TEXTURE DEVELOPMENT DURING RECRYSTALLIZATION PROCESS OF HS–IF STEELS

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1. INTRODUCTION

Texture, along with mechanical properties and microstructure, is one of the basic characteristics of steel sheets. The use of sheets in many cases depends on their texture — preferential orientation that describes anisotropic properties of materials. Proper texture is very important when speaking of deep-drawing steel grades, transformer sheets, and etc. Each end use usually has so-called ideal structure defined. Optimum texture of light-gauge sheet for stamping is {111}<uvw>. The texture type and anisotropy are mostly related to planes {111} — these should be the ones that are primarily present in rolling plane. Common direction record means that primary crystallographic direction in respect to rolling direction is not desired. That means that in a sheet plane, the crystallographic planes {111} should be randomly rotated, in respect to rolling direction, so that none of potential directions of plane {111} should prevail — the most common directions are <112> and <110>. In this context it is necessary to mention the need of recording of texture {111}<uvw>. Although in the recording there is a preference of plain {111} in sheet plain, it does not really influence deep-drawing properties of sheets. What matters is its perpendicular direction <111>, which is the strongest in BCC lattice, so that it should be oriented perpendicularly to sheet plain to prevent distortion of sheet. The relation between plane {111} and its perpendicular <111> with the same Miller indexes is defined by crystallographic law. Since, on the other hand, the direction <100> is the “weakest” in the BCC lattice, its presence in direction perpendicular to sheet surface is inadmissible. Due to abovementioned it is necessary to chose technologic production practice that ensures there are no orientations {100} in sheet plane [1, 2, 3].

Abstract

Texture of samples, taken from recrystallized HS-IF steel, was analyzed via EBSD method. The beginning of texture-related modifications was not in accordance with mechanical properties' modification. More prominent texture modifications were recorded at annealing temperature higher than 750°C. Severe softening was observed at such temperature because the recrystallized ratio reached 90%. After annealing at higher temperature, higher amount of grains with orientation {111} was observed, at the expense of orientation {100}. The first recrystallization nuclei were created in places with orientation {111}, where the highest energy during cold forming was stored; the nuclei had orientation {111}. Due to in situ nucleation the original orientations were conserved. It appears that oriented growth mechanism starts only after oriented nucleation mechanism is depleted.

Keywords: texture, recrystallization, high strength interstitial free steels, HS-IF
2. EXPERIMENTAL MATERIALS AND METHODS

Re-phosphorized IF grades, stabilized using Ti and Nb were subjected to the experiments. The abovementioned steel grades were produced in conditions of technologic flow of hot-dip galvanized sheets. Chemistry of steel sheets subjected to experiments is stated in Table 1.

<table>
<thead>
<tr>
<th>Grade</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Al</th>
<th>N</th>
<th>Ti</th>
<th>Nb</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.0043</td>
<td>0.664</td>
<td>0.009</td>
<td>0.102</td>
<td>0.004</td>
<td>0.026</td>
<td>0.005</td>
<td>0.032</td>
<td>0.039</td>
<td>0.0003</td>
</tr>
<tr>
<td>11</td>
<td>0.0044</td>
<td>0.556</td>
<td>0.009</td>
<td>0.066</td>
<td>0.006</td>
<td>0.036</td>
<td>0.005</td>
<td>0.029</td>
<td>0.037</td>
<td>0.0004</td>
</tr>
<tr>
<td>12</td>
<td>0.0032</td>
<td>0.295</td>
<td>0.006</td>
<td>0.050</td>
<td>0.006</td>
<td>0.029</td>
<td>0.003</td>
<td>0.033</td>
<td>0.036</td>
<td>0.0006</td>
</tr>
</tbody>
</table>

The slabs were hot-rolled at Hot Strip Mill consisting of 5 four-high Roughing mill stands and 7 Finishing mill stands. Finishing temperature was achieved above Ac$_3$, afterwards controlled cooling to coiling temperature followed. The strip was subsequently pickled and cold-rolled through 4-stand tandem mill. Lab simulation of continuous annealing processes was done at Hot Dip Process Simulator pilot line. 3 thermo-couples were welded on the 120 x 200 mm samples in order to accurately determine temperature. This allowed achieving of controlled reheating with uniform area. The annealing itself consisted of reheating by the rate of 10 °C/s, soaking at annealing temperature for 30 s and cooling by rate of 10 °C/s, while annealing temperature of 600 – 900 °C was determined for the study of recrystallization processes. Maximum difference between actual and desired temperature was ± 5 °C. During annealing, reduction atmosphere consisting of 95 % of N$_2$ and 5 % of H$_2$ with dew point of -30 °C was used. Samples subjected to texture analysis using electron diffraction were prepared by grinding with restricted time and force to prevent development of deformation areas. The samples were then polished using diamond paste and vibration-polished using silicone colloidal solution. Prior to measurement the samples were cleaned using alcohol. The texture of the samples was determined using EBSD camera on scanning electron microscope Quanta 400 FEI. The measurement conditions are stated in Table 2. ODF was calculated using Bunge method of spherical harmonics function [4, 5].

<table>
<thead>
<tr>
<th>Table 2 EBSD measurement conditions</th>
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<tbody>
<tr>
<td>Acceleration voltage</td>
</tr>
<tr>
<td>Aperture diameter</td>
</tr>
<tr>
<td>Working distance</td>
</tr>
<tr>
<td>Magnification</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

The main goal of recrystallization annealing was, besides softening, to achieve the highest possible ratio of optimum orientation {111} and suppression of undesired orientation {100}. During continuous annealing where annealing time is several minutes, depending on strip speed, the parameter decisive for recrystallization, is annealing temperature. On Fig. 1, 2 and 3 there are results of measurement of the ratio of decisive texture components {111} and {100} based on annealing temperature of samples No. 10, 11 and 12. In all three cases the dependency of the texture component representation intensity is similar. No texture changes are seen until the temperature of approximately 750 °C. Only when annealing at higher temperature we see increase of the ratio of grains with orientation {111} at the expense of orientation {100}. Between 750 – 900 °C this increase is up to 50 % (from 0.22 to 0.45). The course of texture modifications also points out at dependency of the ratio of texture components {111}/{100} on annealing temperature, see Fig. 4. In sample No. 12 the ratio of intensities (111)/(100) increases from 2 to 18; in sample No. 11 from 2 to 14; and in sample No. 10 even to 21. The start of texture modifications at 750 °C does not correlate with mechanical properties’ modification – significant softening was already observed at this temperature – it was caused by the fact that recrystallization ratio reached 90 %. This is why delay of texture modifications in respect to
Anisotropy corresponds with this interesting result and crystallization texture can be stated. Similar results were achieved in the work [6, 7], where texture modifications only occurred in advanced stage of recrystallization with ratio of $X_{\nu} \geq 70\%$. Based on measurement of recrystallization nuclei orientation using electron microscopy authors determined that the first recrystallization nuclei are created in places with orientation $\{111\}$, this is where the highest energy at cold-forming was stored, and also the nuclei have orientation $\{111\}$. So that it is in situ nucleation, original orientation is maintained. Only once this mechanism of oriented nucleation is “exhausted”, the mechanism of oriented growth starts. Only this stage of texture modifications can be observed via X-ray or EBSD. Sample 10 was also subjected to experimental measurement at annealing temperature of 950°C. In this case the influence of phase transformation $\alpha \rightarrow \gamma$ to final texture can be expected. It is very interesting that texture modifications continue towards even greater representation of orientation $\{111\}$. At that temperature the ratio $\{111\}/\{100\}$ achieved the value 50. This interesting result, especially its origin, along with explanation of orientation relations, sounds like a fitting topic for further papers.

![Fig. 1 Texture components of sample 10](image1.png)

![Fig. 2 Texture components of sample 11](image2.png)

![Fig. 3 Texture components of sample 12](image3.png)

![Fig. 4 $\{111\}/\{100\}$ ratio of samples 10, 11, 12](image4.png)

The above mentioned tendencies of the development of recrystallization texture are displayed by ODF fibre diagrams. Most suitable for describing the texture of deep-drawing steel is $\gamma$-fibre, with the planes $\{111\}$ perpendicular to sample planes and $\alpha$-fibre that is defined by direction $<110>$ parallel to rolling direction. $\gamma$-fibre refers mostly to areal anisotropy, because via one plane $\{111\}$ all potential directions are displayed – this means rotation of plane $\{111\}$ around its normal line $<110>$. Zero areal anisotropy corresponds with texture $\{111\}<uvw>$ where neither of the directions prevails and intensity $f(g)$ in fibre diagram is constant and/or straight line. Besides, $\gamma$-fibre, due to its intensity, points out at overall representation of orientation $\{111\}$ in final texture. Since $\alpha$-fibre has both important orientations in deep-drawing sheets, i.e. $\{111\}$ and $\{100\}$, it is well suited to be used to describe texture modifications. Since around orientation $\{111\}$ there are, on top of obligatory directions $<110>$ and $<112>$, also directions $<223>$ and/or $<554>$, intensity field is
usually extended to wide peak. On Fig. 5 to 10 there are fibre diagrams covering \(\gamma\) and \(\alpha\) - fibre of three analyzed samples. Fibre diagrams confirmed and/or specified the already described texture modifications. In sample 10 at all annealing temperatures especially orientation \(\{111\}<112>\) is preferred, and the beginning of texture modifications depending on annealing temperature is smooth. In sample 11 the texture modifications were first at temperature of 775 °C. Representation of directions \(<112>\) and \(<123>\) is not explicit. There are some differences, especially between 850 and 900°C. Tendency of deflection of planes \(\{111\}\) from direction \(<112>\) to direction \(<123>\) is more explicit in sample 12. As clearly seen on Fig. 9, deflexion of direction only occurs only at temperature 800 and 850°C. Annealing at higher temperature of 900 °C, but also at lower temperature of 775 °C, causes generation of rotary-symmetrical texture that is very close to ideal texture \(\{111\}<uvw>\). What is interesting is the fact that in all samples there was lowest intensity of planes \(\{111\}\) with direction of \(<110>\). As it is known, it is this direction in which the BCC lattice is most densely populated by atoms – this is the direction in which sliding plastic deformation should occur mostly. The differences in preferential directions of plane \(\{111\}\) are more fittingly captured by Fig. 11 that displays \(\gamma\) - fibre of all three samples at the temperature of 850 °C. On the picture we can clearly see strong orientation \(\{111\}<112>\) of sample No. 10, while the orientation of samples No. 11 and 12 is reduced in favor of orientation \(\{111\}<132>\).

Fig. 12 illustrates the course of \(\alpha\) – fibre of all three samples, while no significant differences were observed. An interesting result in this context is the course of \(\gamma\) - fibre in sample No. 10 at 950 °C. In the sample the deviation \(<112>\rightarrow <132>\) is only present at such high temperature. At lower temperature this is not observed. It would be interesting if this was further explored in order to better understand especially questions related to areal anisotropy. Based on analysis of texture state of samples after annealing at temperature of 600 – 900 °C it can be stated that optimum texture for deep-drawing requirements was achieved at annealing temperature of 850 – 900 °C. Within this interval of annealing temperature the structure is fully annealed with maximum value of drawing. No significant increase of the P or Mn content was observed during comparison of samples; isotropic properties of the material remain unchanged. Chemistry has significant impact on drawing and strength properties. Although at annealing temperature of 950°C the highest ratio of planes \(\{111\}\) was achieved, it is necessary to point out at lower exponent of deformation strengthening that decreases deep-drawing material properties.

**Fig. 5** \(\gamma\) - fibre texture of sample 10

**Fig. 6** \(\alpha\) - fibre texture of sample 10
Fig. 7 $\gamma$ - fibre texture of sample 11

Fig. 8 $\alpha$ - fibre texture of sample 11

Fig. 9 $\gamma$ - fibre texture of sample 12

Fig. 10 $\alpha$ - fibre texture of sample 12

Fig. 11 $\gamma$ - fibre texture of samples 10, 11, 12 at temperature 850 °C

Fig. 12 $\alpha$ - fibre texture of samples 10, 11, 12 at temperature 850 °C
4. CONCLUSION

Texture was measured via EBSD analysis. Intensity of texture component representation was similar in all samples. No texture modifications were observed up to annealing temperature of 750°C. The beginning of texture modifications at 750°C was not corresponding with mechanical properties' modifications. Significant softening was observed at this temperature because recrystallized ratio reached 90%. Only when annealing at higher temperature we noticed increase of the ratio of grains with orientation \{111\} at the expense of orientation \{100\}. The first recrystallization nuclei were generated in locations with orientation \{111\} where the highest cold-forming energy was stored, while nuclei had orientation \{111\}. Based on the above it was in situ nucleation with maintaining of the original orientation. It appears that mechanism of oriented growth starts after the mechanism of oriented nucleation is “exhausted”. The requirement for optimum texture with maximum ratio of orientation \{111\} for deep-drawing sheets was achieved at annealing temperature within the range of 850 – 900°C; this applies to all steel grades – this was proven by the same anisotropic properties of sheets.

REFERENCES