# Influence of Hotband Annealing on Texture and Formability of Cold Rolled X6Cr17 Ferritic Stainless Steel

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**Abstract**

*The conditions for hotband annealing of X6Cr17 ferritic stainless steel, annealing time and temperature, were varied. With longer annealing time and higher temperature coarsening of particles (mostly chromium carbides) after cold rolling and recrystallization was observed. Coarser particles lead to a flat texture of the final material and decrease its formability. This is connected to a change of the deformation mechanism during rolling and subsequently to a different nucleation for recrystallization. The surrounding of the coarser particles seems to be deformed more strongly which offers preferred nucleation sites for recrystallization of more randomly oriented nuclei.*

**Riassunto**

Gli autori hanno modificato le condizioni di ricottura del nastro laminato a caldo di acciaio inossidabile ferritico X6Cr17 e il tempo e la temperatura di tale trattamento. L'allungamento del tempo e l'aumento di tale temperatura hanno evidenziato un maggiore ingrossamento delle particelle (per la maggior parte carburi al cromo) dopo la laminazione a freddo e la ricristalizzazione. Tale trasformazione delle particelle conduce alla formazione di una struttura orientata del materiale finale e ad una diminuizione della sua formabilità. Tale fenomeno è legato ad un cambiamento del meccanismo di deformazione durante la laminazione e, successivamente, ad una diversa nucleazione per la ricristallizzazione. La parte intorno alle particelle più grosse sembra essere deformata in modo più significativo. Creando così punti di formazione del nucleo privilegiati per la ricristallizzazione di nuclei la cui orientazione è più casuale.

**Keywords**

Ferritic stainless steel X6Cr17, hot band, annealing, deformation, recrystallization, nucleation, precipitation, texture, formability

## Introduction

The hotband of the ferritic stainless steel X6Crl7 has to be annealed prior the following cold rolling for complete recrystallization and softening. Additionally the precipitation and the forming of carbides is controlled by this annealing. The batch annealing process needs a time of about 20 h and temperatures below the temperature of phase transformation from ferrite to austenite. It is well known that the quality of this hotband annealing affects the properties of the cold rolled sheet after the final annealing. Therefore the optimization of the treatment already in this early stage of production can improve the material.

## Experimental

Conventional 1.4016 (AISI 430) steel was used. To investigate the influence of hot band annealing different conditions for the batch annealing were simulated on a 2.5 mm hot band. For all experiments it was checked that no phase transformation was possible. Therefore only little space was left for variation of the temperature whereas the annealing time could be expanded to one week. Table 1 gives an overview over the different conditions and the sample labels.

After annealing the hot band was cold rolled to a thickness of 0.4 mm (rolling degree about 84%) and recrystallized.

## TABLE 1 - hot band annealing conditions for the different samples

| sample | annealing | |
|---|---|---|
| | time [h] | temperature [°C] |
| A | 25 | 830 |
| B | 30 | " |
| C | 50 | " |
| D | 168 | " |
| E | 30 | 850 |
| F | 35 | " |

Using electron microscopy the size distribution of the carbides was examined.
Texture analysis was carried out on an automatic texture goniometer in different layers.
At last the formability of the final material was tested in the tensile test and in different special tests for stretching and deep drawing, like the collar and bulge test or by determing the deep drawing ratio.

## Texture analysis

For texture measurements Mo-k$\alpha$-radiation was used, which gives a sufficient penetrations depth of nearly 30 µm for a Cr alloyed steel and which allows to separate between different layers of the sample.
For each, the near surface layer and the polefigures of the {011}-, {002}-, {112}- and {013}- planes where measured.
Because the well known polefigures only give qualitative information about textures the Orientation-Distribution-Function (ODF) was calculated for quantitative results. It can be calculated by the series expansion method /1/ out of at least three different pole-figures.

### Description of steel textures

Fig. 1 shows a typical {011} - polefigure of cold rolled steel in the stereographic projection. The corresponding ODF is plotted in fig. 2a in the eulerian space. This space is build up by the three eulerian angles $\Phi_1$, $\Phi$, $\Phi_2$, which describe the rotation from the sample to the crystal coordinate system around well defined axes /1/.

Each point in this eulerian space represents one orientation. For quantitative evaluation of steel-ODF's this space is normally shown in sections of constant angle $\Phi_1$ as shown in fig. 2b by lines of equal orientation density. To compare different samples it is possible to compress the information of ODF's of rolled steel by plotting the orientation-density along special lines in the eulerian space which correspond to rotations along special crystallographic axes and which are called fibre texture components /2/.

The two most important fibres (fig. 3) in rolled steel are:

1. α-fibre: <O11> axis parallel to the rolling direction at $\Phi_1 = 0°$, $\Phi_2 = 45°$ along $\Phi$

2. τ-fibre: <111> axis parallel to the sheet normal at $\Phi = 55°$, $\Phi_2 = 45°$ along $\Phi_1$

Rolling of steel normaly builds up first the α-fibre and for higher rolling degrees the τ-fibre is observed. During recrystallization the α-fibre decreases and the τ-fibre is growing.

## Results and Discussion

The size distribution and volume fraction of the carbides is only affected by the hotband annealing. The following cold rolling may change the geometrical arrangement but during recrystallization the temperature and time do not allow sufficient diffusion for changing these particles.Increasing hot band annealing times lead to growing of the precipitations as shown in fig. 4. After the longest time, sample D, the mean size is nearly doubled (O.91μm) in comparision to the shortest time, sample A (0.56 μm). The samples E and F with increased annealing temperature exhibit an increased particle size too (0.7 to 0.8 μm).
The effect of the different size distribution on the texture development is quite drastic. Fig. 5 shows the ODFs of the final material measured in the central layer.
For sample A a texture is found as observed for most of the ferritic steel grades.The orientation density on the α-fibre is decreased and recrystallization components on the τ-fibre, especially {111} <112> are dominant.The prolongation of the hot band annealing time randomizes the texture of the final material (figs 5, 6). It supports even the development of new texture components like a fibre texture with a {001}-axis parallel to the sheet normal (Sample B) at $\Phi_1 = 0°$, $\Phi = 0°$ along $\Phi_2$ and the single component {001}<250> at $\Phi_1 = 0°$, $\Phi = 0°$ and $\Phi_2 = 22°$ (samples C and D) which is only a minor component in the spread of the α-fibre of sample A. The decrease of the most important recrystallization texture component {111} <112> with increasing hot band annealing time is even better shown in the fibre presentation of fig. 7. The strong deviation from 'normal' development of recrystallization textures of steels for the samples with longer annealing times is believed to be due to the different distribution of the the carbides. During rolling the material has to flow around the coarser particles. This causes a much higher deformation in their surrounding because the stress state is changed completely near this particles /3/. Thus the local texture should differ from the normally observed rolling texture. This highly deformed region therefore offers a lot of nucleation sites for recrystallization with random orientation relationship to the matrix which leads to a randomly oriented recrystallization texture as it was observed above. But good formability can be expected, if orientations of the τ-fibre are dominant in the recrystallization texture and randomization of texture decreases the formability. Some exemplary results of deformation tests shown in figs. 8, 9, 10 support the this considerations. Although the elongation after fracture, fig. 8, increases with increasing annealing time the experiments which are able to describe the practical deformation processes, figs. 9, 10, exhibit the best values for sample A and B. For them the r-value and the ratio of the collar test are higher. The sample B exhibits the best properties considering most of the deformation tests.

## References

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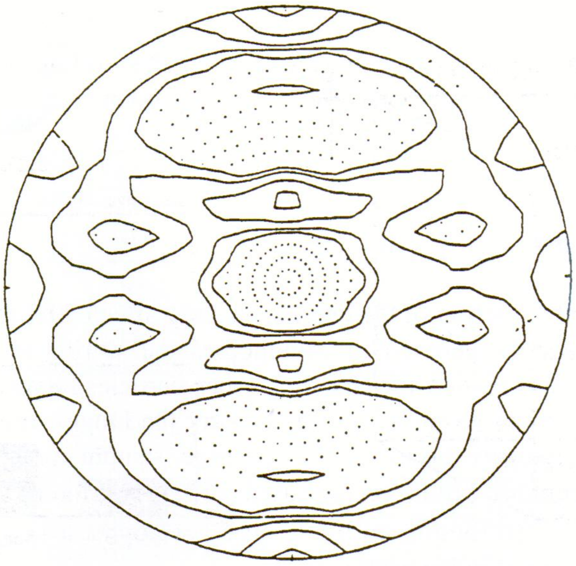


Fig. 1:
{011}-polefigure of a cold rolled steel

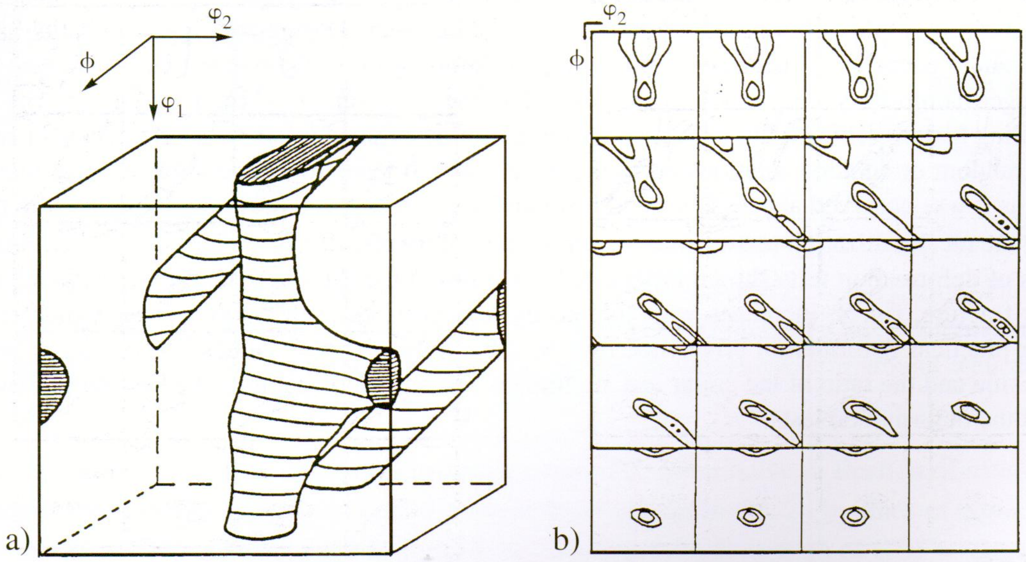



Fig. 2
ODF of the sample of fig. 1

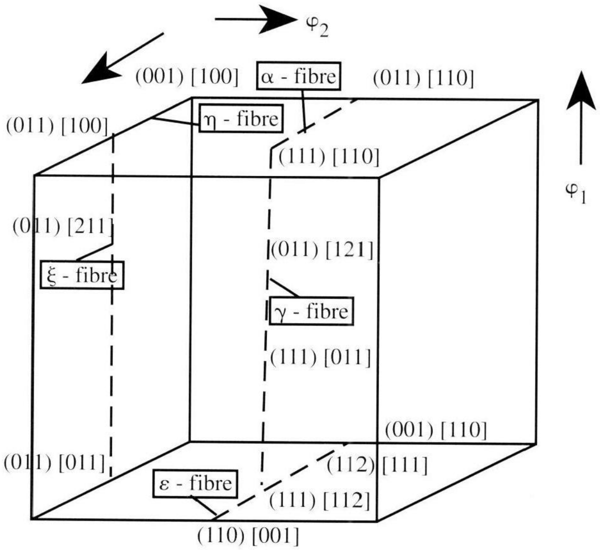



Fig. 3:
Texture components of steel in the eulerian space.

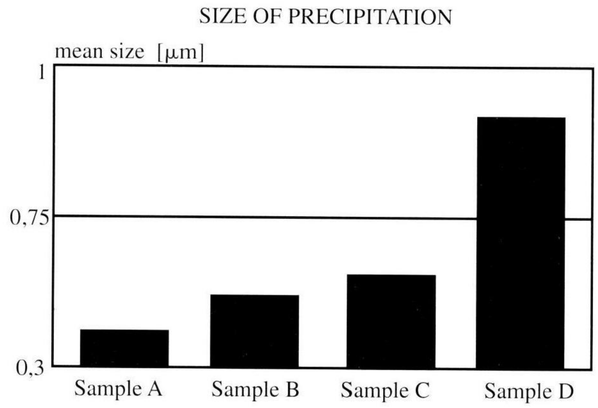



Fig. 4:
Mean size of preciptiations

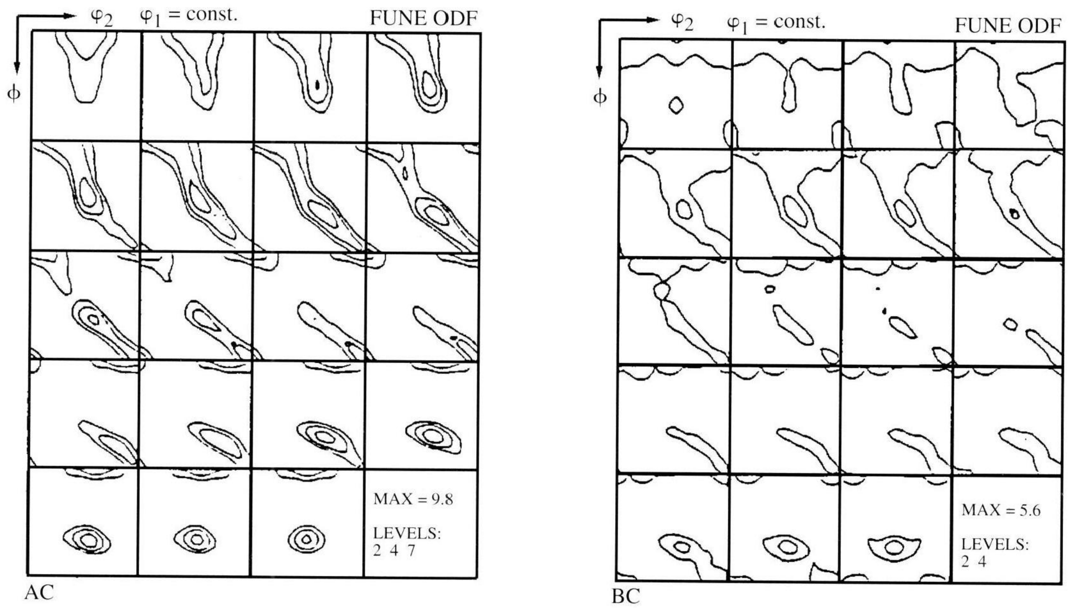
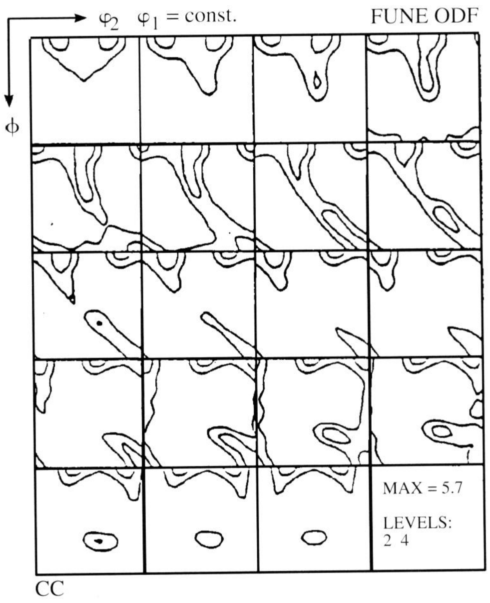



Fig. 5:
ODFs of the recrystallized samples A and B



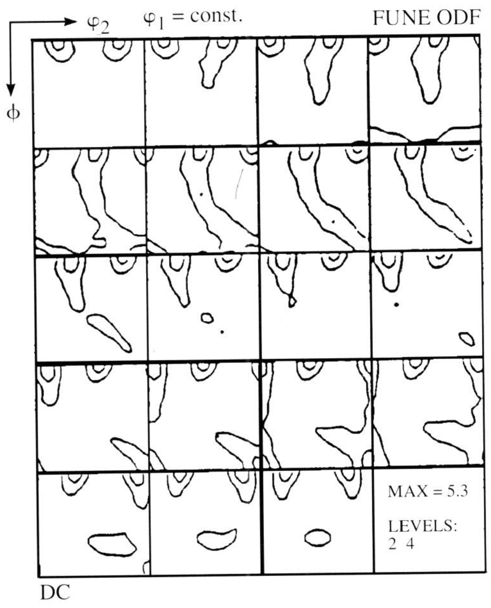




Fig. 6:
ODFs of the recrystallized samples C and D

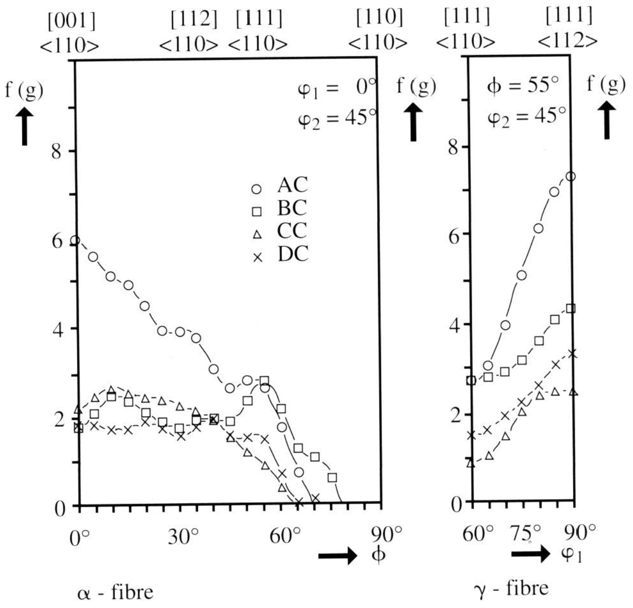



Fig. 7:
Orientation density along the fibres α and τ

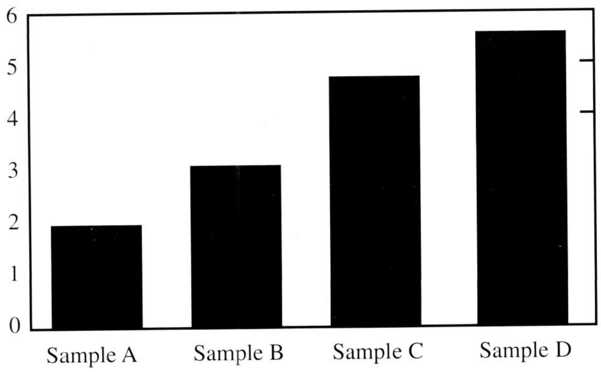



Fig. 8:
Elongation after fracture ($A_{80}$ in %)

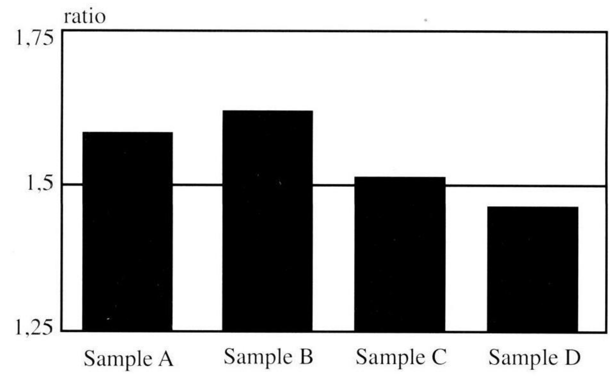



Fig. 9:
Collar test

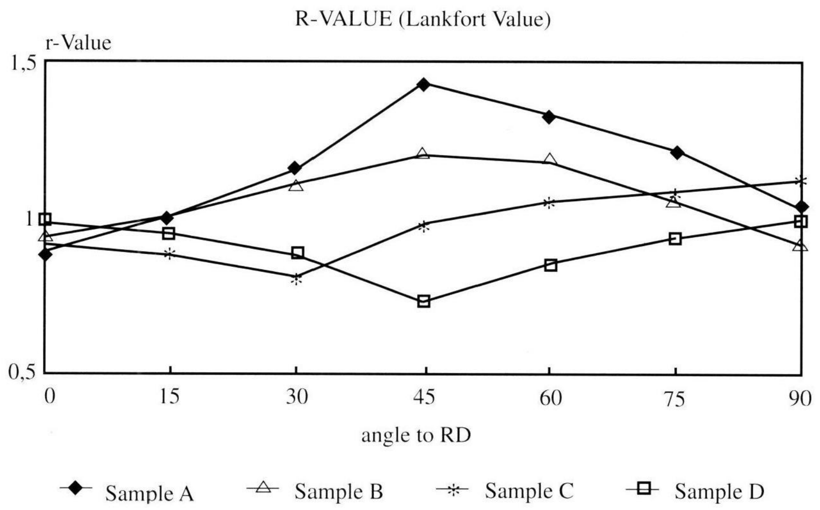



Fig. 10:
R-value vs. angle to rolling-direction