SOME ASPECTS OF STORED ENERGY AND RECRYSTALLIZATION TEXTURE IN COLD DRAWN STEEL WIRE

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Introduction

Different investigations have shown that an orientation dependence of elastic stored energy exists in cold rolled low carbon steels [1-6]. These stored energy values were estimated from X-ray line broadening and electron microscope estimates of subgrain size and misorientation. The sequence of stored energy as a function of orientation was found to depend on the type of steel. In some investigations the orientation dependence was used to explain the formation of recrystallization textures. However, an unambiguous relationship has not been established [3, 5, 6].

The aim of the present work is to consider the stored elastic energy in relation to textural changes during the recrystallization of patented cold drawn 0.7% C steel wire. For that purpose, stored energy values for the (001)[ii0] and (ii0)[ii0] components of the <ii0> fiber texture [7, 8] were estimated from X-ray line shift measurements.

Experimental Procedure

The measurements were carried out on patented 0.7% C steel wire. After patenting the wire was cold drawn from 1.17 to 0.25 mm in diameter. Three types of specimens were examined:
- specimen A: drawn as indicated above.
- specimen B: as specimen A and subsequently chemically thinned to a diameter of 0.21 mm.
- specimen C: as specimen A with an additional reduction in cross-sectional area of 1.2% by a subsequent drawing operation.

The small additional reduction in cross-sectional area is known to considerably change the surface residual strain state [8]. For the investigation of recrystallization behaviour the wires were annealed for 1 h at 400°C, 500°C, 600°C and 700°C in vacuo and were cooled in the furnace. For X-ray measurements each specimen consisted of 20 segments of wire, about 8 mm in length, affixed side by side to a Perspex plate (25x25x3 mm) with double sided adhesive tape.

In order to estimate the occurrence of (001)[ii0] and (ii0)[ii0] texture components (Fig. 1), integrated X-ray intensities were determined from continuous scans on {002} and {110} planes, lying parallel to the wire axis. Within the irradiated area, as discussed below, the normals to these planes make angles between 0° and about 30° with the cylindrical surface of the wire. The measurements were carried out using CoKα radiation on a horizontal goniometer (Philips) fitted with a texture attachment. The wires were placed in an approximately vertical position. The horizontal rotation axis of the texture goniometer was used to maximize the intensity. Rotations up to 3° from the vertical position were found to be necessary.

For a flat randomly oriented powder specimen, the ratio of the diffracted X-ray intensities of the [110] and [200] reflections, R_{110/200}, can be calculated [9]. Using CoKα radiation R_{110/200} = 6.8. With an ideal <110> fiber texture in which the grains are randomly oriented around the <110> wire axis, I_{110/1200} for the position indicated above, can be calculated from
In that case, one will have to correct for the cylindrical shape of the wire surface and for the difference in multiplicity of diffracting planes in comparison with those for the randomly oriented powder specimen [10]. The absorption effect due to the cylindrical shape of the wire surface, can be taken into account approximately, by assuming that only that area which is lying between the lines P and Q gives diffraction (Fig. 1). Along these lines the primary and diffracted X-ray beams are tangential to the cylindrical surface. These areas are proportional to the Bragg angles. With CoKα radiation for the \{110\} and \{001\} reflections, this ratio is 26.2:38.6. With a random specimen the ratio of the multiplicity of diffracting planes for the \{110\} and \{001\} planes is 2:1. For wires with an ideal \langle 110 \rangle fiber texture this ratio becomes 1:1 when both types of planes lying parallel to the wire axis are considered. Taking account of both effects, the ratio \( R_{th} = \frac{I_{110}}{I_{200}} \) for an ideal \langle 110 \rangle fiber texture, \( R_{th.w} = 2.3 \). Because of the fraction of randomly oriented grains in the wire, the ratio can be expected to be larger than 2.3. Lower values will be an indication for a preference of the \{001\} planes over the \{110\} planes to lie parallel to the wire axis.

The occurrence of the \langle 001 \rangle[\{110\}] and \langle 110 \rangle[\{110\}] components was considered in relation to their elastic stored energy in the unannealed wires. For that purpose residual strain measurements were performed from X-ray line shifts using a φ-goniometer, according to the procedure described in references [7] and [8]. For the two texture components shown in Fig. 1, biaxial (σ₁, σ₂) as well as triaxial (σ₁, σ₂, σ₃) stress tensors were calculated from the measured strains [7, 8]. The elastic stored energy \( E \) of the ferrite for the two orientations was then estimated from the expression: \( E = \frac{1}{2} S_{ij} \sigma_i \sigma_j \) [11]. The single-crystal compliances \( S_{ij} \) for iron were taken from reference 12. With the strain measurements, for which Bragg angles up to 81° were applied, the wires were partially screened off from the primary X-ray beam using absorbing powders which did not give rise to disturbing diffraction peaks [7]. In this way, the angle β (Fig. 1) could be restricted to a value of about 30°. This value does not differ much from those with the integrated intensity measurements mentioned above, which means that with both measurements about the same areas were irradiated.

Results and Discussion

The measured values of \( R = \frac{I_{\{110\}}}{I_{\{200\}}} \) for specimen A, B and C in the cold drawn condition and after annealing for 1 h at different temperatures, are shown in Fig. 2. The theoretical \( R_{th.w} \) for
an ideal \( <110> \) fiber texture is also shown therein. \( R_m \) values for the cold drawn specimens A and C are found to be about 1.5. This would mean that there is a preference of \( \{001\} \) planes over \( \{110\} \) planes to lie parallel to the wire surface. This indicates the presence of a cylindrical \( \langle 001\rangle \langle 110\rangle \) component \([10, 13, 14]\) of the \( <110> \) fiber texture. For the cold drawn and thinned wires (specimen B), \( R_m \) is 2.5, meaning that the said preference is less pronounced. These results agree with those obtained on swaged and drawn low carbon steel wire \([13, 14]\), in which a cylindrical \( \langle 001\rangle \langle 110\rangle \) component was found to be present, while conversion to an ideal \( <110> \) fiber texture due to a further deformation, started below the surface of the wire. Figure 2 shows that for specimens A and B, the ratio \( R_m \) increases during annealing, while for specimen C, \( R_m \) does not change. This indicates that for specimens A and B the preference of \( \{001\} \) planes over \( \{110\} \) planes to lie parallel to the wire surface decreases during recrystallization, in which the \( <110> \) texture is retained \([7, 15]\). Recrystallization starts at about 400°C, which was determined from hardness measurements.

The estimated elastic stored energy values for the unannealed wires are given in Table 1. The

<table>
<thead>
<tr>
<th>specimen</th>
<th>Biaxial stress state</th>
<th>Triaxial stress state</th>
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<tbody>
<tr>
<td></td>
<td>( E_{110} )</td>
<td>( E_{001} )</td>
</tr>
<tr>
<td>A</td>
<td>2.9</td>
<td>0.3</td>
</tr>
<tr>
<td>B</td>
<td>3.8</td>
<td>2.0</td>
</tr>
<tr>
<td>C</td>
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<td>0.7</td>
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stored energy values for the \( \langle 001\rangle \langle 110\rangle \) and \( \langle 110\rangle \langle 110\rangle \) orientations are indicated as \( E_{001} \) and \( E_{110} \), respectively. It is shown that for all specimens, for the biaxial as well as the triaxial stress state, \( E_{110} > E_{001} \). The same sequence was found elsewhere \([1-4]\) for cold rolled carbon steel, \( E_{110} \) and \( E_{001} \) being the stored energy of the texture components with the \( \{110\} \) and \( \{001\} \) planes, respectively, parallel to the rolling plane. In these investigations the stored energy was determined from electron microscope estimates of subgrain size and misorientation \([1]\) or X-ray line broadening \([2-4]\). The results in Table 1 indicate that the stored energy as well as \( E_{110}/E_{001} \) values for a biaxial stress state are greater than those for a triaxial stress state. The energy values obtained here are comparable to those reported in references \([1]\) and \([4]\) but lower than the values quoted in reference \([3]\). The ratio \( E_{110}/E_{001} \) for specimen A is greater than those for specimens B and C. This indicates that \( E_{110}/E_{001} \) depends on the location in the depth direction of the wire, and can be influenced by a small additional plastic deformation.

In considering a possible relationship to exist between the texture components in the unannealed wires and the stored energy, in the case of specimen A the preferred \( \langle 001\rangle \langle 110\rangle \) component has a relatively low stored energy. For specimen B in which \( E_{110}/E_{001} \) is relatively low, there is also less preference for the \( \langle 001\rangle \langle 110\rangle \) component (Fig. 2). However, this correspondence does not apply to specimen C in which a low \( E_{110}/E_{001} \) ratio goes together with a preference for the \( \langle 001\rangle \langle 110\rangle \) component.

During annealing of specimens A and B, the \( \langle 110\rangle \langle 110\rangle \) component with a relatively great stored energy value develops more than the \( \langle 001\rangle \langle 110\rangle \) component. This would be consistent with the theory \([16, 17]\) that during the annealing process the highest-energy regions recrystallize first, and become lowest-energy regions which will then be able to consume the less perfect crystals in their vicinity. With specimen C, however, \( R_m \) does not change during annealing, indicating that there is no preference for one or the other of the two texture components for recrystallizing. In comparison with specimen A, this behaviour could be explained by the substantial decrease of
\[ \frac{E_{110}}{E_{001}} \] due to the small additional drawing reduction of specimen C. Compared with specimen B this explanation is not applicable because the \[ \frac{E_{110}}{E_{001}} \] values for both specimens are similar. The observed discrepancy may be due to the fact that the contribution of very localized high energy regions, are not, or are only partially, included in the estimation of the average stored energy from X-ray line shifts as used in the present work. During annealing, however, these regions may become preferred as recrystallization nuclei.

Conclusions

- In 0.7% C patented cold drawn steel wire there is an indication for a cylindrical \((001)[\bar{1}10]\) texture component at the surface.
- The elastic stored energy in the as-drawn condition as estimated from X-ray line shifts of the \((001)[\bar{1}10]\) texture component is lower than that of the \((110)[\bar{1}10]\) component.
- An unambiguous correspondence between the ratio of the stored energy values mentioned above and the textural changes that accompany recrystallization could not be shown.

The ratio of these stored energy values and the relative development of the \((001)[\bar{1}10]\) and \((110)[\bar{1}10]\) texture components during recrystallization can be affected by a small additional drawing reduction.

References