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Texture evolution of ferritic (AISI 430) stainless steel strips during cold rolling, annealing and drawing.

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Abstract The evolution of the crystallographic texture of ferritic stainless steels, starting from the as received (hot rolled) condition from the steel mill, going through cold rolling, annealing and final stamping is analyzed in this paper. Two ferritic stainless steels (Nb stabilized) having a thickness of 3.0 and 0.7mm, have been employed. The thicker one has been cold rolled to 40 and 73% thickness reduction, annealed at 750 and 850°C for 1 hour. The thinner one, with a similar composition, has been 77% cold rolled and annealed at 870°C at the steel plant and subsequently submitted to deep drawing in order to evaluate texture and drawability**.** Texture has been evaluated using DRX in the as received, cold rolled, annealed and after drawing conditions. Drawability has been evaluated using tensile testing in order to obtain the FLC curves. AISI 430 stainless steel, in the as received condition presented a strong {100} texture in the <110> and <120> directions and the gamma fiber. After cold rolling, the material presented stronger gamma and weaker alpha fibers. Annealing of the cold rolled samples conduced to the vanishing of the alpha and strengthening of the gamma fiber, adequate for deep drawing operations. In spite of the AISI 430 of 0.7mm having presented a strong gamma fiber, other deep drawing properties were not adequate and the material cracked during stamping.

Introduction

Ferritic stainless steels present typical Cr contents in the range 11 to 17%, with low Ni and C levels in their chemical composition. Their good corrosion and oxidation resistance is related to the Cr content. They also present low toughness and a ductile-brittle transition temperature close to or somewhat higher than room temperature [1].

Ferritic stainless steels are frequently cold formed to their final application and differ to the austenitic stainless steels by presenting higher YS and a low n (strain hardening coefficient) values. These differences lead to the fact that they are far less adequate than the austenitic ones, for applications that involve stretching operations, despite that they may be used for deep drawing operations [2,3]. The higher levels in YS and the lower ductility of the ferritic stainless steels conduce to lower levels of conformability in relation to the austenitic types, hence leading to less demanding stampings**.**

Ferritic stainless steels present a strong typical cold rolling texture at the end of the hot rolling operation due to the ferrite stability, during hot rolling. Texture is characterized by strong α and γ fibers, and weaker ε and ζ fibers [4].

Cold rolling leads to a strong α fiber and a weaker γ fiber, with a maximum at the

{111}<112>component. Texture intensity increases with the increase of cold working. Annealing texture depends on the initial cold rolling texture and on the microstructure [5].

This work envisages the texture evolution in sheets of ferritic stainless steel of the AISI 430 type, Nb stabilized, during their different stages of production, starting from the as received condition (hot rolled), going through the cold rolling, annealing stages and finishing in the critical areas of an example-piece, as shown in figure 1.

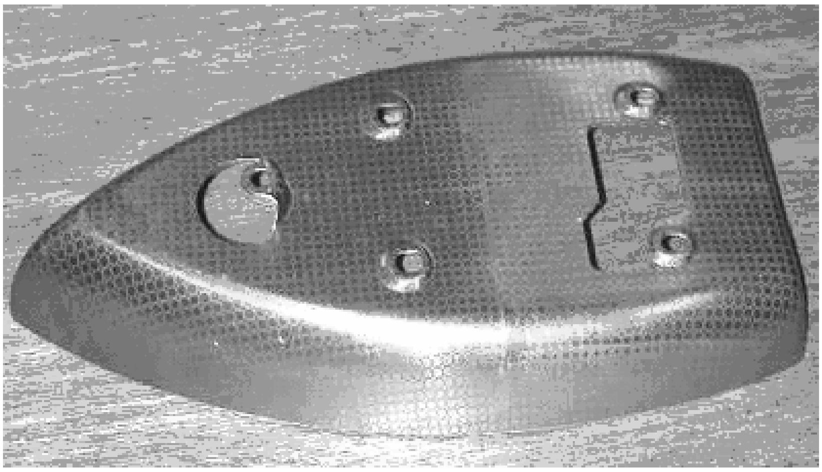

Figure 1 – example-piece

2. Materials and methods

Two casts of AISI 430, Nb stabilized stainless steels have been employed, with thickness of 3.0mm.(identified as AISI 430-E1) and 0.7mm.(identified as AISI 430-E2). Table 1 summarizes the chemical compositions of the studied materials.

Table 1: Chemical composition (wt.%) of the studied steels.

steel	C	Cr	Ni	Mo	S	Mn	Si	P	Al	Ti	Nb	V	N
430-E1 t=3.0mm	0.020	16.22	0.23	0.019	0.007	0.19	0.28	0.019	0.006	0.002	0.370	0.046	0.025
430-E2 t=0.7mm	0.018	16.06	0.21	0.040	0.002	0.12	0.31	0.025	0.006	0.012	0.392	0.047	0.019

The AISI 430-E1 sample had a total thickness reduction (given at the steel plant) of about 50%, followed by annealing (continuous annealing) at a temperature higher than 830ºC. This steel has been subsequently cold rolled to 40 and 73% thickness reductions, without lubrication (dry rolling) in an industrial two-high rolling mill (OD=300mm. rolls). Following, the samples have been submitted to heat treatments in a pit-type laboratory furnace (resistance heated), to temperatures of 750 and 850 ºC, for 1 hour and air cooled. The AISI 430-E2 sample has been supplied from the steel mill in the cold rolled condition with a thermomechanical condition similar to a more extreme condition than the given to the previous sample, namely a thickness reduction of 77%, annealing at a temperature higher than 830°C in a continuous furnace. This AISI 430 E2 steel has been selected only for the evaluation of texture and drawability before and after the production of the example-piece. A 150 ton press has been used to produce these example-pieces.

Texture evolution has been studied using X-ray diffraction, using a Rigaku horizontal texture goniometer (IPEN/CNEN-SP), employing Mo Kα1 (λ =0.7093 Å) radiation. The analysis has been performed at the surface of the sheet samples for the as-received rolled and annealed conditions, while in the stamped samples the evaluation has been carried out in a region next to the crack initiation. Samples have been ground to 1000 paper and subsequently polished with 6, 3 and 1 µm. diamond paste. For the ODF evaluation, the program that has been developed at the IPEN has been used.

Tensile tests have been carried out on a Zwick model-1475 machine, having hydraulic chucks and extensometer. The stamping samples have been prepared on a automatic press with borders ground subsequently in order to remove the hardening introduced due to the stamping operation. Sample dimensions are according to ASTM E8M-01. From these test samples the values of the YS, TS, El, n , r and (Δr) have been evaluated . The n e and r values have been obtained from strains between 10% and 20%, with intervals of 2% strain. Erichsen tests have been conducted according to ASTM E 643-00 on 80 mm wide samples.

For the evaluation of the FLD on the AISI 430-E2 steel, an Erichsen machine has been used. The FLD has been obtained with Nakazima- type samples. Eletrochemical etching of 3mm diameter tangential circles on the samples has been performed prior to testing. Samples have been compared at a sample height of 50±3mm, with a punch speed of 10 mm/min. Graphite grease has been used as lubricant in order to minimize friction between material and tooling. Deformation readings have been made with the help of the image analysis of the CAMSYS.®

3. Results and discussion

3.1. AISI 430-E1 steel

The mechanical properties of the 430-E1, 3mm thick material, in the as-received condition are given in Table 2.

Table 2: Mechanical properties of the as-received AISI 430-E1 steel

YS (N/mm^2)	TS (N/mm^2)	El (80) (%)	n	r_m	Δr	Hardness HV1)	E.I.(mm)
306	450	34.0	0.17	0.91	0.14	161	17.2

YS =Yield strength; TS = tensile strength; El (80) = Elongation on 80 mm; n = strain hardening coefficient; E.I. = Erichsen index; r_m = normal anisotropy index; Δr = planar anisotropy index.

The YS, TS, and El values have been obtained from samples taken in the RD, while the n, r_m and Δr values have been obtained from samples tested in the TD and diagonal to the RD. Due to lack of space only the fiber figures will be here presented and analyzed. These fiber figures have been obtained from the ODFs and pole figures obtained from the X-ray diffraction analysis.

Figure 2 summarizes the results obtained for the α and γ fibers for the AISI 430-E1 sample in the as-received condition, 40% and 73% cold rolled conditions. It may be observed that the (112) $[1\bar{1}0]$ component gets stronger with the cold rolling reduction, in a similar manner reported in the literature [5], apart from the Goss type- {110}<001>, fairly common at the surface of hot rolled ferritic stainless steels.

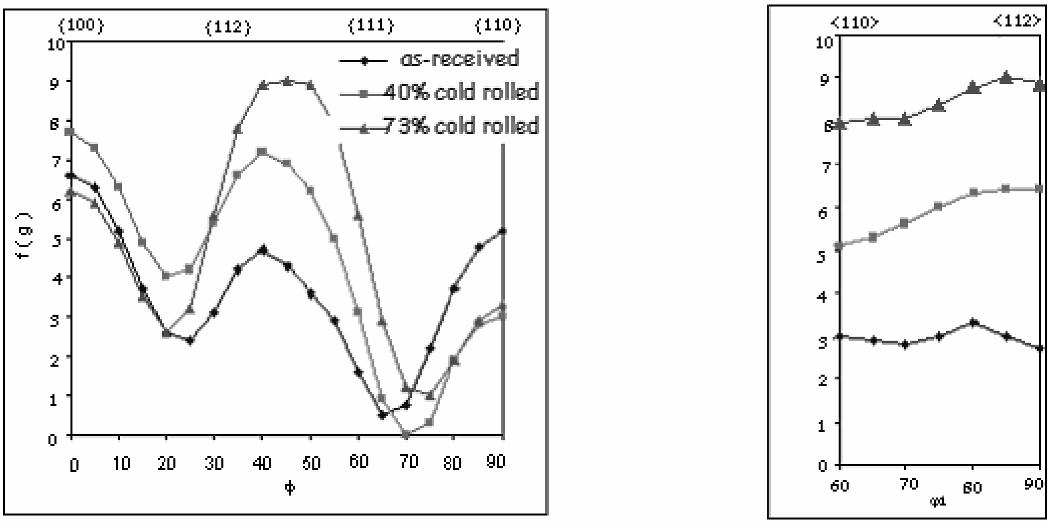

Figure 2: α and γ fiber intensity evolution for the AISI430-E1 steel in the as-received and cold rolled conditions.

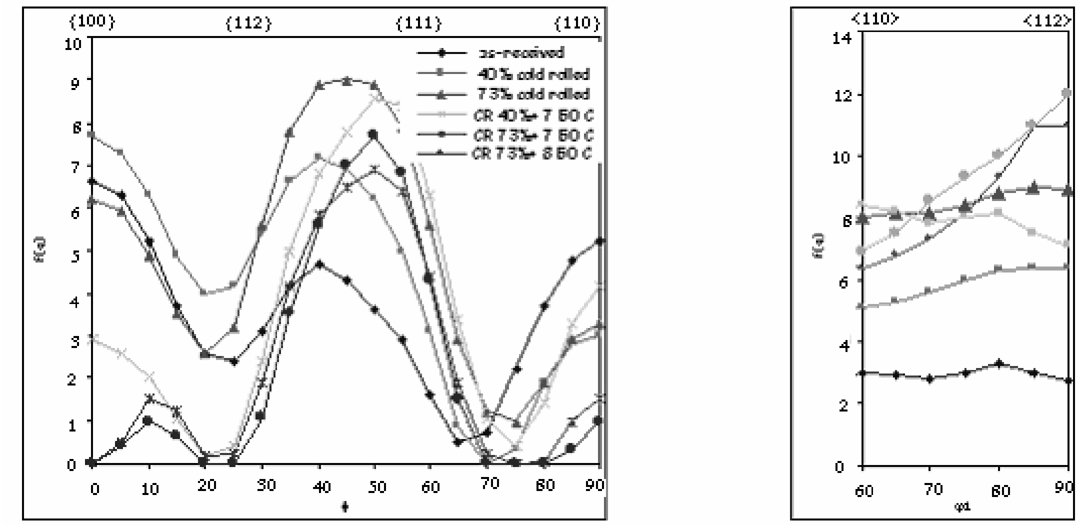

Figure 3: α and γ fiber texture evolution for the different studied conditions.

Annealed texture for the 40% and 73% cold rolled samples annealed at two different temperatures are quite similar, differing only in their intensity, as may be observed from figure 3.

3.2. AISI 430-E2 steel

The mechanical properties of the 430-E2, 0.7mm thick material, in the as-received condition are given in Table 3.

Table 3: Mechanical properties of the as-received AISI 430-E2 steel

YS (N/mm^2)	TS (N/mm^2)	El (80) (%)	n	r_m	Δr	Hardness (HV1)	E.I.(mm)
328	470	38.2	0.17	1.31	0.12	110	10.0

YS =Yield strength; TS = tensile strength; El (80) = Elongation on 80 mm; n = strain hardening coefficient; E.I. = Erichsen index; r_m = normal anisotropy index; Δr = planar anisotropy index.

The FLD for the AISI 430-E2 steel has been assessed for the 0.7mm sheet thickness, together with the critical regions, as shown in figure 4. It may be observed that those associated with the frontal part are located, as expected close to the FLD curve (plain strain condition), some exceeding the curve, hence the fracture that can be seen in figure 5.

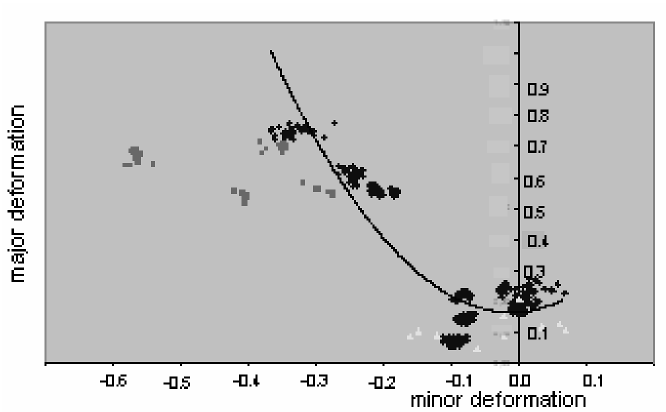

Figure 4: FLD for the 0.7mm AISI 430-E2 sheet.

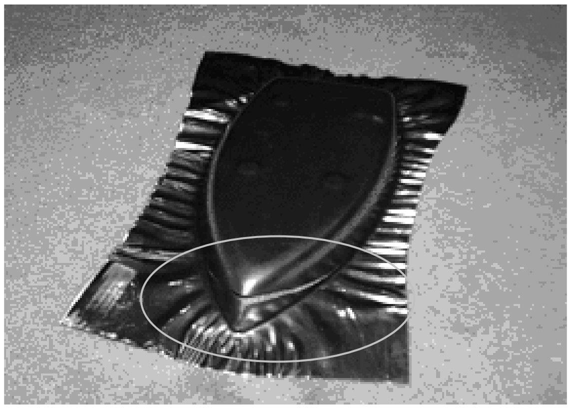

Figure 5: Example-piece stamped in AISI 430- E2 stainless steel sheet.

Figure 6 summarizes the results obtained for the α and γ fibers for the AISI 430-E2 sample in the cold rolled and annealed (as-received) condition and after stamping, frontal position.

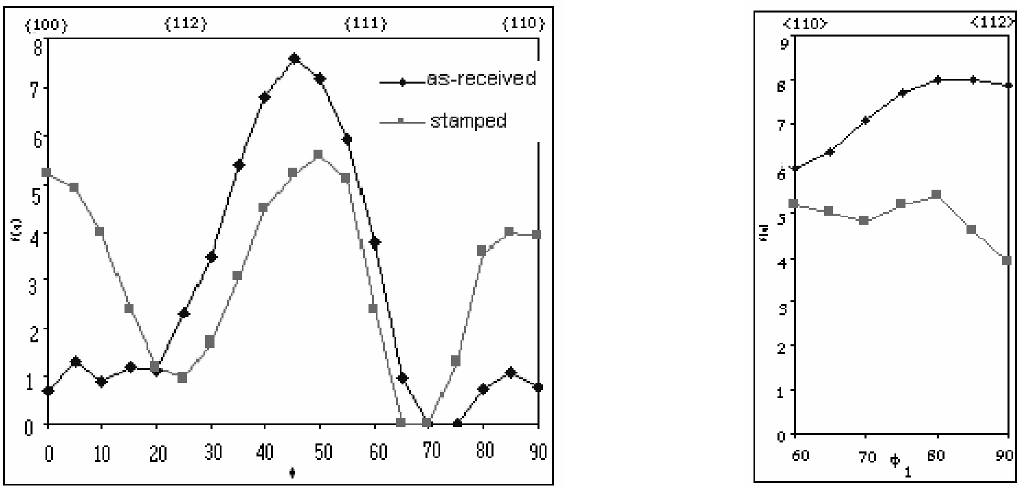

Figure 6: α and γ fiber texture evolution for the different studied conditions.

In the as-received condition a stronger γ fiber may be observed, compared to the previous analyzed steel. On stamping the reappearance of a strong {100} texture component in the <001>, <310> and <110> directions may be observed in the α fiber with a weakening in the γ fiber components. This {100} texture component reappearance in addition to the low strain hardening coefficient (n=0.17) and the low position of the FLD_0, seem to be the main reasons that lead to the early fracture of the stamping.

4 - Conclusions

The analysis of the obtained results for the AISI 430-E1, Nb stabilized stainless steel (initial thickness of 3.0mm) in the different conditions as received, cold rolled and annealed, lead to the following conclusions:

- In the as–received condition the steel presented a heterogeneous texture with {001} components in the <100>, <110> and <120> directions, the Goss component, {110} <001>, and the γ fiber.
- Cold rolling conduced to a strengthening of the α and γ fibers with increasing cold working.
- Annealing conduced to γ fiber strengthening with the disappearance of the α fiber. The γ fiber, for higher strains, presented a strong {111} <112> component.

The analysis of the obtained results for the AISI 430-E2, Nb stabilized stainless steel (thickness of 0.7mm), lead to the following conclusions:

- In the as–received condition the steel presented a strong γ fiber with strong <231> and <121> components, similar to the one presented in the AISI 430-E1 steel, cold worked to 40% and 73 % thickness reduction and annealed at 750°C and 850°C for 1 hour, however presenting a γ fiber of smaller intensity.
- After stamping the texture presented some changes in that the γ fiber weakened and the {001} texture reappeared in the <001>, <310>, <110> directions, with a higher intensity than that of the γ fiber.
- The probable cause of the stamping failure of the example-piece using the AISI 430-E2 steel, despite its good crystallographic texture, may be attributed mainly to its low strain hardening coefficient (n=0.17), making that the corresponding FLD_0 value would be placed well bellow the corresponding value for low carbon steel. This effect conduces to a low capability of a uniform strain distribution in the presence of large strain gradients.

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