A Novel Texture Improving Young’s Modulus in Rolling Direction of Hot Rolled Low Carbon Sheet Steel

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A novel texture, which improves Young’s modulus in rolling direction, has been found in a hot rolled low carbon sheet steel. This unique texture is observed in sheet surface area, which consists of sharply developed {110} < 111 > –{110} < 112 > fiber without {110} < 001 >. Together with {112} < 111 > orientation, this fiber can significantly contribute to increase Young’s modulus in rolling direction. The measured Young’s modulus in rolling direction in the present material is 236 GPa, which is more than 10% increase, compared to the one in conventional steels.

KEY WORDS: Young’s modulus; sheet steel; hot-rolling; transformation texture; shear deformation; surface.

1. Introduction

High strength sheet steels with superior formability have been more developed and applied recently in order to reduce the weight of automobiles.1) However, weight reduction, i.e. thickness thinning, by means of high strength sheet steels tends to deteriorate the stiffness of automobiles. In order to overcome this matter, it is also demanded to increase Young’s modulus of sheet steels. For this purpose, it has been investigated to blend stiff phases with steel matrix, recently.2,3) On the other hand, it is well known that Young’s modulus of steels depends on crystal orientation, e.g. the ones in <111> and <001> direction show 284 GPa as highest and 132 GPa as lowest, respectively.4) Young’s modulus of each crystal orientation can be seen by comparing Figs. 1(a) and 1(b). Figure 1(a) demonstrates the representative crystal orientations in φz=45 degree section of ODF and Fig. 1(b) shows corresponding Young’s moduli in rolling direction (RD), which were reported by Yamamoto et al.4)

Therefore, a planar anisotropy of Young’s modulus can be clearly observed in sheet steel with sharply developed texture. Controlled rolling, hot rolling in unrecrystallized temperature range of austenite, generally gives rise to {112} < 110 > intensified transformation texture at the mid-plane of thickness.5–10) In this case, the transverse direction (TD), which is perpendicular to RD, must be parallel to <111> so that Young’s modulus in TD can increase. In fact, Itami and Koyama11) have reported that Young’s modulus in TD reaches approximately 240 GPa in Mn, Nb and Ti alloyed hot rolled low carbon sheet steel, while the one in RD is only about 210 GPa, in contrast.

In the present study, the emphasis was placed on to develop the texture improving the Young’s modulus in RD in hot rolled sheet steel, which has not been reported yet. In order to achieve this purpose, <111>/RD type texture has to be potentially developed.

2. Experimental

Two different vacuum melted ingots were employed in this study. The one consisting of 0.07C, 0.01Si, 1.00Mn, 0.03Al, 0.001N, in mass%, was reheated at 1 523 K for 3 600 s and hot rolling was finished at 1 163 K. This hot-rolled sheet steel will be called specimen A, hereafter. Specimen A was prepared in order to have a commonly observed hot-rolling texture of low carbon steel for a comparison. Another one with chemical composition of 0.05C, 0.01Si, 2.97Mn, 0.52Mo, 0.031Ti, 0.041Nb, 0.0 019B, 0.04Al, 0.002N, in mass%, was also reheated at 1 523 K for 3 600 s. The hot rolling finishing temperature was 976 K. This hot rolled material will be called specimen B, hereafter.

Fig. 1. (a) Representative texture components on φz=45° section of ODF, (b) Young’s modulus (GPa) in rolling direction (RD) of corresponding each orientation.

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No lubrication was employed for the hot rolling experiment. Conventional X-ray diffraction method was used to measure the pole figures. The samples used for the texture measurement were taken from the mid-plane and 1/8 plane of the thickness. Orientation distribution function (ODF)\(^{13}\) was calculated from the \{110\}, \{100\}, \{211\} and \{310\} complete pole figures.

Young’s modulus was experimentally determined using following equation:
\[
E = 0.9467 \times \left( \frac{l}{t} \right)^3 \times \left( \frac{m}{w} \right) \times f^2 \times 10^{-6} \quad \ldots \ldots \quad (1)
\]
where \(E\) is Young’s modulus in GPa, \(l\), \(t\), \(w\), \(m\) are length, thickness, width in mm and weight in kg of the specimen, respectively, and \(f\) is primary resonance frequency. In Eq. (1), \(l\), \(t\) and \(w\) were 130, 1.60 and 10.0 mm, respectively. The primary resonance frequency was measured by horizontal vibration method according to JIS standard Z2280.

3. Results and Discussion

[Figure 2](a) represents \(\varphi_2=45^\circ\) section of ODF measured at the mid-plane of specimen A. There are no major components close to <111>/RD in the texture of mid-plane of the thickness as can be seen by comparing Fig. 2(a) with Fig. 1(a). On the other hand, some components near <111>/RD are found in 1/8 plane of the thickness in Fig. 2(b), such as \{112\}<111>, \{110\}<111> and \{110\}<223>. From this aspect, we have paid attention to the surface texture of hot rolled low carbon sheet steels.

As can be seen in Fig. 2(c), \(\varphi_2=45^\circ\) section of ODF measured at the mid-plane of specimen B consists of \{112\}<110> and \{332\}<113> intensified components, which are typically observed in a texture of ferrite transformed from deformed austenite. In contrast, the ODF measured at 1/8 plane of the thickness, Fig. 2(d), shows a distinct texture consisting of \{110\}<111>–\{110\}<112> and \{112\}<111>. The maximum orientation density in this ODF is more than 22. This sharply developed novel texture formed near surface has not been reported so far. It is noteworthy that the intensity of \{110\}<001>, which significantly deteriorates Young’s modulus in RD, is scarcely observed in Fig. 2(d). It has been reported that \{110\}<001> component is generally observed in vicinity of surface in hot rolled steel sheet regardless of the hot rolling temperature whether in austenite\(^{10}\) or in ferrite region.\(^{13,14}\)

Moreover, ferrite rolling tends to promote the formation of \{110\}<001> intensified texture.\(^{13,14}\) In this sense, it is considered that the texture shown in Fig. 2(d) is formed by transformation as mentioned later.

Young’s modulus was calculated by means of the elastic compliances\(^{15}\) and the ODFs shown in Fig. 2, based on the hypothesis proposed by Hill.\(^{16}\) For this calculation, the software developed by Van Houtte\(^{17}\) was used. The Young’s modulus in RD calculated using the ODF measured at 1/8 plane of specimen B is extremely high, compared to that of specimen A, as can seen in Figs. 3(b) and 3(d). This result is attributable to the novel texture observed at 1/8 plane of the thickness shown in Fig. 2(d). All the components belong to \{110\}<110>–\{110\}<112> fiber can result in increase in Young’s modulus in RD according to Fig. 1(b). Therefore, it is considered the sharply developed \{112\}<111> component and the fiber from \{110\}<111> to \{110\}<112> without \{110\}<001> in Fig. 2(d) mainly contribute to the extremely high Young’s modulus in RD of the 1/8 plane of the specimen B. It should be noted that this texture also increases the Young’s modulus in TD because of the intensified \{110\}<112> component, corresponding to <111> direction in TD.

The measured Young’s modulus of specimen A and B are represented in Fig. 4. It is obvious that the Young’s modulus in RD of specimen B is rather high compared to the one of specimen A or the one investigated by Itami and Koyama.\(^{11}\) In fact, the measured Young’s modulus in RD of specimen A, B and the one obtained by Itami and Koyama\(^{11}\) are 213, 236 and about 210 in GPa, respectively. Although the fiber consisting of \{110\}<111>–\{110\}<112> is also clearly found in the surface texture reported by Itami and Koyama,\(^{9}\) the components \{110\}<112>–\{110\}<001> are also developed together, which drops Young’s modulus in RD significantly.

It should be noted that Young’s modulus was determined by measuring primary resonance frequency using horizontal vibration which corresponds to bending mode. Therefore, the influence of surface portion of the specimen on Young’s modulus tends to be more pronounced than that of mid-layer.

The transformation texture near surface is formed through two events mainly. The first one is deformation under plain strain mode and additional shear deformation introduced due to friction between the steel sheet and rolls in austenite region. The second one is transformation from the deformed austenite above mentioned, which involves variant selection rules\(^{9}\) based on Kurdjumov-Sachs orientation relationship between austenite and ferrite.\(^{18}\) In specimen B, the chemical compositions and the rather low finishing rolling temperature are considered to develop the shear deformed and unrecrystallized austenite in vicinity of surface. Moreover,
The austenite to ferrite transformation temperature must be quite low compared to that of specimen A, because of its chemical compositions, which could influence on the transformation mechanism and the variant selection.

The mechanism of this novel transformation texture formation represented in Fig. 2(d) should be clarified in detail in the future.

4. Summary

The hot rolled sheet steel containing 0.05C-3Mn-Mo-Ti-Nb-B exhibits the novel and distinct transformation texture in vicinity of surface. The ODF measured at 1/8 plane of the thickness shows the sharply intensified \{112\} <111> and \{110\} <111> – \{110\} <112> fiber without \{110\} <001>, which significantly increase the Young’s modulus in RD. In fact, the measured Young’s modulus in RD is 236 GPa, which corresponds to 10% increase or more compared to the one in conventional steels.

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