

## TEXTURE DEVELOPMENT OF STRIP CAST FERRITIC STAINLESS STEEL

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### ABSTRACT

A ferritic stainless steel which was produced by means of the recently introduced strip casting technology was investigated by means of quantitative texture analysis. The application of strip casting allows to manufacture a cast steel band with equivalent geometry as the hot rolled band and thus permits to bypass the hot rolling procedure. The random casting texture and the homogeneous microstructure have evidenced to avoid the well known ridging phenomenon in the final steel sheet. In the present work a stainless steel containing 17% Cr was strip cast, cold rolled and finally annealed. The textures were measured in various thickness layers and compared to conventionally produced material.

### INTRODUCTION

Flat products of ferritic stainless steels are typically manufactured by continuous casting, hot rolling, hot band annealing, subsequent cold rolling and final recrystallization. The recent development of the strip casting technology [1] however provides two major advantages in comparison to the conventional processing. First a cast steel band is produced, which provides equivalent thickness and width as the hot rolled band. This permits to bypass the entire hot rolling process. Second the nearly random initial strip texture and the homogeneous through thickness microstructure have evidenced to avoid the well known ridging phenomenon of the final product. The strip casting technology is thus supposed to play a competitive role in the future production methods for stainless steel sheets.

The texture evolution of the initially strip cast and subsequently cold rolled and recrystallized steel sheets is of main interest for various reasons in this context. First the texture determines the Lankfort value, i.e. the deep drawing work properties. Second the strength of the steel is affected in terms of the Taylor factor. Third the ridging phenomenon, which deteriorates the surface quality of the final sheet is strongly affected by the texture. Finally it can be sensitively investigated, whether the amount of cold work prior to the annealing treatment suffices to cause recrystallization instead of recovery.

In this work a ferritic stainless steel with a Chromium (Cr) content of 16% was strip cast, cold

rolled and finally annealed. The same procedure was executed with an initially hot rolled, i.e. conventionally produced sample. The textures were measured in the sheet center and at the sub-surface layer. The mechanical properties and the ridging behaviour have been determined in tensile tests.

### EXPERIMENTAL PROCEDURE

All textures were examined by measuring the four incomplete pole figures {110}, {200}, {112} and {103} with  $\text{MoK}\alpha_1$  radiation in the backreflection mode [2]. From the pole figures the orientation distribution function (ODF) was calculated by the series expansion method ( $l_{\text{max}}=22$ ) [3]. In case of cubic crystal symmetry and orthorhombic sample symmetry an orientation can then be presented by the three Euler angles  $\phi_1, \phi, \phi_2$ .

In order to reveal the differences in the texture development during cold rolling and recrystallization of conventionally hot rolled sheets, "HR", on the one hand and strip cast material, "SC", on the other hand, samples were prepared from both types of material (figure 1).

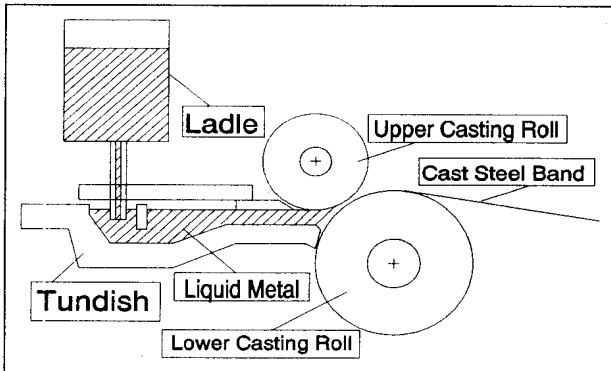


Figure 1: Schematic cross section of the strip caster [1].

The initial thickness of both samples was 4 mm in both cases. Both steels contained about 16% Cr and 0.05% C (Table 1).

The specimens were cold rolled homogeneously in a strictly reversing manner under oil lubrication on a laboratory rolling mill. Samples were prepared after  $\epsilon=75\%$ , 80% and 85%, which are the most relevant degrees of deformation in regard to the industrial practice. The recrystallization treatment was performed at 930°C for 30 minutes under ambient atmosphere. Since the texture and microstructure of ferritic

stainless steels is often inhomogeneous through the thickness, all samples were measured in the center and in the sub-surface layer. The 85% cold rolled samples have only been measured in the

Table 1: Alloy in weight %

Specification	Cr	C	N	Ti	Nb
1.4016	16.5	0.05	0.03	0.01	0.01

sample center since in this case the distance between the two layers reaches the range of the X-ray penetration. To remove a surface layer of  $20 \cdot 10^{-6}$  m, that is to get rid of disturbing grinding effects before the texture measurements, the samples were etched in a solution of 100 ml  $\text{H}_2\text{O}_2$ , 10 ml HF, 5 ml

$\text{HNO}_3$  and 5 ml HCl. The ridging behaviour and the mechanical properties as well as the grain size have been investigated applying tensile testing and optical microscopy, respectively.

### EXPERIMENTAL RESULTS

The SC material reveals a very weak texture in the center layer (figure 2a). In the sub-surface layer the texture is unequal for both sides of the sheet. Whereas on the lower side (figure 2b) a

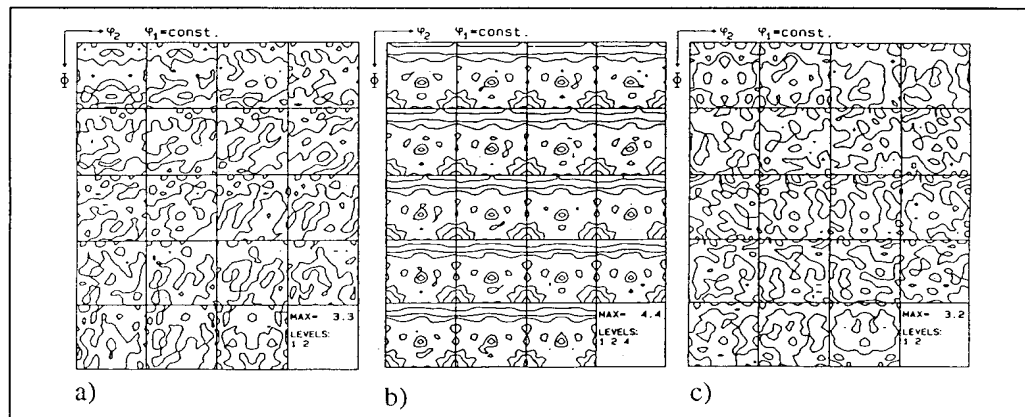


Figure 2: Strip cast FeCr, (a) center layer, (b) lower side, sub-surface, (c) upper side, sub-surface.

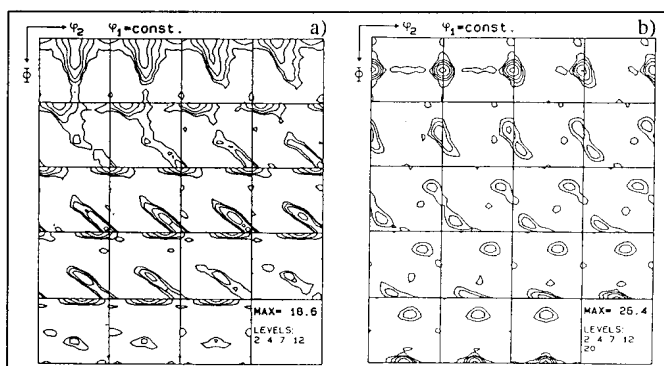


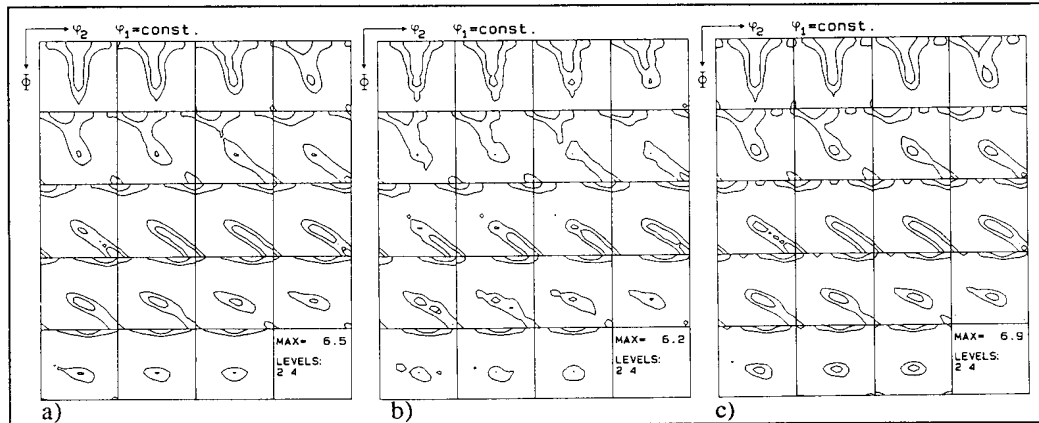
Figure 3: Hot band, (a) center layer, (b) sub-surface layer.

shear texture at the sub-surface layer (figure 3b) [5,6,13]. The cold rolling textures of the SC steel reveal the development of a weak  $\alpha$ -fibre accompanied by a  $\gamma$ -fibre in both inspected layers (figure 4). The cold rolled samples of the HR material show two striking differences to the SC samples. First, the rolling textures are much sharper and second, the textures in the center layer (figure 5) are much more pronounced, than at the surface (figure 6), due to the different initial hot rolling textures in both layers (figure 3).

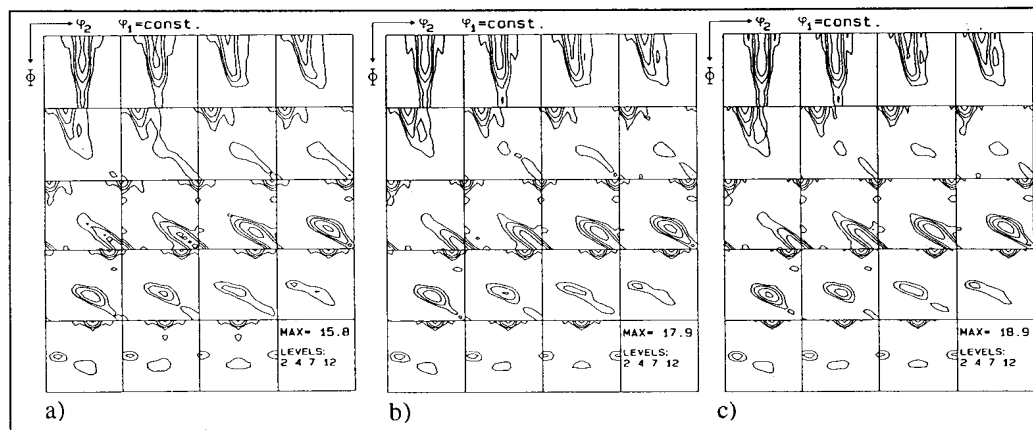
The recrystallization textures of the SC material elucidate a weak, but regularly shaped  $\gamma$ -fibre in both examined layers (figure 7). Although the recrystallization textures of the HR samples also reveal a  $\gamma$ -fibre, here shown exemplary for the 85% rolled sample (figure 8), two main differences with respect to the SC specimen are apparent. First the  $\gamma$ -fibre is stronger and second it is not equally shaped, but reveals a maximum close to the  $\{111\}\langle 112 \rangle$  orientation. This is also valid for lower degrees of deformation.

The mechanical behaviour of the cold rolled and subsequently recrystallized samples is equal for both materials. The yield strength  $R_{p0.2}$  reaches about 300 MPa, the tensile strength  $R_m$  about 500 to 550 MPa, the elongation after fracture  $A_{80}$  23% to 27% and the average grain size yields about  $12 \cdot 10^{-6}$  m (ASTM 10). The main progress is however that after 7% tensile elongation the

fibre texture with a  $\langle 001 \rangle$  axis parallel to normal direction and a weak  $\gamma$ -fibre is elucidated, on the upper side (figure 2c) the texture shows the same weak orientation distribution as in the center layer. These weak textures, which are comparable to those of continuously cast steels before rolling are completely different from the initial textures of the HR material which exhibits a strong rolling texture, i.e.  $\alpha$ -fibre in the center layer (figure 3a) and a sharp



**Figure 4:** Cold rolling of strip cast samples, (a) 75%, (b) 80%, (c) 85%, center layer.

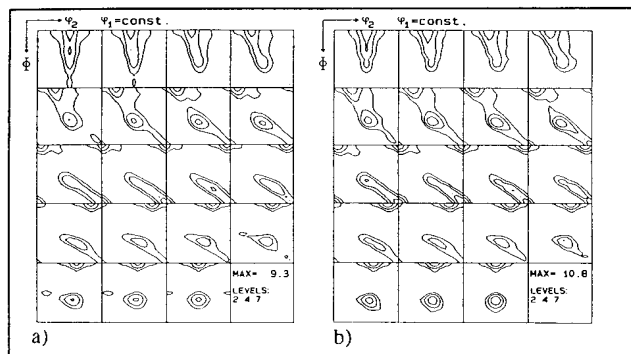


**Figure 5:** Cold rolling of hot band, (a) 75%, (b) 80%, (c) 85%, center layer.

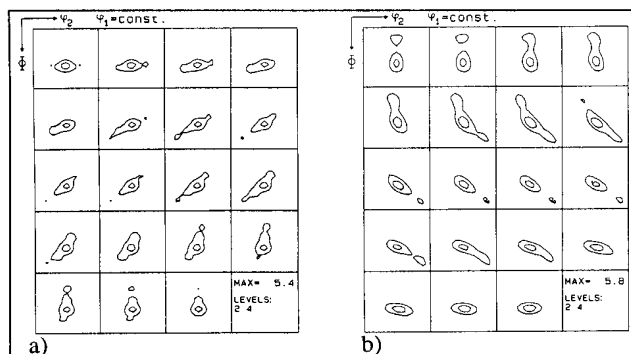
rolled, recrystallized and subsequently polished SC sample does not reveal any kind of ridging, whereas the HR specimen revealed the well known ridging phenomenon.

#### DISCUSSION AND EVALUATION OF THE RESULTS

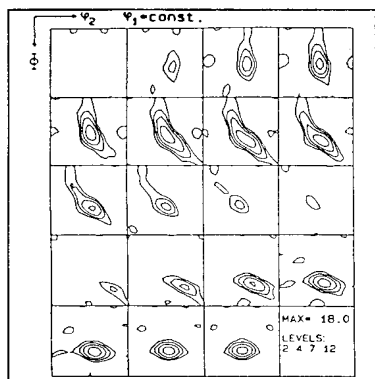
The first important difference between the initial materials is the nearly random orientation distribution of the SC steel on the one hand and the strong and inhomogeneous hot rolling texture of the HR samples on the other hand. The almost random textures of the SC strips can be explained by the weak growth selection, due to the high solidification velocity. As an exception the slight  $\langle 001 \rangle$  cube fibre close to the surface, which is also known from continuous casting can be attributed to the selective growth mechanism [7]. The weak  $\gamma$ -fibre in this sample can be explained by the weak deformation that takes place during impingement of the two films, which are formed on the surfaces of the casting rolls.



**Figure 6:** Cold rolling of hot band, (a) 75%, (b) 80%, sub-surface layer.



**Figure 7:** Recrystallization of strip cast and cold rolled sheets, (a) 80%, (b) 85%, center layer.



**Figure 8:** Recrystallization of hot and cold rolled sheets, 85%, center layer.

The strong hot rolling textures in the center layer are due to the strong recovery and the missing phase transformation. This leads to the development of typical "cold rolling" textures, which are not randomized by phase transformation. The  $\{011\}\langle 100\rangle$  and the  $\{112\}\langle 111\rangle$  component in the sub-surface layer of the hot rolled sheet are caused by the there occurring strong shear deformation [13,14]. These different starting textures give rise to the unequal evolution of the subsequent cold rolling textures. Ferritic steels usually develop a pronounced  $\alpha$ -fibre and a weaker  $\gamma$ -fibre texture during cold rolling [13,14]. This can be explained by the "Relaxed Constraints Taylor Theory" [8]. In the SC material in both layers very similar textures are developed during cold rolling according to the negligible differences in the starting material. In the HR material the strong initial texture gradient influences the development of the cold rolling textures. Whereas in the center layer a strong  $\alpha$ -fibre was present after hot rolling, which is strongly sharpened during cold rolling, close

to the surface the orientations from the initial shear texture still rotate into the  $\alpha$ -fibre, i.e. the texture is weaker [5,6,13]. The  $\gamma$ -fibre, which is created during recrystallization (RX) of the cold rolled SC material reveals a higher intensity in the center, than in the sub-surface layer. This can be understood if two features of the preceding rolling textures are considered. First, in the center layer of the 75% and 80% rolled samples the  $\{111\}$ - $\gamma$ -fibre is developed stronger than at the surface. Second, in the sub-surface layer the  $\alpha$ -fibre is not shaped uniformly, but shows a maximum at  $\{001\}\langle 110\rangle$ . The first fact is relevant for the nucleation of  $\{111\}$  grains within the  $\gamma$ -fibre itself, i.e. by nucleation at the grain boundary between two symmetrically equivalent  $\{111\}\langle 112\rangle$  orientations [9]. The second feature means that the texture is stronger at the sub-surface, which usually would also lead to stronger recrystallization textures. That this does not happen here is due to the indolence of

{001}<110> grains during recrystallization [10]. Besides the oriented nucleation a good {111} texture is also created by growth selection between the recrystallization component {111}<112> and the cold rolling orientation {112}<110>. These are associated by a 32° rotation relationship about <110> lying close to the Σ19a coincidence boundary which is well known for high growth rates [11]. The intensity of the initial {001}<110> orientation is however less important, because it does not reveal such a rotation relationship to a γ-fibre orientation. The uniform {111} texture of the SC material has a very beneficial effect on the r-value. The above mentioned elimination of the ridging phenomenon in the SC steel is due to its homogeneous through thickness texture and microstructure. In the HR material, which reveals ridging after 7%-18% elongation, the inhomogeneity of the texture and microstructure, i.e. the presence of elongated regions with similar orientations, which is inherited from the hot band, is supposed to be the main reason for this failure [14]

## CONCLUSIONS

The texture development and the mechanical properties during rolling and annealing of a strip cast ferritic stainless steel with 16% Cr have been investigated and compared to conventionally processed, i.e. hot rolled material.

Whereas the mechanical properties of the two materials did not reveal major differences, the initial texture, as well as the cold rolling and recrystallization textures of the strip cast steel were weaker and more homogeneous through the sheet thickness, than that of the initially hot rolled sheets. The strip cast steel reveals thus two major improvements. First the r-value is higher than that of the initially hot rolled material and second the ridging phenomenon, which is one of the most serious shortcomings of these ferritic stainless steels, is eliminated.

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