TEXTURE AND PROPERTIES OF WARM ROLLED INTERSTICIAL FREE STEELS

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Abstract. *The Interstitial Free (I. F.) steels are novel materials of Ultra High Drawability used extensively in modern car industry, especially for the fabrication of car bodies of intricate and modern design. The exceptional formability is attributed to the specific chemical composition of very low carbon (~ 0.003-0.006 %), titanium microadditions (~ 0.06-0.09 %), and to the development of desired crystallographic texture during the steel thermomechanical processing. Stable carbides are formed in the austenite range, rendering the steel matrix almost carbon free, which allows high thickness reductions in the ferrite range. An I. F. steel was rolled at 600^oC and 400^oC under 60 % reductions, and cooled in air. At these temperatures, recrystallization is inhibited and the texture developed during rolling may be analyzed at room temperature. Texture was determined from Electron Back Scattering Diffraction (EBSP) using Orientation Imaging Microscopy (OIM). The Crystal Orientation Distribution Functions (CODF) correspond to the average texture across the sample thickness, and along the rolling direction. The results were compared with the CODF for samples rolled at room temperature. Independent of the rolling temperature, sample annealing returns similar texture components. These results encourage the development of continuous IF steels rolling schedules spanning down to lower temperatures*

Keywords: *Interstitial Free Steel, Warm Rolling, Crystallographic Texture, Sheet Drawability*

1. INTRODUCTION

Following the evolution of the automotive industry in the last few years, the need of producing lighter vehicles of modern design was brought forward. This was a driving force for the development of the I. F. steels, of very low C and N concentrations, and better drawability than conventional steels.

The exceptional drawability of these steels is directly related to the intense preferential orientation of the grains along the γ fiber (ND $//\langle 111 \rangle$). This distribution of preferential orientation is responsible for the high value of the material plastic anisotropy coefficient.

The present work investigates the presence of this fiber texture through detailed analysis of the microstructure and microtexture, using the modern methods of analysis of Electron Back Scattered Diffraction (EBSD) and Orientation Imaging Microscopy (OIM). These techniques allow the analysis of small regions and consequently the recording of the γ fiber texture.

Texture determination was performed on warm, cold rolled and annealed I.F. steel. Sample observation and analysis were performed in the scanning Electron Microscope, coupled with the EBSD and OIM hard and softwares. The microstructure, microtexture, texture, and Mechanical Properties were determined and correlated with sheet drawability

1. 1 Hot and warm rolling

Rolling is the most frequently used process of mechanical transformation of metals and is the process that presents a high productivity including considerable dimensional precision. In this process, the material is submitted to high compressive stresses, as a result of the cylinder loading, and to surface shear stresses, resulting from the friction between the cylinder and the material.

The rolling operation may be performed at relatively high temperature (hot rolling) or at room temperature (cold rolling). During hot rolling of steel strips, the continuous operation includes heating the steel plates within the 1100°C and 1300°C temperature range, with final rolling passes performed between 900^{o}C and 700^{o}C, followed by coiling of the strip product. After cooling down to ambient temperature, the coil is extended and pickled before cold rolling. At the end of cold rolling the material is coiled again or cut in the form of sheets, depending on the final material destination.

In the I. F. steels, in which the C and N concentration is lower than 50 ppm., hot rolling may be achieved both in the austenite or in the ferrite regions. When hot rolling is finished in the austenite region, the texture of the strip is weak (close to random). However, when rolling is finished within the ferrite region, a strong $\{111\}\langle uvw\rangle$ texture may be obtained. These components are responsible for the excellent drawability of the steels (Ávila, 1998).

Currently, the steel industry is greatly interested in warm rolling due to lower costs and better properties of the finished product. Hot rolling implies considerable costs in order to maintain the high temperature range. According to Harlet *et al.* (1993), a reduction of 200 to 300^{o}C in the temperature of the slab reheating furnace, which is possible when rolling the I. F. steels within the ferrite range, implies a significant reduction of costs. moreover, in cold rolling, the working loads and rolls wear are high, which also reflects high costs. Therefore steel working within an intermediate temperature range (between hot rolling and the cold rolling finishing) represents a more economical operation. Moreover, in warm rolling, the holding time required for the hot strip to cool down to room temperature before cold rolling is also reduced.

The objective of this paper is to characterize the texture and microstructure as well as the mechanical properties of warm rolled I. F. steels. In this text, warm rolling refers to working the steel below Ar_3 transformation temperature and above 200^{o}C.

2. MATERIALS AND EXPERIMENTS

The steel used in this work is a titanium I. F. steel supplied by the Brazilian National Steel Company (Companhia Siderúrgica Nacional – CSN), in the form of hot rolled strips, 3. 64 mm thick, and the nominal chemical composition shown in table 1.

Table 1 – Chemical Composition of the I. F.-Ti steel

C	**Al**	**Ti**	**Mn**	**Ni**	**P**	**N**	**S**	**Nb**
0,003	0,052	0,075	0,18	0,006	0,017	0,0047	0,007	0,002

Warm rolling reductions of 60% were performed at 400 and 600^{o}C, followed by annealing at 800^{o}C for 5 minutes. The 60% reduction is a limit imposed by the necessity to obtain distinguishable Kikuchi patterns, which become indistinguishable under the 85% reductions used in industry. The Kikuchi lines are the patterns resulting from the electrons back scattered off a given crystal, and the sharpness of the pattern is indispensable for the success of the definition of the crystal orientation as determined by the OIM analysis.

Taking into consideration the feasibility of cold rolling of the relatively thin starting material (3.64 mm), the texture of the warm rolled samples was compared with a similar cold rolling processing; 60 % reduced samples, annealed under the same conditions.

A FINN type laboratory rolling mill was used for warm reductions of 100 mm wide square strip samples. Heating was done in a muffle type furnace, and the samples were rolled along the original rolling direction. Samples were sectioned along the rolling direction and the surface polished using a 1 μm diamond paste, followed by electrolytic etching.

The etched samples were initially observed under the optical microscope, in order to determine the medium grain size according to the ASTM E112 standard.

Texture characterization was performed in a JEOL (model JSM-5800LV) scanning microscope through the EBSD microtexture analysis technique. The back scattered patterns are analyzed online by OIM Microscopy. The software attributes the most probable crystallographic orientation (index) to the Kikuchi pattern diffracted at each scanning position, the method being an iterative vector processing. Each position of the sample surface is scanned and crystallographically indexed within 0.33 seconds. The orientation data is processed by the software, which allows the construction of the Crystal Orientation Distribution Functions (CODF). As seen below, the Distribution Functions are the material texture characterization maps and were used to predict the mechanical properties and the deformation anisotropy R ratio using the programs developed by the Crystallographic Texture Group at the Military Institute of Engineering (IME).

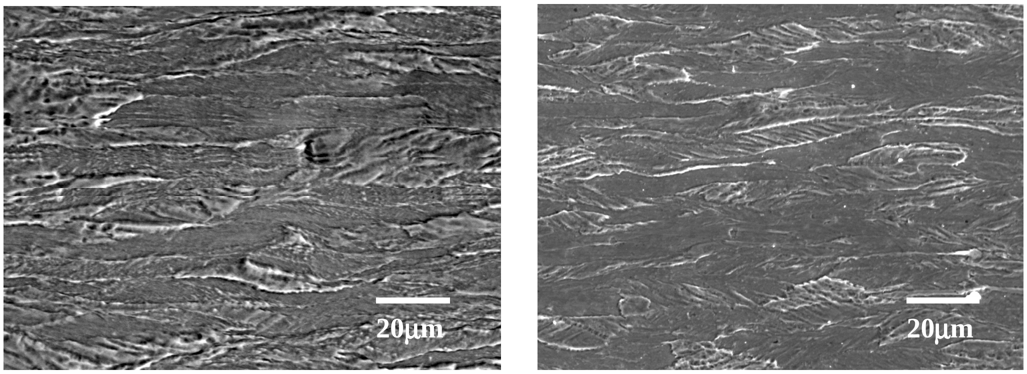
It is important to observe that the analysis of only one region under the scanning microscope is usually not sufficient to cover a number of grains sufficient to obtain a representative CODF, comparable to the results of the standard x ray texture analysis. In this work at least 2300 grains were analyzed, spanning between two to ten areas, depending on the average grain size (Matheus, 1999). After scanning each area of a given sample, the corresponding orientation data files were summed up using a program developed by the IME texture group (Lopes *et al*, 1998).

Due to the through thickness deformation gradient, Vickers microhardness was measured using a 50g pre-load in order to determine the strain hardening gradient through the longitudinal section. In this way, the limits of each scanning area may be determined and, the significance of the corresponding texture analyzed.

3. RESULTS AND DISCUSSION

The microstructures of the samples rolled at 400^{o}C and 600^{o}C are shown In figure 1. It is observed that the microstructure is characteristic of the steels deformed within the ferrite range; elongated grains and a distribution of shear bands. Through optical microscope analysis, and a grain counting software, an average grain size of 20μm was determined for both conditions, and the shear band distribution was 30% and 35% respectively.

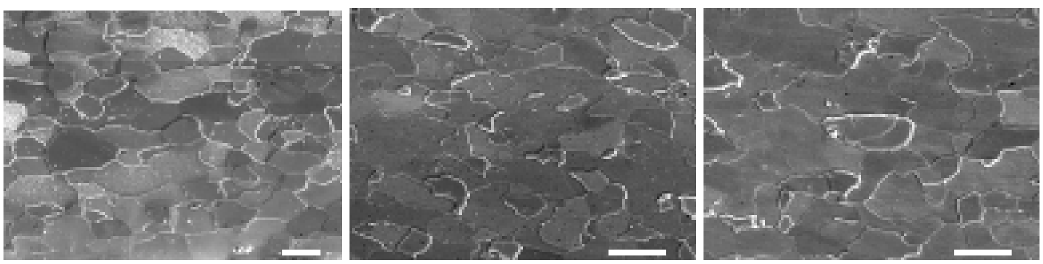
The annealed samples were totally recrystallized as shown in figure 2. The first micrograph shows the result of cold rolling, and figure 2b and 2c show the microstructure after warm rolling



(a) (b)

Figure 1 – Elongated grains after 60% deformation: (a) at 400^{o}C, (b) at 600^{o}C

at 400^{o}C and 600^{o}C. All three samples were reduced 60%, annealed for 5 minutes at 800^{o}C and air cooled. The final average grain size was 19μm; 13μm and 14μm respectively.



(a) (b) (c)

Figure 2 – 60% deformed microstructure (a) cold rolled and annealed; (b) rolled at 400°C and annealed; (c) rolled at 600°C and annealed

The abacus of figure 3 is used to identify the crystallographic systems of the Crystal Orientation Distribution Functions, CODF, shown in figure 4. The Distribution Functions are

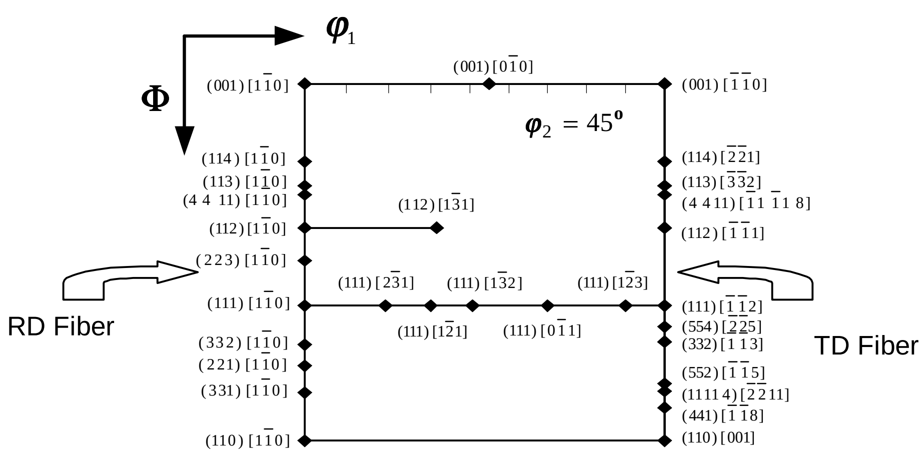
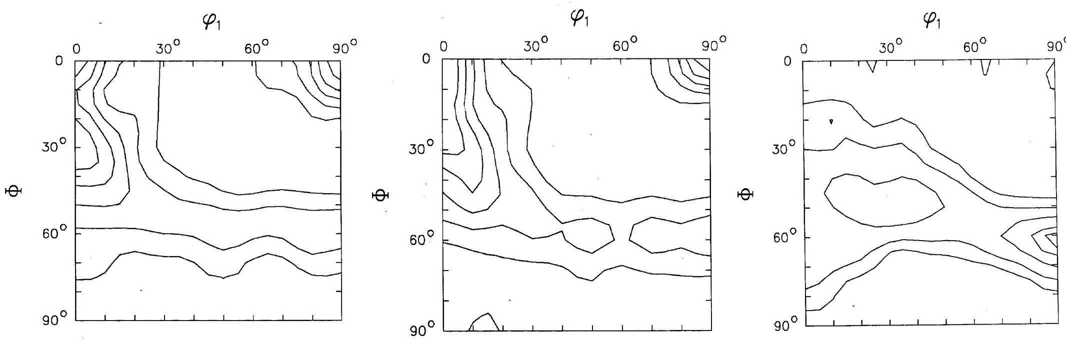


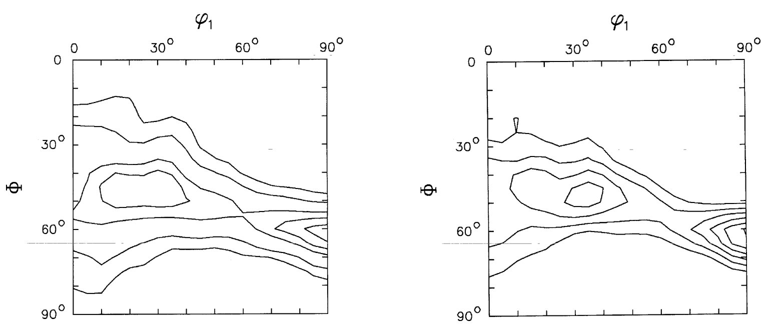
Figure 3 – Section φ_2 = 45°, Bunge notation, with the principal texture components and the RD and TD fibers (Matheus, 1999).

iso-contour lines diagrams of the relative intensity of the back scattered electrons. Specifically, the abacus of figure (3) allows the definition of the texture along the RD (rolling direction) and TD (transverse direction) macroscopic fibers, as indicated by the arrows.

Figure 4 shows the CODF of the steel at different conditions. The orientation distribution of the steel rolled at 400°C, figure 4(a), indicates a maximum of the $\{112\}\langle 110\rangle$ crystallographic component (relative intensity of 5.8) as well as a relatively significant $\{001\}\langle 110\rangle$ component. At 600°C, figure 4(b), the component of maximum intensity switches to $\{113\}\langle 110\rangle$, (relative intensity of 6.1), along with the $\{001\}\langle 110\rangle$ component. Figures 4(c) to 4(e) show that, independent of the rolling temperature, sample annealing returns similar texture components, and higher relative intensities near to the $\{111\}\langle uvw\rangle$ desirable orientations. The characteristics of the annealed textures are detailed in figure (5).



(a) 1 to 5 (b) 1 to 5 (c) 1,2,4,6,7



(d) 1,2,4,5,6 (e) 2 to 6

Figure 4 – CODF for 60% reduction (a) at 400°C, (b) at 600°C, (c) cold rolled and recrystallized, (d) at 400°C and recrystallized; (e) at 600°C and recrystallized. Contour values under the figures

According to Daniel and Jonas (1990), and Lopes *et al*. (1998), the development of strong $\{001\}\langle 110\rangle$, $\{223\}\langle 110\rangle$, $\{113\}\langle 110\rangle$ and $\{112\}\langle 110\rangle$ texture orientations is not favorable for good sheet drawability. As shown in figures 4(c) to (e), and with the help of the abacus of figure 3, we observe that these texture components are weak or absent after annealing. Consequently, the texture of the annealed samples promotes satisfactory drawability properties, which is confirmed by the predicted values of $\overline{R}$, ΔR, shown below. Using the data of figure (4) and the abacus of figure (3), the crystallographic distribution along the rolling (RD) and transverse (TD) fiber directions may be drawn, as shown in figure 5. The comparison of these macroscopic fiber textures is essential for the evaluation of sheet drawability.

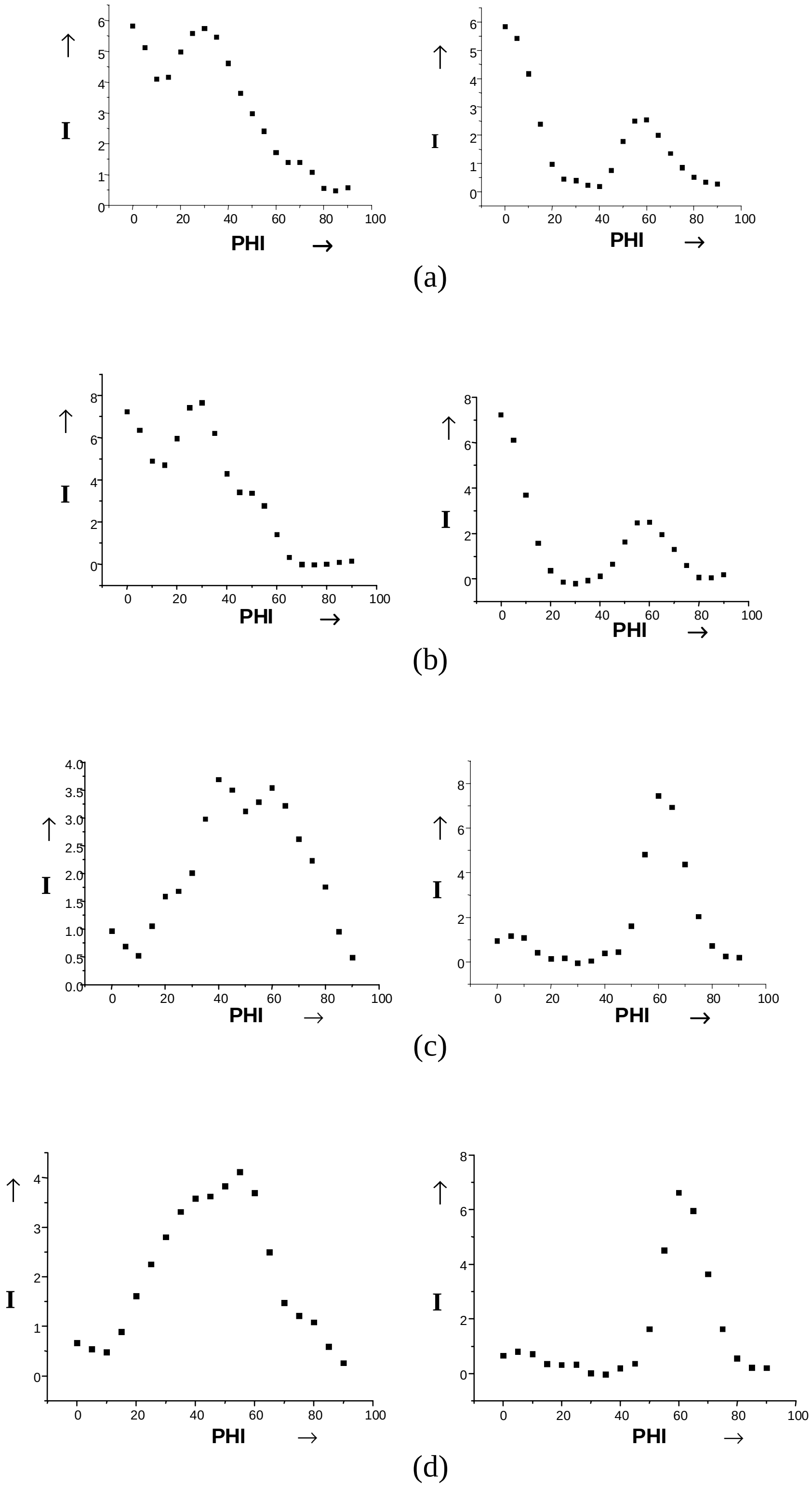


Figure 5 – RD and TD fibers of 60% reduced samples : (a) at 400^0C (b) at 600°C (c) cold rolled and recrystallized, (d) at 400°C and recrystallized

It should be observed that the intensity maps in figure (5) correspond to actual scanning angular positions and the corresponding relative intensities as obtained from the EBSD data file, while the contour lines of the Orientation Distribution Functions in figure (4) represent coherent extrapolations of the intensity levels as calculated by the OIM software. Therefore, the CODF of the sample rolled at 600^{o}C and annealed was given by the software. However, actual orientation measurements obtained along the RD and TD fibers was insufficient for the definition of intensity peaks along these fibers.

Independent of the warm rolling temperature, the RD and TD fiber textures are similar as seen in figure 5(a) and 5(b); both showing a two peaks texture. The first peak along the RD fiber is the $\{001\}\langle 1\bar{1}0 \rangle$ component, at $\phi = 0^o$, and the second peak at $\phi = 30^o$, 5^0 away from the $\{113\}\langle 1\bar{1}0 \rangle$ and $\{112\}\langle 1\bar{1}0 \rangle$ principal texture components, figure (3). On the other hand, the maximum along the TD fiber shows a $\{111\}\langle \bar{1}\bar{1}0\rangle$ component at $\phi = 0^o$, and a $\{554\}\langle \bar{2}\bar{2}5 \rangle$ component at $\phi = 60^o$, 5^0 away from the $\{111\}\langle \bar{1}\bar{1}2\rangle$ orientation. In the case of the cold rolled and annealed steel, figure 5(c), the sample returns double intensity peaks along the RD fiber including the $\{335\}\langle 1\bar{1}0\rangle$ and the $\{554\}\langle 1\bar{1}0\rangle$ orientations, and a maximum along the TD fiber corresponds to the $\{554\}\langle \bar{2}\bar{2}5\rangle$ orientation. In figure 5(d), the sample warm rolled at 400^{o}C and recrystallized returns a maximum intensity of the $\{111\}\langle 1\bar{1}0\rangle$ orientation along the RD fiber at $\phi = 55°$, and a maximum at $\phi = 60°$ of $\{554\}\langle \bar{2}\ \bar{2}\ 5\rangle$ component along the TD fiber.

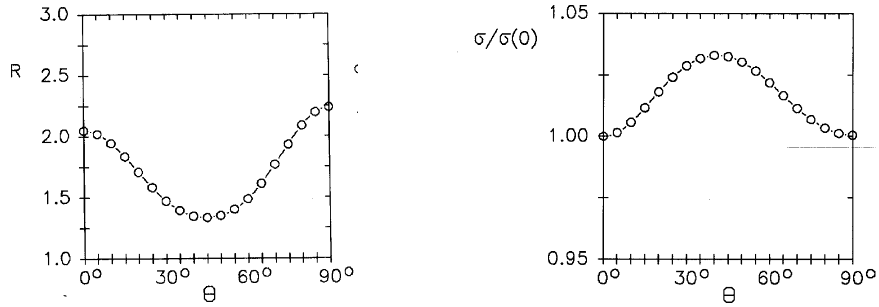
These results are coherent with recent work. On cold rolling IF steels, Ávila (1998) obtained peaks close to the $\{112\}\langle 1\bar{1}0\rangle$ and $\{223\}\langle 1\bar{1}0\rangle$ orientations along the RD fibers, and a peak of the $\{554\}\langle \bar{2}\bar{2}5\rangle$ orientation along the TD fibers. Moreover, on warm rolling IF steels, Barnett and Jonas (1997) found maximum intensities at $\{111\}\langle 1\bar{1}0\rangle$ for the RD fiber and the $\{554\}\langle \bar{2}\bar{2}5\rangle$ orientation for the TD fiber.

The similarity of the results found in this paper with those found by Ávila (1998) and Barnett and Jones (1997) is observed in spite of the different reduction levels and rolling sequence adopted in their work. That is texture development is independent of these thermomechanical parameters. This result is a significant for the optimization of the production of IF steel. Since the texture of the final IF product is ultimately related to the drawability of the sheet, production of IF steels may be achieved following relaxed warm rolling sequences and reduction levels, targeting the desired texture and the optimization of the production costs and time.

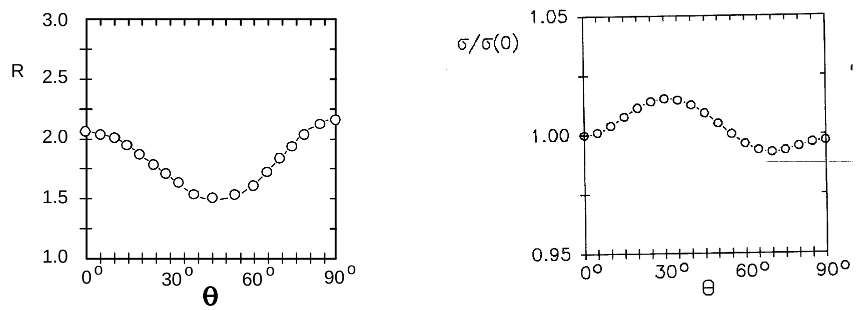
At the same time, the similarity of texture of the annealed cold and worm rolled samples indicates the possibility of adopting higher finish rolling temperatures. This would reduce the finishing rolling loads and further reduce production costs.

It should be noted that, as expected, the Vickers microhardness measurements across the sample thickness confirmed that, after rolling, a higher microhardness is developed at the sample surface, and is reduced down to a minimum value at the center plane. This is attributed to the texture gradient developed across the thickness, and shows that the scanned area effectively returns average CODF functions. In this work, the scanned areas where chosen as near as possible to the central plane.

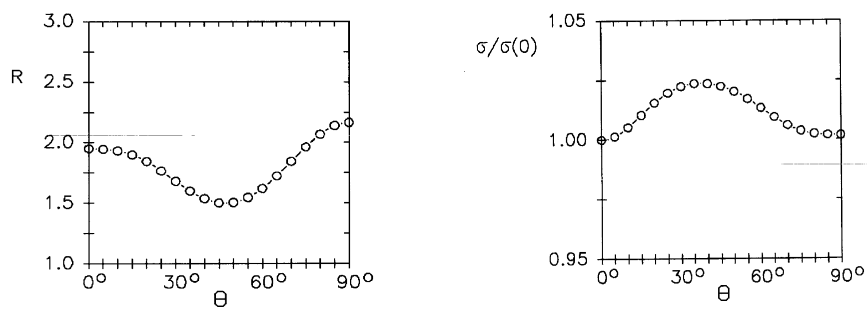
Figure 6 shows the curves of the angular variation of plastic anisotropy (R) and of the normalized yield limit along the sheet plane. These curves are obtained using the data file of the OIM analysis and the softwares developed by the Texture group at IME.



(a) 60% cold rolled, 800°C, 5min



(b) 60% at 400°C, recrystallized



(c) 60% at 600°C, recrystallized

Figure 6 – Angular variation of R and of the normalized yield limit (σ/σ_0).

The $\overline{R}$ value for a steel of good drawability should be near 2.0, since reduction of the cup wall thickness is lower for higher values of $\overline{R}$. At the same time, planar anisotropy, ΔR, should be as low as possible to limit the formation of earings. The values obtained for the above samples were : $\overline{R}$=1,74 e ΔR=0,81; $\overline{R}$=1,78 and ΔR=0,56; $\overline{R}$=1,72 and ΔR=0,77, respectively. An increase in the $\overline{R}$ value is directly related to the intensification of the γ fiber. It is observed that, as for the coefficient of plastic anisotropy, R, the yield limit is also anisotropic. The planar variation of the yield limit is, relatively, quite modest (compare variation ranges) though coherent with the corresponding R variation. In order to check the validity of these projected results, the (σ/σ_0) curves should be calibrated against a tensile test in the rolling direction. However, It is important to emphasize that the profile of the cup in the Swift drawability test has a form near to the presented R curves, Ávila (1993). In this manner, these curves allow a qualitative visualization of the earings of the Swift test.

4. CONCLUSIONS

- Worm rolling of IF steels within a range of temperatures in the ferrite region is a feasible industrial operation and allow the study of different rolling schedules for the production of sheet of desirable textures for ultra high drawability
- The use of the programs developed by the Texture Group of the Mechanical and Materials Engineering Dept. at IME, in conjunction with EBSD and MIO analysis constitute an important and advanced tool for the prediction of the mechanical properties of different materials.
- Texture measurements through the EBSD technique is a rapid recording method that, under carefully predetermined microstructure parameters, can substitute standard x-ray measurements.

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