General paper

The Influence of Tension on the Development of Rolling Textures

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Abstract: The texture inhomogeneity during rolling is one of the greatest problems. Especially, shear textures develop more easily during ferritic rolling of steel sheets at high temperatures owing to friction between rolls and the material. In this study, the influence of front and back tensions on the texture development during ferritic rolling has been studied. The rolling textures were simulated using the full constraints Taylor-Bishop-Hill model with the strain history obtained from finite element analysis. The calculated textures showed that the back tension rolling could reduce the shear component more effectively than front tension or rolling without tension. However, the experimental results showed that the tension effect was very small compared to the prediction. The results were discussed based on the effects of friction, initial sheet texture, back tension, and flow stress.

Key words: Ferritic rolling, Inhomogeneous texture, Deformation texture, Tension rolling

1. INTRODUCTION

Ferritic rolling is a process that is performed by entering the finishing stands at the hot mill at a temperature in the ferrite range. Compared to the conventional hot rolling in the austenite range and subsequent cold rolling process, ferritic rolling has many advantages of lower energy consumption, lower scale loss, improved edge conditions, and so on [1,2]. In spite of these advantages, high friction coefficients and low mechanical properties at high temperatures result in strain inhomogeneity through the thickness of sheet. This inhomogeneity makes shear textures in the surface region of the sheet, which cause the lower formability and inhomogeneous recrystallization behavior. The inhomogeneous texture formation during rolling has been studied by many people [3-6]. In this study, the influence of tension during rolling on the deformation texture has been investigated.

2. EXPERIMENTAL PROCEDURE

The material used was 1.5mm thick titanium-bearing extra low carbon steel sheet containing 0.0025% C, 0.04% Ti, 0.1% Mn, 0.01% P, 0.01% S, and 0.04% Al. To prepare a weakly textured initial specimen, a 3.4mm thick hot rolled sheet was held at 950°C for a few minutes and rolled by 30%, followed by water quenching. The quenched specimen was rolled by 30% at room temperature and heated at 700°C for 10min. These hot rolling and subsequent cold rolling with heat treatment were repeated to 1.5mm in thickness. The 1.5mm thick sheet was used as an initial specimen. The initial specimen was rolled at 700°C to 1.2mm in thickness by one pass without lubrication. The rolling speed was about 5rpm. Immediately after rolling, the specimen was water quenched to suppress the recrystallization. In order to apply a back tension of 50MPa during rolling, a 785N (80kgf) weight was suspended at the end of the sheet (Fig. 1). The tension of 50MPa is equivalent to the flow stress of the steel at a strain of 0.008 (Section 3).

For the analysis of deformation texture, X-ray pole

Fig. 1. Process of back tension applied rolling.

figures were measured at various thickness layers between the center and the surface using the Schultz reflection method with Fe filtered Co-K α radiation. The layer of sheet is identified by a parameter, $s = \Delta x / (d_0/2)$, where Δx represents the distance between the layer and the center of sheet and $d_0/2$ the half thickness, i.e., $s=1.0$ for the surface layer and $s=0.0$ for the center layer.

3. SIMULATION OF TEXTURE DEVELOPMENT

The rolling processes were simulated by the static implicit method of 2-D finite element method (FEM), which is independent of the mass (or volume) of sheet and rolls, with elasto-plastic material model. Fukumura et al. reported that the dynamic explicit and static implicit methods for rolling gave almost the same results [7]. The flow behavior of the steel used in this experiment is approximated by $\sigma = 2.828 \epsilon^{0.229} \dot{\epsilon}^{0.071} \exp(3875/T)$ [8]. The flow behavior of the specimen in this experiment can be approximated by the Hollomon relation $\sigma = K \epsilon^n$ with $K=140\text{MPa}$ and $n=0.229$. The relation was used to simulate the deformation. Although the thermal properties could influence the deformation texture, the thermal properties were not considered in this study for simplicity. The friction coefficient between rolls and sheet was assumed to be 0.35, which was adopted from the other re-

Fig. 2. (110) pole figure of initial steel specimen ($s=0.9$).

sults [9,10]. Two cases of 20 and 40% rolling reductions were simulated. In each case, rolling with and without a back or front tension of 50MPa was considered.

The strain increments of each layer of sheet were calculated from the deformation gradients obtained from FEM, which were also used to calculate the texture evolution. The rotation of crystals during rolling was calculated using the full constraints Taylor-Bishop-Hill model [11,12]. In this calculation, the $\{110\}\langle 111 \rangle$ and $\{112\}\langle 111 \rangle$ slip systems were assumed to be active. The initial orientation of the sheet was assumed to have randomly distributed 978 single crystals per element.

Fig. 3. Measured (110) pole figures of 20% rolled Ti bearing extra low carbon steel sheet.

Fig. 4. Calculated (110) pole figures of 20% rolled Ti bearing extra low carbon steel sheet.

Fig. 5. Calculated (110) pole figures of 40% rolled Ti bearing extra low carbon steel sheet.

4. RESULTS AND DISCUSSIONS

Figure 2 shows the measured (110) pole figure of initial specimen, in which a weak texture developed. Figure 3 shows the measured (110) pole figures of the steel sheet through the thickness after rolling. In the center layer, typical bcc plane strain rolling textures develop in both cases with and without back tension. In the surface layer, shear components of $\{110\}\langle 001 \rangle$ and $\{112\}\langle 111 \rangle$ develop. Even for rolling with back tension, the texture variations through the thickness are almost the same as the case without tension, that is, the tension effect is negligible.

For the 20% rolling reduction, the calculated pole figures are shown in Fig. 4. The pole figures of the steel sheet rolled without tension are similar to the experimental data. However, in the calculated pole figures of the sheet rolled with back tension, shear components are suppressed through the thickness. For rolling with front tension, there are weak shear textures in the surface layer.

For the 40% rolling reduction, the calculated pole figures are shown in Fig. 5. The shear component develops in the surface layer in all the cases. This means that the effect of tension on the texture development decreases with increasing reduction. Especially, the front tension has a less effect on the texture development than the back tension. Tension can change the position of neutral point in rolling. The sense of the relative velocity between rolls and sheet changes before and after the neutral point, which in turn brings about the positive and negative shears before and after the neutral point, respectively (Fig.

6). The front tension moves the neutral point toward entrance and the back tension toward exit of the roll gap.

The positive and negative shears can be varied with tension. Tension also reduces the shear stress, which in turn decreases the absolute value of shear strain. Figure 7 shows the rates of deformation during rolling with the 20 and 40% reductions. A condition in which a particular orientation is stable depends on the value of $d\epsilon_{13}/d\epsilon_{11}$, where $d\epsilon_{13}$ and $d\epsilon_{11}$ are the shear and normal strain increments with subscripts 1 and 3 indicating the rolling and plane normal directions. When $d\epsilon_{13}/d\epsilon_{11} = 0$, the plane

Fig. 6. Schematic shape change of volume element during pass through roll gap.

Fig. 7. Rate of deformation, D_{13} , during rolling.

strain condition prevails. Therefore, the shear strain should be reduced to obtain the plane strain condition. For 20% rolling reduction, shear strain increments in the surface layer could be reduced below 50% by back tension (Fig. 7(a), (c)), which results in the suppression of shear textures. However, the reduction of shear strain by front tension is slight (Fig. 7(e), (f)). Without tension, shear strains for 40% rolling reduction are much larger than for 20% rolling (Fig. 7(a), (b)). Even with the back

tension of 50MPa, the shear strains in the surface layer for 40% reduction are still as high as for 20% reduction without tension rolling. So it can be concluded that the back tension has a less effect on the decrease of shear textures in the case of high reductions.

The little effect of tension in the experimental results can be attributed to various factors. First, the friction coefficient might be higher in the experiment than in calculation. Figure 8 shows the (110) pole figures of surface

Fig. 8. (110) pole figures of surface layer, calculated with various friction coefficients in case of 20% reduction with back tension of 50MPa.

Fig. 9. (110) pole figures of surface layer calculated from initial orientation of weak shear texture in case of 20% reduction.

Fig. 10. (110) pole figures of surface layer calculated with varying back tension in case of 20% reduction.

layer, which were calculated at various friction coefficients. As the friction coefficient increases, $\langle 110 \rangle // ND$ shear components also increase. When $\mu=0.5$, tension effects almost disappear. Friction coefficients between roll and specimen during rolling are difficult to know, and have been one of the main concerns. But there are very diverse results obtained by investigators. The value of $\mu=0.35$ is the mean value of results in references [9,10]. In the process of preparing the initial specimen, weak shear textures developed in the surface layer (Fig. 2), which might influence the measured final texture unlike

the results simulated from initially random orientation. Figure 9 shows the (110) pole figures of the surface layer calculated from the initial orientation of a weak shear texture. The shear texture is slightly rotated even under a back tension. When no tension is applied, there develop rather strong $\langle 110 \rangle // ND$ shear textures at surface layer as in Fig. 4. The importance of initial texture has been recognized from many investigators [13-15]. Despite the same strain history, the rotation rates of orientations are different. Therefore, it could result in somewhat different final texture.

Fig. 11. (110) pole figures of surface layer calculated varying flow stress and back tension in case of 20% rolling ((a), (b), (c); $K=156\text{MPa}$, and (d), (e), (f); $K=170\text{MPa}$).

Figures 10 and 11 show the calculated (110) pole figures of the surface layer with varying back tension. The tension effect of suppressing shear texture increases with increasing back tension. Figure 11 shows the effect of flow stress for a given back tension. As the flow stress increases, the back tension effect decreases (Fig. 8(a), 11(a), (d)). The flow stress of steel used in the experiment might be higher than that used in calculation due to a lowered temperature of specimen during rolling. Even though the experimental results were not well simulated, it is apparent that back tension can suppress the shear textures, when rolling conditions are appropriately given.

5. CONCLUSIONS

Both front and back tensions reduce the shear strains during rolling and in turn reduce the shear textures in rolled sheets. The back tension can suppress the shear texture more effectively than the front tension. As the reduction increases, The shear strain and in turn the shear texture decrease with increasing tension and decreasing friction, reduction, and flow stress.

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