Deep-drawable Thin-gauge Hot Strip of Steel as a Substitution for Cold Strip

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In a conventional production of deep-drawable steel sheets, a hot rolling in austenite and a cold rolling at room temperature together with a subsequent recrystallization annealing are applied to achieve a desired texture in the final cold strip. As a cost saving replacement for this, a thin-gauge hot strip with a required deep-drawability can be employed by applying the ferritic rolling with the finishing shifted down into the temperatures below Ar1. To optimize the process parameters, laboratory tests on an IF steel were carried out by using the hot deformation simulator WUMSI. By the measurements of the texture development as well as by the computing of r-values, the texture formation in a hot strip after ferritic rolling could be optimized achieving a deep-drawability in hot strips comparable to that of a cold strip.

KEY WORDS: deep-drawability; hot strip; cold strip; ferritic rolling; texture; r-value.

1. Introduction

The aspired good deep-drawability can be realized by a favorable anisotropic material flow during the deep-drawing process. For this, the distribution of the orientations of individual grains plays a decisive role and is determining for the r-values.1,2) Outgoing from a statistic disorderly distributed grain orientations, r-value increases with increasing fraction of {111}-oriented grains and decreasing amount of those with {100} orientation parallel to sheet plane, Fig. 1.3)

Fig. 1. Effect of texture on the mean r-value rm. I{111} and I{100} are the texture intensities of the corresponding orientations.5)

To realize the requirements for deep-drawable steels with a pronounced {111}-texture by a conventional route, hot rolling is traditionally carried out in the austenite range followed by cold rolling with a sufficient deformation (70–80%) and a subsequent batch or continuous annealing for recrystallization. A cold strip is a final product in such case. In order to reduce production costs there is a tendency to achieve a sufficient deep-drawability without cold rolling, that means already with a hot strip as a final product. Fast developments of the rolling technique make it possible to produce so-called thin-gauge hot strips with minimum thicknesses that are nowadays within the range of those of cold strips. Such production requires unavoidably lowering finishing temperatures because of large heat losses of thin hot strips. But, the austenitic rolling with low finishing temperatures is not easy to perform because of high transformation temperatures of extra low carbon steels (ELC) and low carbon interstitial free (IF) steels with manganese content less than 0.2%. The reheating temperatures above 1250°C would be necessary for final thicknesses of 2–5 mm. Hot strips thinner than 1.8 mm are not producible at all by a conventional “austenitic” hot rolling of such steels.

Considerable cost reductions by ferritic rolling may be achieved in different ways. The most evident one is a reduced reheating temperature in the ferritic rolling practice, which gives also the potential for an increased throughput of the furnace. Lower reheating temperatures for ferritic rolling result to a reduced AlN dissolution (enhancing ferrite recrystallization kinetics) and a smaller initial austenite grain size. This low rolling temperature practice leads also to an improved hot rolled product quality with less surface defects, improved flatness of the hot strips because of complete γ–α-transformation prior to cooling on the run-out table.
Fortunately, moderate rolling loads in the finishing mill enable the application of ferritic rolling even on existing mills. As shown in Fig. 2,4) the flow stresses—and so the rolling loads—of the IF steel are lower in the temperature range between 870 and 700°C than those at 950°C in the conventional austenitic temperature region. At lower temperatures higher flow stresses of ELC steel are measured presumably due to dynamic strain aging in these steel grades. Two different groups of ferritic rolled deep-drawable thin-gauge hot strips can be produced, Fig. 3:

“Soft” hot strip: In this product group the coiling condition must guarantee a complete recrystallization in the coil (becoming soft), Fig. 3(a). For this, the finishing and coiling temperatures must be appropriate high.

“Hard” hot strip annealed: By further lowering finishing temperatures in this processing, compared to the production of soft hot strip, thinner hot strips can be produced (<1 mm). Such hot strip does not recrystallize in coil (becoming hard) and must additionally be recrystallized by annealing, Fig. 3(b).

The texture development in simulated warm (ferritic) rolled strips was the main objective of this work. The study was focused on the potential final products mentioned above: a “soft” hot strip and a “hard” hot strip additionally annealed.

2. Experimental Procedure

The investigations were done on an IF-steel as a typical representative of deep-drawable steels. The chemical composition was as follows (in mass%): C: 0.002%, Si: 0.007%, Mn: 0.097%, P: 0.010%, S: 0.004%, N: 0.003%, Al: 0.042%, Ti: 0.038%, Nb: 0.007%. The low carbon and nitrogen amounts and an overstoichiometric content of titanium should guarantee the fixation of interstitial atoms.

The laboratory tests were done on the hot deformation simulator WUMSI5) by using the plane strain hot compression test as a simulation of rolling. The size of specimens allowed the machining of secondary pieces for the metallography, texture measurements and mechanical testing. The texture was measured on a Siemens D500 texture goniometer. For the description of texture development the method of grain orientation distribution (ODF) was applied.6) In this method each orientation corresponds to one point of the Eulerian space, defined by three angles \( \phi \), \( \varphi_1 \), and \( \varphi_2 \), Fig. 4. For deep-drawable steels investigated, only two special lines, so-called fibres, are important: \( \alpha \)-fibre (\((110)||RD\)) and \( \gamma \)-fibre (\((111)||ND\)). In this way the pole densities could be expressed in the form of two 2D-diagrams. The \( r \)-values were computed from the texture measurements by an “ANIS-MPI” program of the University Birmingham.7)

3. Results and Discussion

For the design of the rolling schedules in ferritic region the determination of the range of the \( \gamma \rightarrow \alpha \)-transformation temperatures as well as the knowledge of the recrystallization behavior of ferrite is indispensable. Figure 5 shows the...
range of coiling temperatures in which the ferrite can recrystallize completely in coil in the production of “soft” hot strips. It can be seen, that 670–700°C is the lowest level of coiling temperatures which guarantees a complete recrystallization after a warm rolling of the IF steel investigated. Coiling below this temperatures leads to a “hard” hot strip (not completely recrystallized) that has to be additionally annealed to achieve a designed texture. So, depending on the process parameters, a recrystallized (soft) hot deformed specimens or a not recrystallized (hard) hot deformed specimens were produced after a simulated coiling.

3.1. Deformation Texture

In the development of texture during the production of deep-drawable hot strip, the deformation texture just after finishing is decisive for the quality of the recrystallized texture after coiling or annealing. Generally, the deformation texture should involve a sufficient intensity of γ-fibre including typically some component of {001} as well. After finishing with ε=4×0.3 the deformation texture was measured for various finishing temperatures in ferrite and compared with that after finishing in austenite, Fig. 6. The high finishing temperature in ferrite (810°C) leads to an unfavorable rolling texture with a poor coverage of {111} and the maximum amount of grains with α-fibre near to {001} component. By reducing finishing temperature (760°C or lower) more distinctive γ-fibre components with a strongest coverage of α-fibre in the range of {112} can be observed. By lowering deformation temperatures less pronounced recovery processes proceed. Therefore, the complex multiple slipping, that leads to the formation of energy-rich {111}-oriented grains, can be less avoided by the thermal activated dislocation movements which results to a sharper {111} texture. In contrast to ferritic rolled specimens, there is nearly irregular texture with random oriented grains after the γ-α-transformation of austenitic rolled steel, as also reported in Ref. 8.

3.2. Deep-drawable “Soft” Hot Strip

Meeting the limit of the minimum coiling temperature a complete recrystallization occurs in coil. Figure 7 displays the texture development of a favorable deformation texture (a low finishing temperature of 710°C) due to the recrystallization in coil. The formation of a typical recrystallized texture with a strong γ-fibre orientation and a reduced coverage of {001} component of α-fibre can be observed. There is a striking increase in the (112) component of γ-fibre.

As observed, the lowering finishing temperature improves the deformation texture with an increasing amount of {111} oriented grains which supports the formation of a sharper {111} recrystallized texture after coiling. This is reflected by a significant increase in \( r \)-values (as computed from the texture measurements) with decreasing finishing temperature, Fig. 8. With lowering finishing temperature the distribution of \( r \)-values over the angle to RD becomes similar to that of conventional cold strips with a typical appearance of a marked maximum in the direction cross to RD (\( r_{90} \)) and a pronounced minimum at the direction of 45° to RD.

3.3. Deep-drawable “Hard” Hot Strip

By further lowering of finishing temperature thinner hot strips with a more favorable rolling texture can be produced. Nevertheless, the coiling temperature becomes too low for a complete recrystallization of the “warm” deformed material in the coil and, therefore, an additional recrystallization annealing is necessary by using batch or continuous processing.

The texture development during a simulated batch annealing of specimens finished at 660°C with two different coiling temperatures is given in Fig. 9. Whereas the higher coiling temperature of 550°C leads to a rather low γ-fibre coverage, the lower coiling temperature of 400°C brings about a significant improvement in texture with a high level of γ-fibre showing a maximum at the {111} component. Such a strong effect of coiling temperature is sup-
posed to reflect the recovery processes during the coiling at higher temperatures that reduce the stored energy surplus of \{111\}-oriented grains and so diminish their amount after recrystallization.

The \( r \)-value distributions after the simulation both of the possible annealing processes (batch and continuous), are displayed in Fig. 10. The distribution of \( r \)-values as a function of the angle to RD shows considerably higher values, especially in RD \((r_0)\), in comparison to those of “soft” hot strips. So the form of the curves is more similar to that of deep-drawable cold strips. The reason for this can be seen in the lower finishing temperatures during the production of “hard” hot strips in comparison to “soft” strips. It results to the higher density of \{111\} components in the deformation texture (see Fig. 6) due to less effective dynamic recovery processes, as already mentioned above. This supports the formation of a more favorable recrystallized texture and higher \( r \)-values.

The mean \( r \)-values >1.5, \( \Delta r<0.6 \) as well as other mechanical properties (elongation \( \Delta >50\%\), 0.2%-proof strength \( R_{0.2}<100 \text{ MPa} \), strengthening exponent \( n=0.3 \)) achieved in hot strip are quite sufficient for a lot of applications without necessity of manufacturing cold strips.

4. Concluding Remarks

In the laboratory tests carried out in this study the hot rolling was simulated by the plane strain hot compression test. The comparison of both these deformation modes showed a good agreement concerning microstructure, mechanical properties and texture.\(^9\) Nevertheless, the investigation was focused on the interior properties of the strip. It is well known that the shear strain are induced close to the strip surface as a result of friction forces appearing at the strip–work roll interface. Such shear strains produce an unfavorable texture and lead to a significant deterioration of the deep-drawability of the strip.\(^10,11\) In terms of a surface shear stress control, very effective lubrications should be applied in all, except the first, finishing stand.\(^11,12\)

It is further to be remarked that ferritic rolling brings about important benefits in the subsequent cold rolling stage due to much softer hot rolled strips produced by the ferritic rolling. This enables to increase rolling speed and/or to decrease the number of rolling passes by increasing reduction per pass both leading to increase of productivity and lower costs.

It is also anticipated that the ferritic rolling practice could be of great interest in combination with the thin slab casting technology realizing the production in a very compact line. For this application some additional problems arising from a considerably change in physical metallurgy of direct rolling must be solved.\(^13\)
5. Conclusions

(1) The beneficial texture development, similar as by the production of the conventional cold strip, can be achieved already in a thin-gauge hot strip by finishing in a temperature region of ferrite by so-called ferritic rolling.

(2) By reducing finishing temperature of ferritic rolling a more favorable initial rolling texture can be generated as a pre-condition for a beneficial final recrystallized texture.

(3) A minimum coiling temperature (670°C for the IF-steel tested) must be met if producing deep-drawable “soft” hot strips directly after coiling.

(4) By a further lowering of finishing and coiling temperature (to achieve even lower hot strip thicknesses) “hard” (not recrystallized) hot strips must additionally be annealed after coiling to guarantee a complete recrystallization. Lower coiling temperatures are more desirable for these products.

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