closely to its effects on texture changes in other processing prior to annealing. Our researches point out that annealing texture change of ELC-BH sheet is not only related to the texture evolution during annealing, but also to hot and cold rolling process (Guan). It is obvious

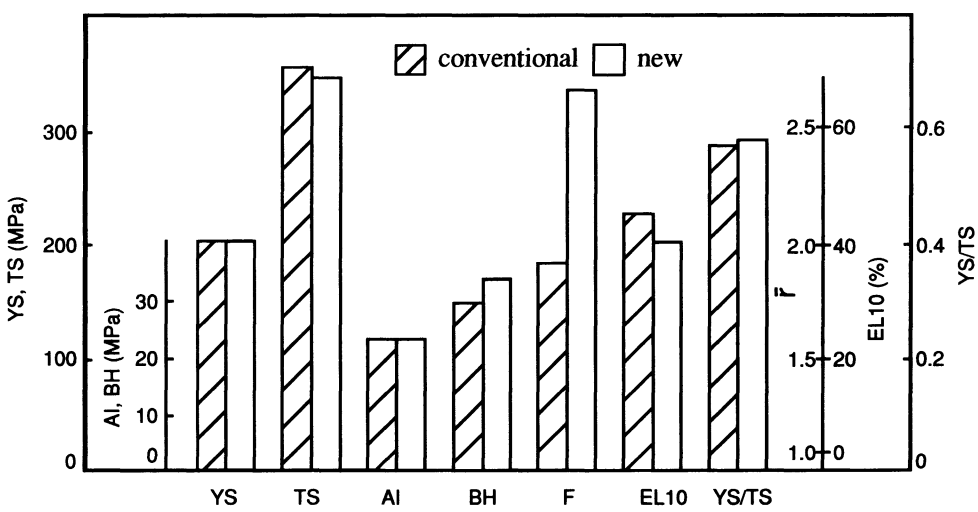

Figure 1 Comparison between properties of the sheets treated by two technologies respectively.

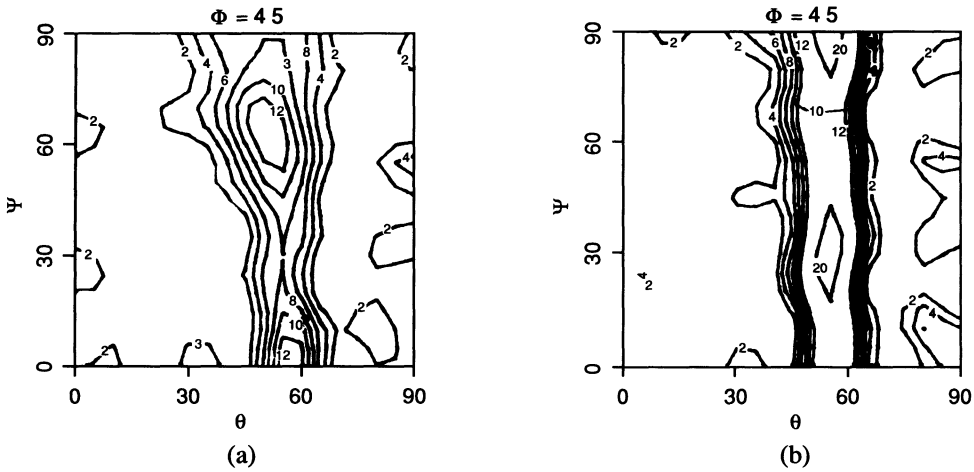

Figure 2 $\varphi = 45°$ sections of ODFs of annealing textures obtained by two technologies respectively.
(a) conventional processing (b) new processing

that the annealing texture closely relates to cold rolling texture for this new technology through the comparison of two processes of experimental sheets. As Figure 5 to Figure 7 showing, conventional cold rolling texture consists of strong α-fiber axis textures and weak γ-fiber axis textures, while the cold rolling texture gained by the new method, which mainly composed of γ-fiber axis textures, is basically congruent

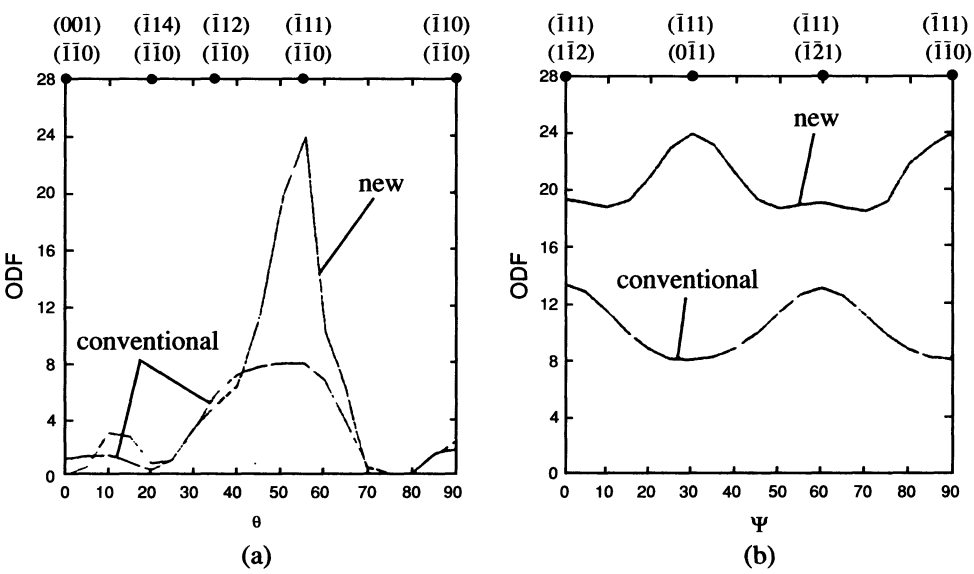

Figure 3 Comparison of α- and γ-fiber axis textures of annealing textures obtained by two technologies respectively.
(a) α-fiber axis textures (b) γ-fiber axis textures

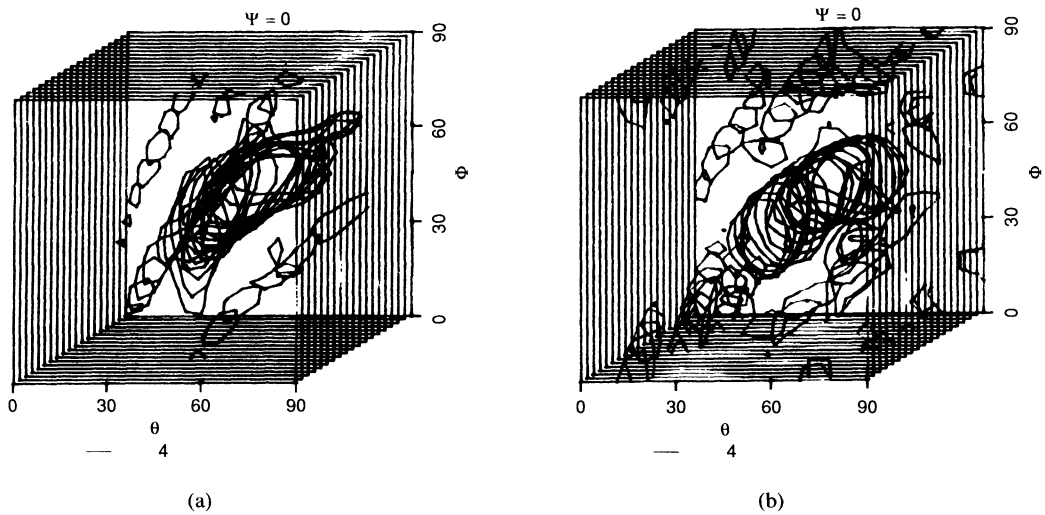

Figure 4 ODF figures of annealing textures obtained by two technologies respectively.

with conventional annealing texture. Because the mechanism of recystallization nucleation follows the oriented nucleation theory, two mechanisms of prior nucleation and continuous development for {111} annealing textures exist in ELC-BH sheet (Guan and Wang). Hence, even stronger {111} annealing textures are surely multiplied through annealing in a cold-rolled sheet in which strong {111} textures exist. For above discussion, the comparison between the cold rolling or annealing textures obtained by

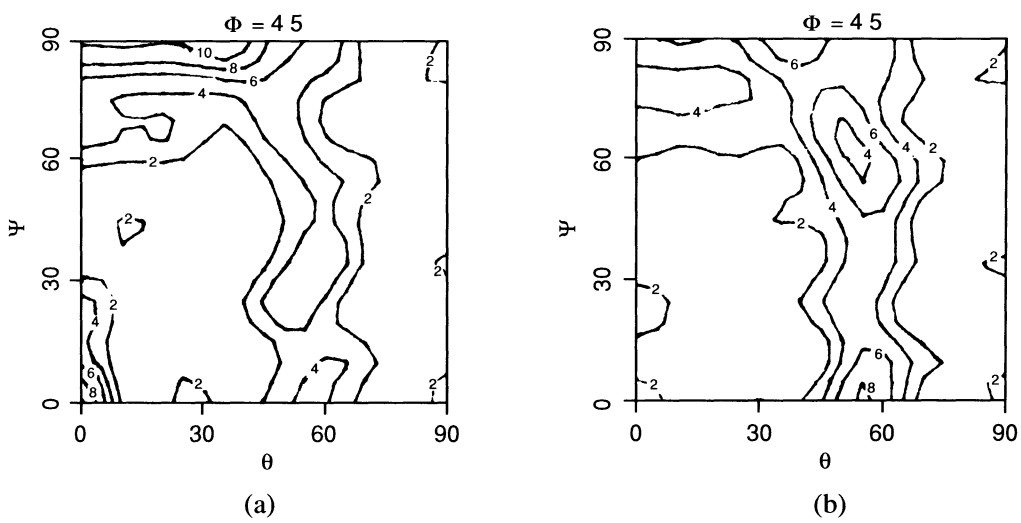

Figure 5 φ = 45° sections of ODFs of cold-rolling textures obtained by two technologies respectively.
(a) conventional processing (b) new processing

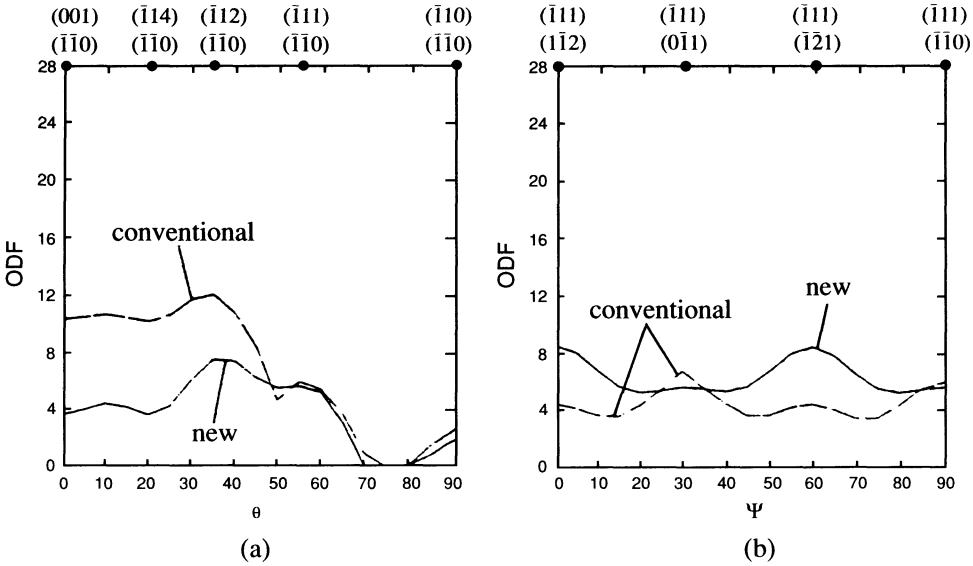

Figure 6 Comparison of α- and γ-fiber axis textures of cold-rolling textures obtained by two technologies respectively.
(a) α-fiber axis textures (b) γ-fiber axis textures

two technologies respectively is shown in Table 3. In short, a nucleus of this new technology is supplying a cold rolled parent state which benefits to the nucleation and development of {111} annealing textures through controlling texture.

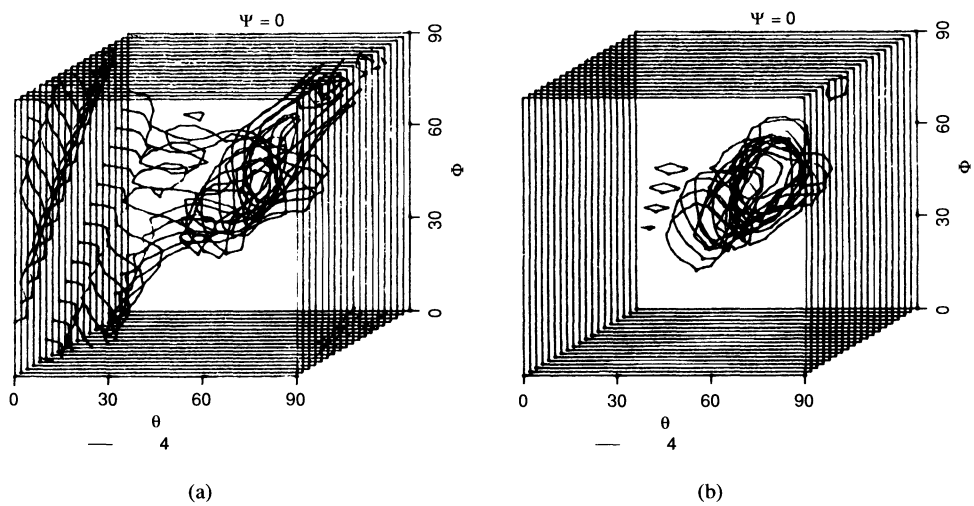

Figure 7 ODF figures of cold-rolling textures obtained by two technologies respectively.
(a) conventional processing (b) new processing

Table 3 The texture comparison between conventional and new.

technology	*cold rolled state*	*annealed state*	*$\bar{r}$-value*
conventional	weak {111} textures	strong {111} textures	1.92
new	strong {111} textures	even stronger {111} textures	2.67

CONCLUSIONS

1. The $\bar{r}$-value of the experimental sheet treated by the new technology is as high as 2.67, and this is the highest $\bar{r}$-value published so far for phosphorus-added high strength and deep drawing sheet steels. And the contradiction between deep drawability and strengthening is successfully solved too.
2. A nucleus of the new technology is supplying a good cold rolled parent state which benefits to the development of [111} annealing textures through controlling textures, while strongly developmental {111} annealing textures can cause very high $\bar{r}$-value.
3. The cold rolling and annealing texture obtained by the new technology are quite different as compared with that of conventional process. New cold rolling texture has stronger {111} components and weaker {100} components than conventional cold rolling texture. The concentrations of {111} components of new annealing texture are not only distinctly general increase, but also the crystal orientations corresponding to the peak values of orientation concentrations of the texture have been also changed from conventional $(\bar{1}11)[1\bar{1}2]$ orientations to $(\bar{1}11)[0\bar{1}1]$ orientations.

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