ICOTOM-12

PROCEEDINGS OF THE TWELFTH INTERNATIONAL CONFERENCE ON TEXTURES OF MATERIALS

Volume 2 of 2 Volumes

McGill University, Montreal, Canada
August 9–13, 1999

Edited by
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NRC·CNRC

NRC Research Press
Ottawa 1999

TEXTURES AND MICROSTRUCTURES OF STRIP CAST STAINLESS AND LOW-CARBON STEELS

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Abstract
The crystallographic textures and microstructures of strip cast austenitic stainless steels and of ferritic low carbon steels are presented and discussed. The stainless steels were produced in an unequal-diameter twin roll caster and the low carbon steels in an equal-diameter twin roll caster. The textures and microstructures are investigated in various through-thickness layers. The austenitic steels reveal weak textures with some pronounced components close to the {001}<uvw> texture fiber. In low carbon steels two types of textures are observed. While some of the low carbon strips show pronounced textures close to the {111}<uvw> fiber others reveal a weak texture with minor components close to {011}<uvw> fiber. All strip cast steel samples reveal weak through-thickness texture inhomogeneity. The austenitic steel shows martensite in the center layer. Chemical segregation is stronger in the stainless steel strips than in the low carbon steel strips.

Keywords: strip casting, stainless steel, low carbon steel, fiber texture, microstructure

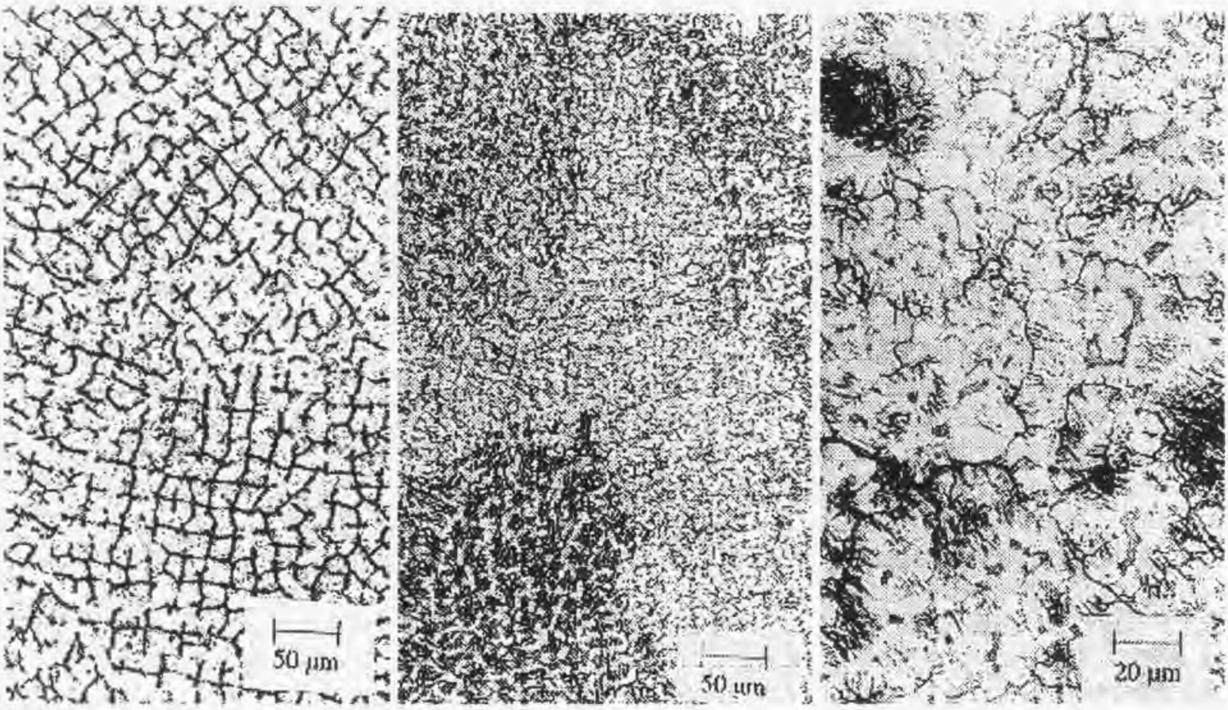
1. Introduction

Steel sheet coils are industrially manufactured by continuous casting, hot rolling, hot band annealing, cold rolling, and a final annealing treatment. Recent progress in producing cast steel sheets in pilot-scale unequal-diameter or equal-diameter twin roll strip casters has stimulated efforts to convert such devices to commercial production. Strip casting technology offers the ability of bypassing the hot rolling processing stage by solidifying liquid steel on the surface of two rotating water cooled rolls and producing thin strips that are directly coilable.

Strip casting provides some main advantages compared to the conventional process. First, it can supply steel bands which have the same thickness and width as conventional hot band sheets. Second, strip cast steels exhibit weak initial crystallographic textures and weak through-thickness texture gradients, yielding favorable strength and deep drawing properties of the final sheets. Third, the high solidification rate on the roll surfaces entails a refined microstructure. Fourth, it is possible to directly cast steel sheets which are not endowed with a sufficient intrinsic ductility for rolling processes, such as certain transformer or stainless steels. The paper gives an overview of the crystallographic textures and microstructures observed in strip cast steels. The investigation includes low carbon steels and austenitic stainless steels.

2. Experimental

The austenitic stainless specimens were strip cast on a pilot-scale unequal-diameter twin roll caster (Ohno et al. 1990; Hentrich et al. 1991). The low carbon steel specimens were cast on an equal-diameter twin caster (Teicher et al 1998). The stainless steel samples were provided by former Krupp-VDM and the low carbon steel samples by Bethlehem steel. Both methods work by casting liquid steel into a preheated tundish which contacts water cooled steel rolls. Thin steel layers solidify on the roll surfaces just before reaching the bite of the rolls. The casting process is usually conducted in a way to ensure that the contact length between the liquid steel and the roll surface is equal on both rolls. The as-cast stainless steel specimens had a thickness of 2.8 *mm* and the low carbon steel strips of 0.6 *mm*.



surface mid-thickness center

Fig. 1: Microstructure of a strip cast austenitic stainless steel, flat sections.

The textures of the austenitic steels were examined by measuring the {111}, {200}, {220}, and {113} pole figures and those of the low carbon steels by measuring the {110}, {200}, and {211} pole figures in the back reflection mode using CoK$_\alpha$ radiation (Schulz 1949). The specimens were descaled prior to the pole figure measurements. The orientation distribution functions were for all samples calculated by applying the iterative non-negative series expansion method to the corrected and normalized pole figures using a maximum expansion coefficient of l_{max}=22 (Dahms and Bunge 1989).

As is well known from various previous studies, the textures and microstructures of both ferritic and austenitic steels are often inhomogeneous through the sheet thickness (Raabe and Lücke 1992, 1993; Raabe 1995). This applies especially to samples which were produced by conventional hot rolling (Raabe and Lücke 1994; Raabe 1997). For this reason the textures and microstructures of both types of strip cast steels were investigated in various through-thickness layers. The low carbon steels were etched in 2% nitol. The austenitic stainless steels were prepared using concentrated HCl at 330 *K* or a solution of 50 *ml* H_2O, 50 *ml* alcohol, 50 *ml* HCl, and 2 g $CuSO_4$.

3. Strip cast austenitic stainless steels

Figs. 1 and 2 show the microstructure of a strip cast austenitic stainless steel in flat and in cross sections. Between the surface and the near-center layers uniformly oriented blocks of primary austenitic dendrites branched out up to the second generation can be observed. The dendrite blocks have an average diameter of 140 μm and a length of up to 500 μm parallel to their growth direction.

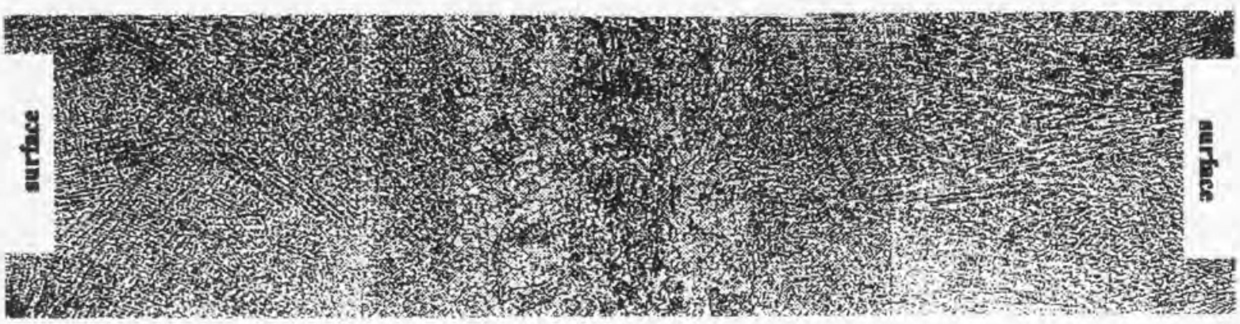


Fig. 2: Microstructure of the strip cast austenitic stainless steel, cross section.

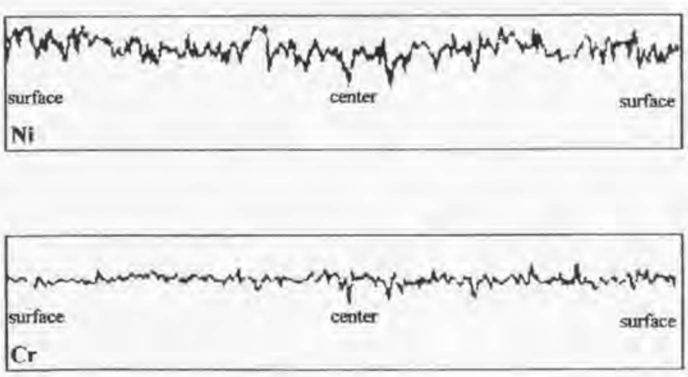


Fig. 3: Macroscopic segregation profile across the sheet thickness of the austenitic stainless steel (Teicher et al. 1998).

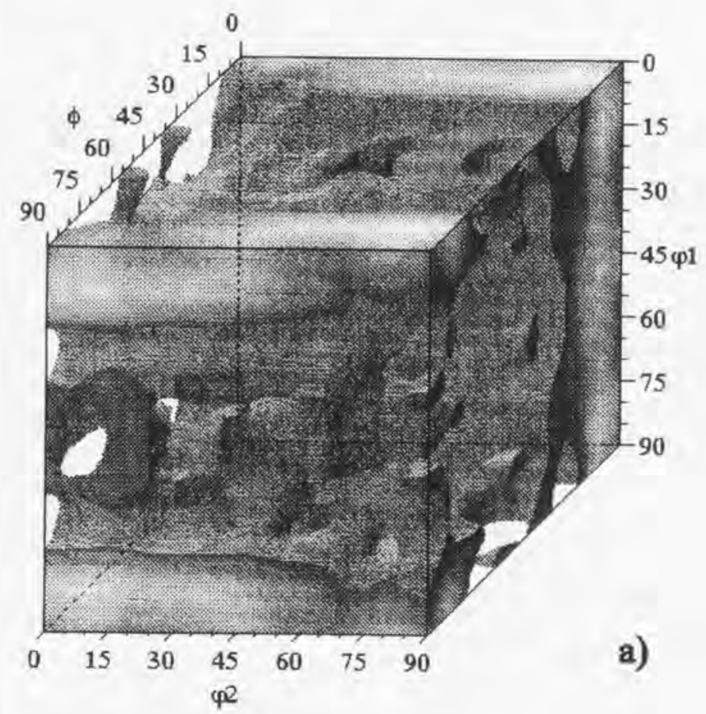


Fig. 4a: Strip casting texture of an austenitic stainless steel; the diagram shows the orientation density above $f(\mathbf{g}) = 1$; a) surface layer, $f(\mathbf{g})_{max} = 2.3$.

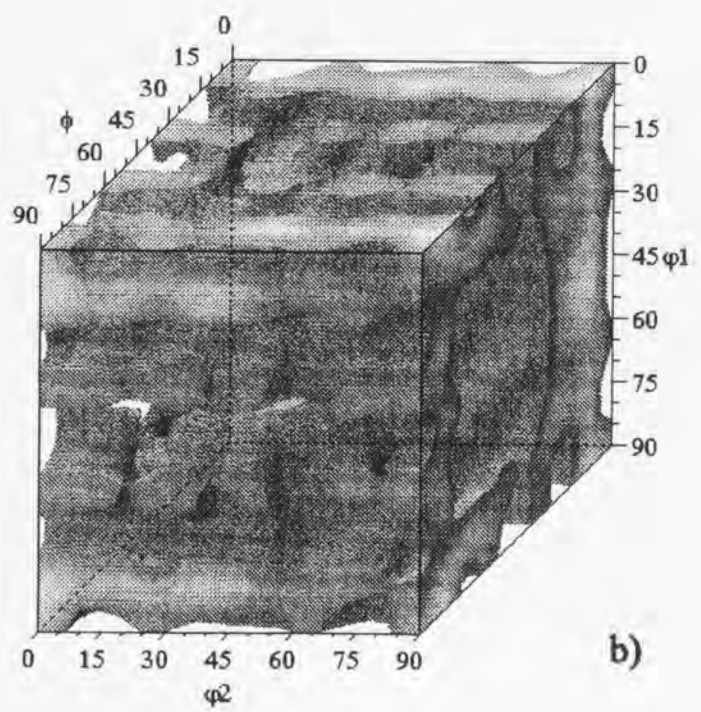


Fig. 4b: Strip casting texture of an austenitic stainless steel; the diagram shows the orientation density above $f(\mathbf{g}) = 1$; a) mid-thickness layer, $f(\mathbf{g})_{max} = 2.5$.

The microsegregated interdendritic regions appear dark while the austenite appears bright. Nickel and chromium are enriched while iron is depleted between the dendrites (Siegel et al. 1986). Especially the reduction of nickel in the dendrites might destabilize the austenite with respect to strain induced martensite transformation

(Raabe 1997). Fig. 3 shows the macrosegregation profile through the sheet thickness of the austenitic stainless steel. The analysis was performed in the scanning electron microscope using backscattered electrons. The stainless steel samples were investigated for chromium and nickel segregation. The data show that substantial macrosegregation across the strip thickness do not occur (Teicher at al 1998). While iron and chromium reveal a nearly constant distribution across the sheet thickness the nickel content reveals a slight depletion in the center layers.

Close to the center layers a blocky and nearly equiaxed morphology of the austenite is found. In this region some martensite platelets occurred as well. Further details of the initial microstructures of both ferritic and austenitic strip cast steels were reported earlier (Raabe et al. 1993; Raabe 1995, 1997).

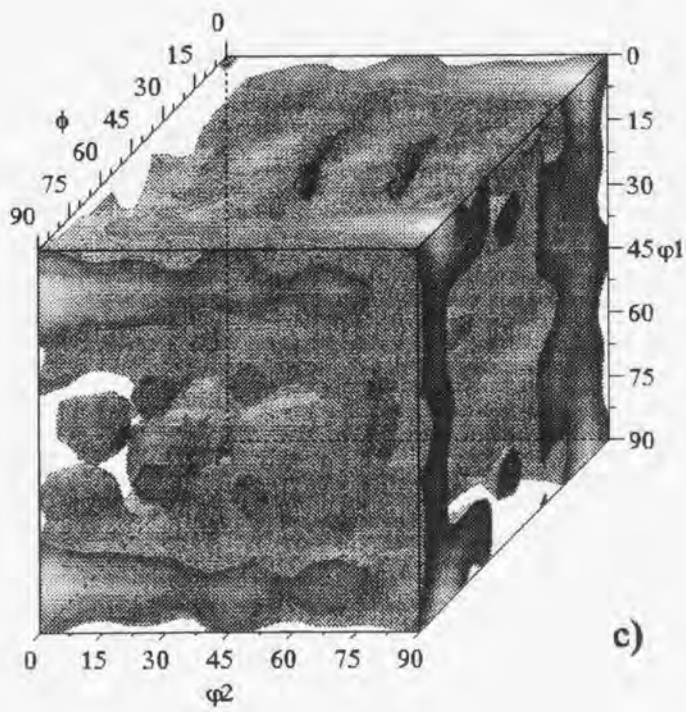


Fig. 4c: Strip casting texture of an austenitic stainless steel; the diagram shows the orientation density above $f(\mathbf{g})=1$; c) center layer, $f(\mathbf{g})_{max}=2.4$.

The texture of the strip cast material is very weak and does not show relevant through-thickness gradients. The orientation distribution function determined in the surface layer (Fig. 4a) shows a weak texture fiber {001}<uvw>.

The micrographs reveal that the layers close to the surface are not deformed or bent but appear as large blocks of austenitic dendrites. The observed texture fiber is thus attributed to growth selection among the austenitic dendrites during solidification subsequent to their nucleation on the surfaces of the casting rolls (Raabe 1997). The textures in the other layers are similar, i.e. no pronounced texture gradient as in hot rolled material is observed (Figs. 4b,c). From directional solidification experiments on other face centered cubic metals it is well established that {100}<uvw> has a larger growth rate than other orientations (Hirsch et al. 1987).

4. Strip cast low carbon steels

Fig. 5 shows the texture of the a low carbon steel. Whilst the stainless steels revealed a nearly random orientation distribution in all through-thickness layers some of the body centered cubic strip cast steels reveal a pronounced {111}<uvw> fiber texture.

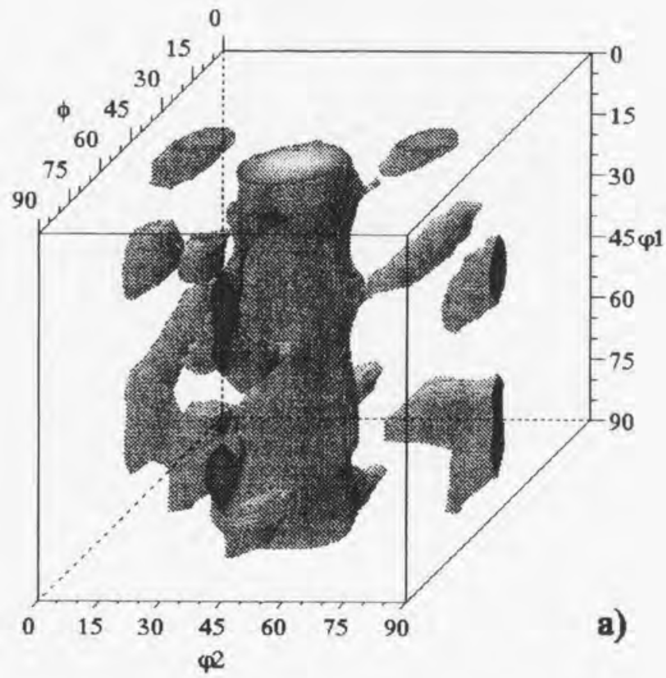


Fig. 5a: Strip casting texture of a low carbon steel with a {111}<uvw> texture; the diagram shows the orientation density above $f(\mathbf{g})$ =2.5; a) surface layer, $f(\mathbf{g})_{max}$=9.5.

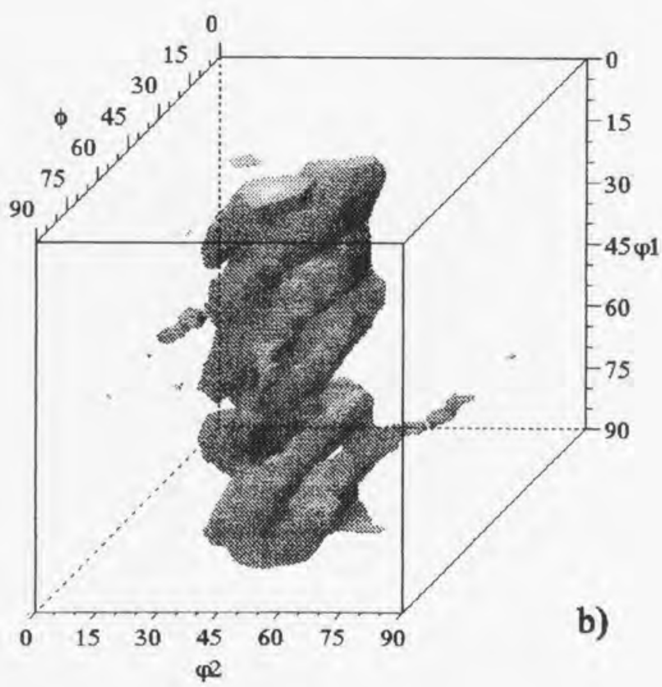


Fig. 5b: Strip casting texture of a low carbon steel with a {111}<uvw> texture; the diagram shows the orientation density above $f(\mathbf{g})$ =2.5; a) mid-thickness layer, $f(\mathbf{g})_{max}$=4.2.

The texture is stronger at the surface than in the center layer. The generation of a {111}<uvw> texture might be due to the influence of plastic deformation and recrystallization. Although exact operational details of the caster are unknown to the authors most strip casting constructions impose a certain amount of plastic deformation when the two newly solidified steel films impinge upon each other in the roll gap. This effect might entail primary recrystallization.

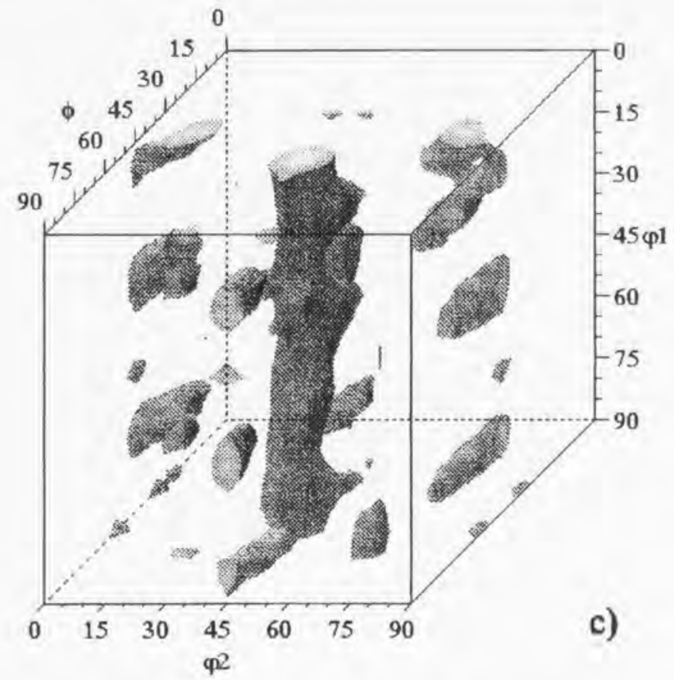


Fig. 5c: Strip casting texture of a low carbon steel with a {111}<uvw> texture; the diagram shows the orientation density above $f(\mathbf{g})$ =2.5; a) center layer, $f(\mathbf{g})_{max}$=4.2.

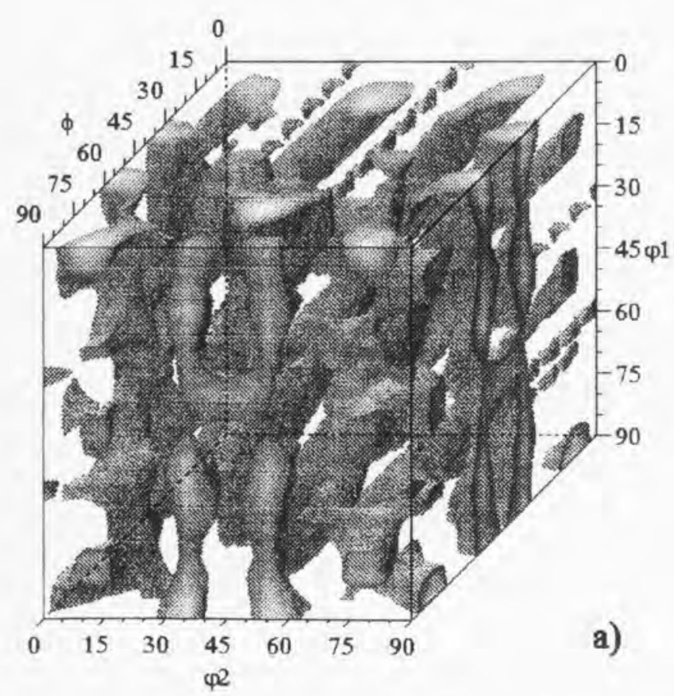


Fig. 6a: Strip casting texture of a low carbon steel with a weak {011}<uvw> texture; the diagram shows the orientation density above $f(\mathbf{g})$ =1; a) surface layer, $f(\mathbf{g})_{max}$=3.2.

Producing a pronounced {111}<uvw> starting texture is very beneficial since it would most likely be further sharpened during subsequent cold rolling and thus would provide an ideal starting texture for a final heat treatment and the creation of a strong final {111}<uvw> recrystallization texture.

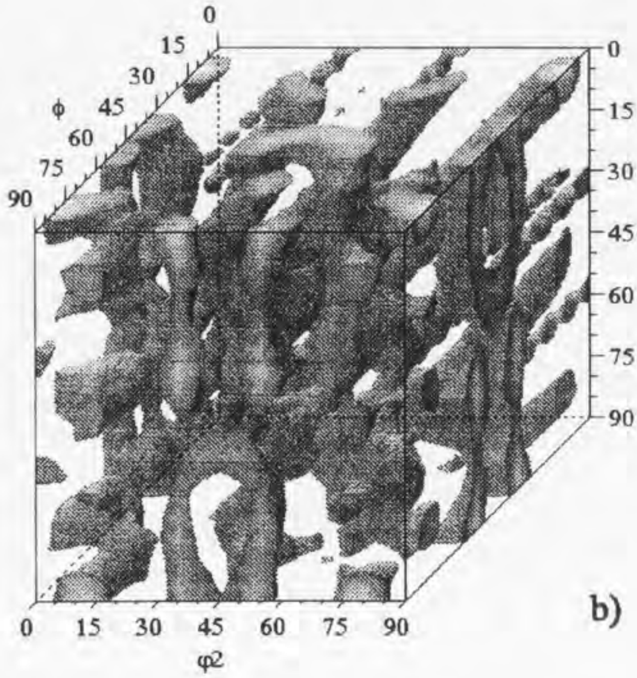


Fig. 6b: Strip casting texture of a low carbon steel with a weak {011}<uvw> texture; the diagram shows the orientation density above $f(\mathbf{g}) = 1$; a) mid-thickness layer, $f(\mathbf{g})_{max}=3.1$.

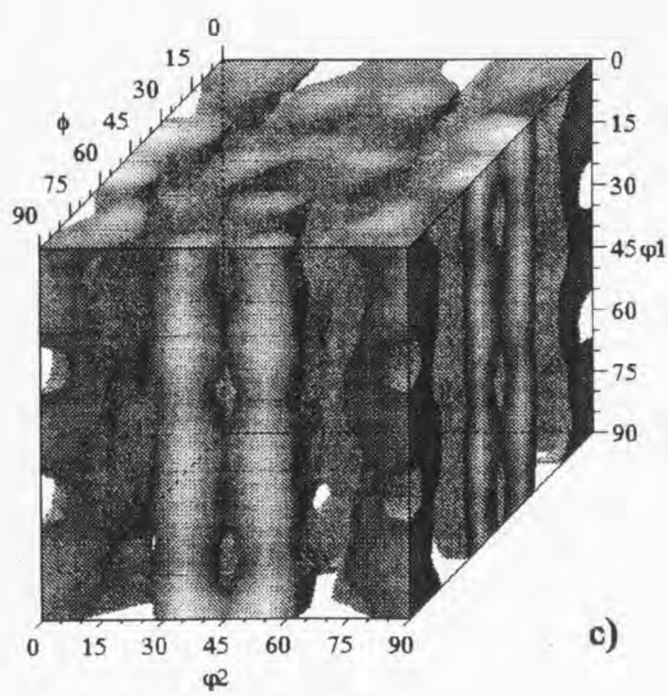


Fig. 6c: Strip casting texture of a low carbon steel with a weak {011}<uvw> texture; the diagram shows the orientation density above $f(\mathbf{g}) = 1$; a) center layer, $f(\mathbf{g})_{max}=2.5$.

Another set of strip cast low carbon steel samples revealed less pronounced textures characterized by a weak fiber close to {011}<uvw>. The textures of these materials were similar to strip casting textures observed earlier in strip cast ferritic stainless steels (Raabe et al. 1993, 1994).

Fig. 7: Macroscopic segregation profile of manganese across the sheet thickness of a strip cast low-carbon steel.

The strip cast low carbon steel specimens were investigated for manganese segregation (Fig. 7). The experimental data show that substantial macrosegregation across the strip thickness do not occur (Teicher at al 1998).

5. Summary

The textures and microstructures of strip cast austenitic and low carbon steels were presented. The stainless steels were produced in an unequal-diameter twin roll caster and the low carbon steels in an equal-diameter twin roll caster. The textures and microstructures were investigated in various through-thickness layers. The austenitic steels revealed weak textures close to the {001}<uvw> fiber. In low carbon steels two types of textures were observed. While some of the low carbon strips showed textures close to the {111}<uvw> fiber others revealed a weak texture with minor components close to {011}<uvw> fiber. All strip cast steel samples revealed weak through-thickness texture gradients. Chemical segregation effects were stronger in the stainless steel strips than in the low carbon steel strips.

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