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Deformation and Recrystallization Textures in Duplex Stainless Steel

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ABSTRACT. Hot rolled plate samples of duplex steel DIN W Nr. 1.4462 were examined in the following states: a) "as received", b) solution annealed at 1050 °C, c) cold deformed by rolling, with (thickness) reductions of 20 and 50%, with directions parallel and perpendicular to the original rolling direction and d) recrystallized. The orientation distribution functions (ODFs) of the two phases (ferrite and austenite) in all the samples were determined by X-ray diffraction. The ODFs were obtained from 4 incomplete pole figures. The orientation relations between the phases were also considered.

INTRODUCTION

Ferritic-austenitic stainless steels with duplex microstructure have been increasingly specified in applications that demand superior mechanical strength, toughness, and corrosion resistance when compared to conventional stainless steels. The favourable combination of properties of duplex steels is intrinsically related to its microstructure. These steels solidify with ferritic structure and the austenite is formed in the solid state. During hot deformation (in temperatures between 1000 and 1200^0 C), alternated layers of ferrite and austenite are developed in the microstructure. Due to the fact that the α/γ interface energy is lower than the grain boundary energy of the α/α and γ/γ grains, the layered microstructure is facilitated [1]. The volumetric fractions of the phases present must be nearly equal; the minor phase must not have its volumetric fraction lower than 30 %[2].

Steel mechanical properties are a function of microstructure, crystallographic anisotropy and of the ODF of the material grains. Dealing specifically with duplex steels, the macroscopic mechanical properties (such as yield point and tensile strength) depend strongly on the ODF of the two phases (austenite and ferrite). Moreover, their morphology and distribution also contributes to the final result [3]. For example, DIN Werkstoff Nr 1.4462, 4.1 mm rolled plates present, in the annealed state, yield point in the transverse direction (TD) (to the rolling direction) is 10 % higher than in the rolling direction (RD) [4].

The ODF (f(g)) is represented as a function of the Euler angles (φ_1, ϕ, φ_2,)=g, which, in turn, represent the necessary rotations that the crystal's co-ordinate system (the axes of the cube) suffers to coincide with the sample's co-ordinate system; rolling direction (RD), transversal direction (TD) and normal direction (ND).

Texture is defined by the volumetric fraction of the crystallites that have the same orientation **g**, defined by the Euler's angles [6].

$$\frac{dV}{V} = f(g)dv = f(\varphi_1, \phi, \varphi_2)dg$$

$$dg = \frac{1}{8\pi^2} sin\phi d\varphi_1 d\phi d\varphi_2$$

It must be pointed out that the ODF cannot be measured directly; it must be calculated from pole figures [6]:

$$P_{hkl}(\alpha, \beta) = \frac{1}{2\pi} \int f(\varphi_1, \phi, \varphi_2) d\gamma$$

Another important indicator of the degree of preferential orientation is the texture J-index [6], defined by:

$$J = \int_{o}^{2\pi} (f(g))^2 dg$$

J=1 means that the sample does not present texture and for J= ∞ means that the sample is a single crystal.

The aim of present work is to study the texture of rolled plates of DIN W Nr. 1.4462 duplex stainless steel, in the following conditions:

i) "as received";

ii) solution annealed at 1050^0 C;

iii) cold rolled in the (initial) rolling direction(RD);

iv) cold rolled in the transverse direction (TD) to the original rolling direction (i.e. cross-rolling) and;

v) recrystallized .

The ODFs were determined by X-ray diffraction in the two phases (ferrite and austenite) in all samples and were obtained from four incomplete pole figures.

MATERIAL AND EXPERIMENTAL PROCEDURE

The rolled plates were received hot rolled with 1.45 mm thickness and probably solution annealed. Chemical composition is given in Table 1. The "as received" material was solution annealed at 1050 C for 20 minutes. Following, samples were taken from the plates in the original rolling direction (RD) and in the transverse direction (TD). These samples were cold rolled with (thickness) reductions of 20 and 50%. Cold rolled samples went through a recrystallization treatment at 1050^0 C for 20 minutes.

The incomplete pole figures of each phase were determined for all samples: as received, solution annealed, cold rolled and after recrystallization, totalling 10 samples. All measurements were made with an automatic texture goniometer. To obtain the ODFs, 4 incomplete pole figures from each phase were processed: (111), (200), (220), and (311) for austenite and (110), (200), (211), and (310) for ferrite. Cr-Kα and Mo-Kα radiation were used.

Data processing was performed based on the series-expansion method proposed by Bunge [6] employing the software developed in the X-ray Diffraction Laboratory of IPEN/CNEN-SP [7].

Table 1: Chemical composition (wt.%)

Element	wt. %	Element	wt. %
C	0.03	Mo	3.03
Si	0.60	V	0.11
Mn	1.64	Ni	5.6
P	0.02	Co	0.11
S	0.018	Nb	0.012
Cr	22.51	Ti	0.012
W	0.04	Cu	0.06
N	0.134		

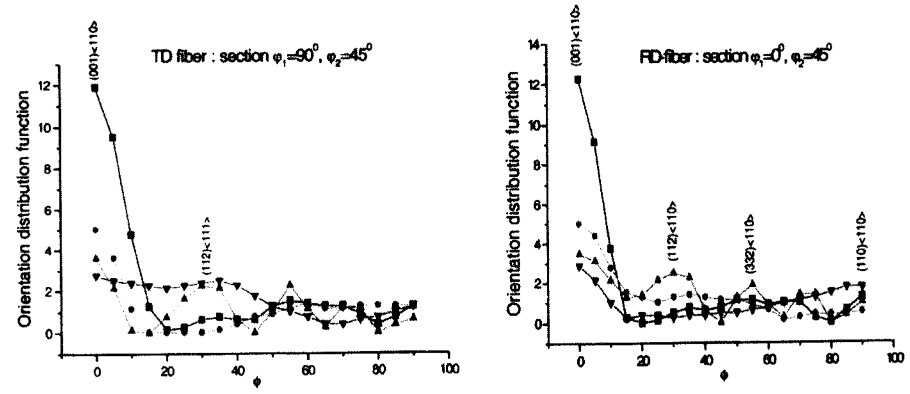

Figure 2- Orientation distribution function of ferritic phase. The symbols mean:
■ 50% rolled in the TD
● 20% rolled in the TD
▼ 20 % rolled in the RD
▲ 50 % rolled in the RD

RESULTS AND DISCUSSION

Eighty pole figures (40 for austenite and 40 for ferrite) were determined from 10 samples with different microstructures. The 10 microstructures could be classified in 3 main types, namely:

initial state
deformed state
recrystallized state
Diffraction results will be presented in various ways, such as:
texture J-factor for each phase per sample;
ODF for each phase per sample;
Fibre-graphics (of the α,β, RD, TD-fibres) obtained from the ODFs and;

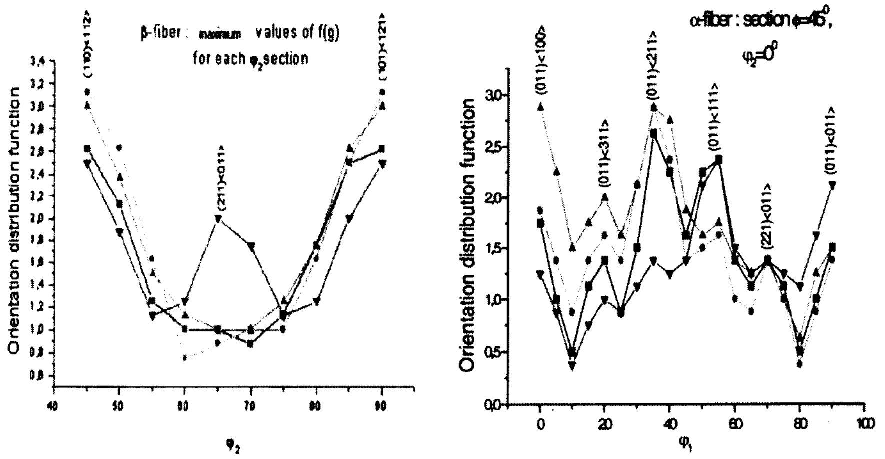

Figure 3- Orientation distribution function of austenitic phase. The symbols mean:

■ 50% rolled in the TD
• 20% rolled in the TD
▼ 20 % rolled in the RD
▲ 50 % rolled in the RD

stereographic projection also obtained from the ODFs, aiming at the determination of the orientation relations between phases.

Results will be presented and discussed according to the following sequence: texture of the two phases in their initial state, cold deformation and, subsequently, recrystallization effects on the texture of the two phases. Therefore, the J-factor will be employed in all cases. Because of space limitations, the ODFs presented will be only those to illustrate typical situations. For each state (solution annealed, cold worked and recrystallized), considerations will de made about orientation relationships between phases.

Texture of the solution annealed initial state. At this state the texture J-index was 22 for ferrite and 48 for austenite. The main crystallography orientations were (001)<110> for ferrite and (112)<110>, (110)<112> and (011)<100> for austenite. The orientation relationships between phases are those suggested by Nishiyama-Wasserman [8], relating the deformation induced α'-martensite and the austenite in the austenitic stainless steel. It should be mentioned, also, that the texture components (001)<110> for ferrite and (011)<211> for austenite that were present in the solution annealed state, are typical of deformation textures.

Recrystallization texture of cold deformed ferrite . The deformation texture is shown in Figure 2 through the TD and RD fibres.

For 20% reduction in the RD, the disappearance of (112)<110> in the ferrite orientation may be observed, in addition to the decrease of the J-index from 4.7 to 3.6. The (001)<110> orientation stayed stable. For 50% in the RD the J-index reached the value of 9.4, with an increase in the (001)<110> and (112)<110> orientations.

On cross-rolling, it may be observed that the (001)<110> component became more intense, directly proportional to the level of cold working. The same trend was observed in the appearance of the cube (001)<100> orientation. The texture J- indexes were: 4.8 for 20% reduction and 13.2 for 50% reduction.

On recrystallization, higher levels of cold working conduced to a more random crystallographic orientation (see table 2).

Recrystallization texture of cold deformed austenite. The deformation texture is shown in Figure 3 through alfa and beta fibres.

Cold working caused lighter texture variations in austenite than in ferrite. In the RD, the texture J-index was higher than 6.9 in the solution annealed condition, 4.9 for the 20% reduction and reached 8.0 for 50% reduction. Cross-rolling had a similar behaviour: J=4.8 and J=6.2 for 20% and the 50% reduction, respectively. On recrystallization, in the case of austenite, higher levels of cold working conduced also to a more random orientation (see table 2).

Table 2: Texture J-index

Sample Treatment	J-Index	
	Austenite Phase	Ferrite Phase
As received	3.0	7.8
Solution annealed	6.9	4.7
20 % rolled in the RD	4.9	3.6
50 % rolled in the RD	8.0	9.4
Recrystallized after 20 % in the RD	5.0	5.1
Recrystallized after 50 % in the RD	3.2	2.8
20% rolled in the TD	6.0	4.8
50% rolled in the TD	6.2	13.2
Recrystallized after 20 % in the TD	5.5	6.2
Recrystallized after 50 % in the TD	5.2	2.0

CONCLUSIONS AND FINAL COMMENTS

Texture results obtained in this work suggest that, during cold working, ferrite deforms more than austenite. Reasons for this behaviour can be linked to the lower number of slip systems in austenite and its lower stacking fault energy [8]. The detailed microstructural analysis showed that, while ferrite stretches, there are small "islands" of less stretched austenite.

The recrystallization of highly deformed materials (50% thickness reduction) leads to the decrease of texture. This is due to the fact that, the higher the deformation level, higher will be the number of recrystallization nuclei. For lighter reductions (20%), the number of nucleated and recrystallized grains is lower. In this case, to attain a full recrystallization, the recrystallization fronts (high angle grain boundaries) will have to travel larger distances until their impingement. Therefore, the nucleation has a more important role for high deformation levels, while for lower deformation levels growth of nucleated grains plays a more important role.

The orientation relationship found in the solution annealed condition is similar to the one given by Nishiyama-Wasserman [9] and it did not modify in any significant level due to deformation. After recrystallization, the orientation in ferrite become almost random, indicating the absence of preferential orientation relationship between the phases.

Finally, accentuated cold working leads to a highly preferential oriented materials. In this case, cross- rolling is more effective in accentuating this preferential orientation. However, the recrystallization after high levels of cold working (50% reduction) leads to an almost textureless material (and with no texture distinction between the cross- or parallel rolling directions).

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