Variant selection in samples of austenitic stainless steel cold rolled and deformed by tension

Hamilton Abreu, Nathanael Morais, Flávio Herculano , Marcelo Silva, Alex Nascimento

Universidade Federal do Ceará- Fortaleza - Brasil

40°
0 50 100 150 mi
0 100 200 km
Jericoacoara
OCEANO
ATLÂNTICO
Área de
Litígio
CHAPADA DA IBIAPABA
Acaraú
Sobral
Parque Nacional
de Ubajara
Cumbuco
Caucaia
Fortaleza
Maranguape
Aquiraz
Guaramiranga
Açude
Araras
Curu
Cascavel
4°
Beberibe
Aracati
Canoa Quebrada
Área de
Litígio
CEARÁ
Quixadá
Morada
Nova
Quixeramobim
PIAUÍ
Açude
Banabuiú
Jaguaribe
CHAPADA DO APODI
RIO GRANDE
DO NORTE
SERRA GRANDE
Mombaça
Acopiara
6°
Açude Orós
Iguatu
Icó
Juazeiro
do Norte
CHAPADA DO ARARIPE
Crato
PARAÍBA
PERNAMBUCO
38°

Objectives of this work

- To apply the phenomenological theory of martensite crystallography (PMTC) and Patel-Cohen´s theory for variant selection to predict crystallographic texture of samples deformed by cold rolling.
  - Comparing texture measured by EBSD in cold rolled samples with predicted texture assuming the phenomenological theory of martensite crystallography (PMTC) and Patel-Cohen´s theory for variant selection.
  - Applying both theories in predicting orientation distribution function (ODF) in martensite and compare with ODF´s obtained from pole figures measured by X=ray diffraction.

Introduction

- Patel and Cohen theory and the phenomenological theory of martensite crystallography (PTMC) have been applied to samples deformed in a tension test to predict martensite texture;
- In a recent study Kundu applied with success both (Patel and Cohen theory and PMTC) to samples deformed under complex conditions of rolling to predict the final texture of martensite in Fe-Ni alloys.
- Metastable austenitic stainless steels such as AISI-304L and 301L partially transform to martensite when deformed.

Introduction

- The amount of martensite induced by deformation depends on the processing parameters such as the state of stress, temperature, way and rate of deformation.
- When an appropriate stress is applied at temperatures above M_s, it is possible to activate displacive transformations because the applied stress provides mechanical driving force.
- The work done by external stresses contributes to a free energy change, either raising or lowering the M_s temperature.

Patel and Cohen Theory

- The interaction energy that provides the mechanical driving force for transformation is given by:

  $U = \sigma_N \delta + \tau s$ (1)

  σ_N is the stress component normal to the habit plane;

  τ is the shear stress resolved on the habit plane in the direction of shear

  δ, s are the respective normal and shear strains associated with transformation

- $\Delta G = \Delta G_{CHEM} + \Delta G_{MECH}$ (2)

  $\Delta G_{MECH} \equiv U.$

- It would be reasonable to assume that there is strong variant selection when the ratio of $\Delta G_{MECH} / \Delta G$ is large

Experimental

- The steels used were commercial stainless steel;

- Microtexture studies were performed by EBSD in an Oxford Crystal 300 EBSD system attached to a SEM Philips XL-30 and for acquisition Channel-5 software from HKL was used for analysis.

- A Philips X'Pert Pro X-ray diffractometer with Mo K_{α} radiation was used for macrotexture studies.

Experimental

- Three incomplete pole figures for α'-martensite – (200), (211) and (222) – and for austenite – (200), (220) and (211) – with maximum tilt of 75^{o} were measured .

- ODF´s were calculated with the software Labotex.

- The predicted texture resulting from $\gamma \rightarrow \alpha$ transformation was performed with software *crystal_habit_poly.f* developed by Saurabh Kundu and available at www.msm.cam.ac.uk.

Results

- Measured lattice parameter of austenite in these steel was 0.36106 nm and for martensite 0.28764 nm.
- Prediction of martensite texture calculated as in Geometry of Crystals (Harry Bhadeshia)
- Standard set used for texture simulation is:
- a_γ/a_α=1.2552
- Habit plane $\vec{p}=(-0.169784275 \quad -0.762072862 \quad -0.62483458)$
- Deformation direction $\vec{d}=(-0.191285635 \quad -0.683992424 \quad 0.703963188)$
- δ= 0.0112061159 s= 0.228823027 m=0.22909726

- Coordinate transformation matrix:

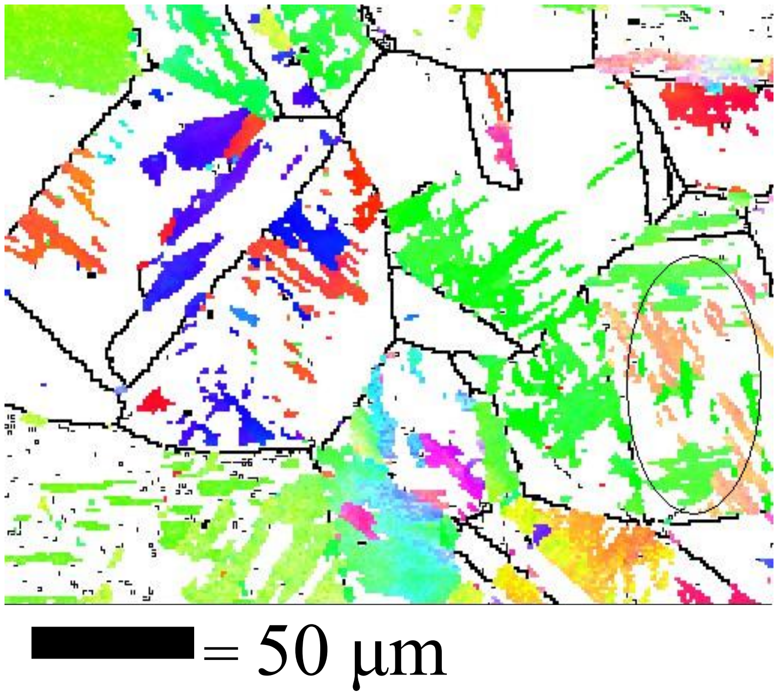
$$(\gamma J \alpha)=\begin{pmatrix} 0.575516581 & 0.542120251 & 0.0976951561 \\ -0.550778282 & 0.568639138 & 0.0891675977 \\ -0.00905503033 & -0.131959122 & 0.785597138 \end{pmatrix}$$

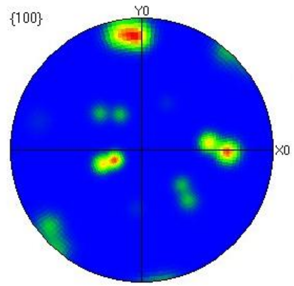
Applied tensor during deformation

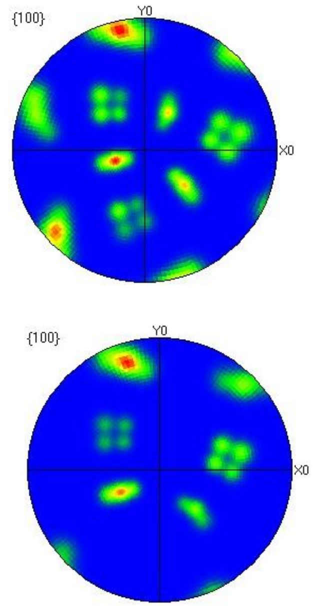
Tensor for deformation in a tension test $\Rightarrow \begin{pmatrix} \sigma & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$

Tensor for deformation by cold rolling $\Rightarrow \begin{pmatrix} \sigma & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -\sigma \end{pmatrix}$

Austenitic stainless steel deformed by tension



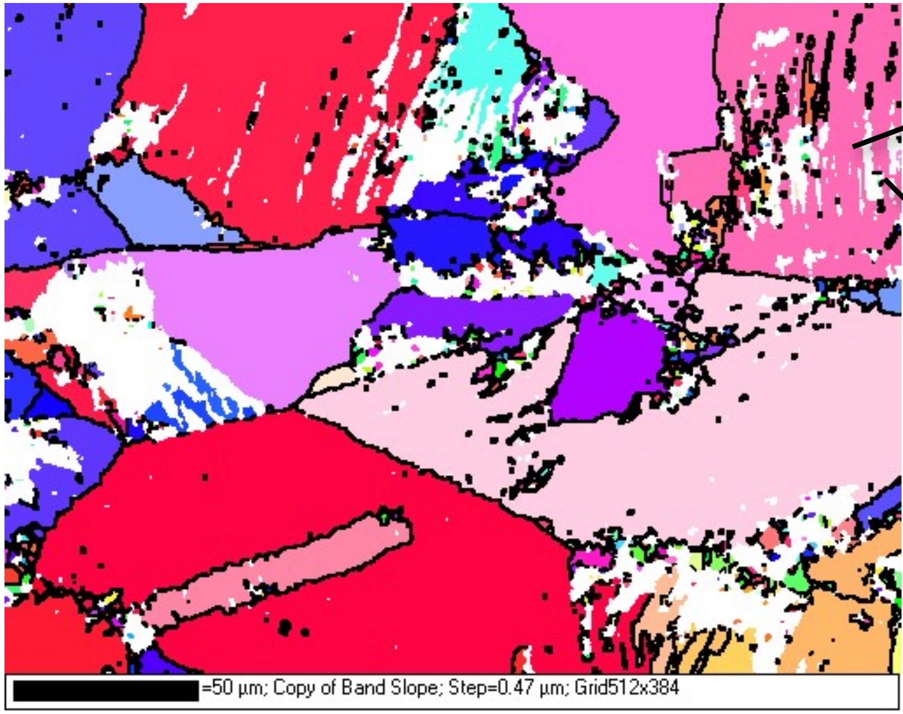




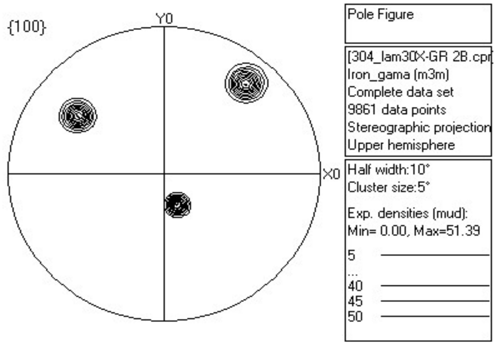
24 V

12 V

Orientation of selected grain of austenite



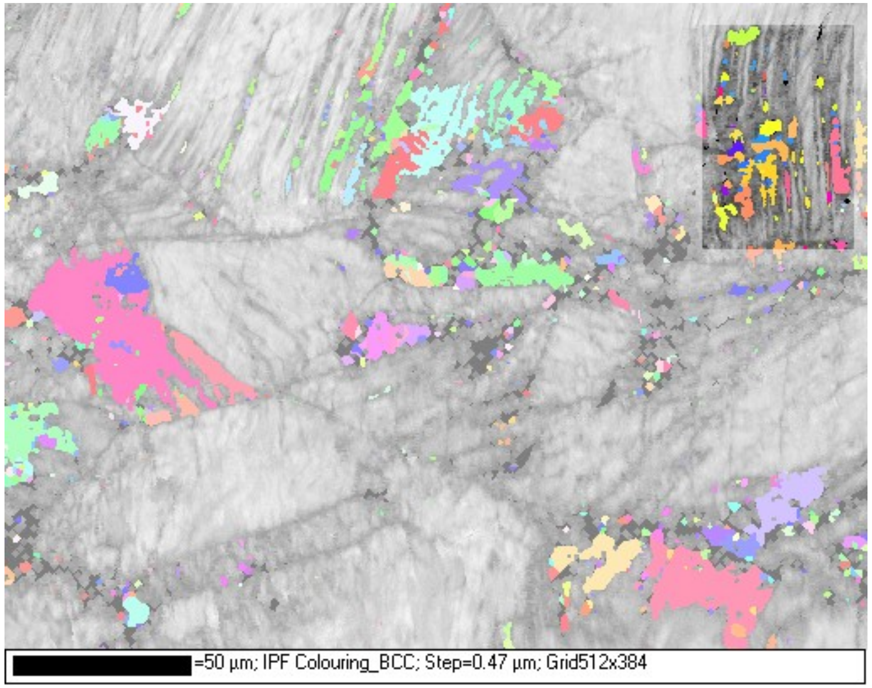
φ_1=21.6°, ϕ=25.6° and φ_2=30.3°

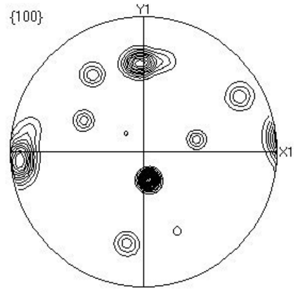


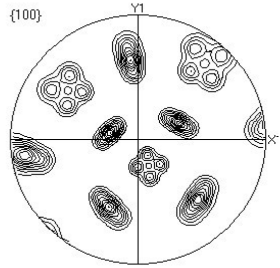
Calculated values of U for austenite texture

Ranking	Variant no.	U (J mol^{-1})
1	7	29.49
2	1	29.23
3	16	26.98
4	9	25.54
5	12	23.19
6	15	22.65
7	6	18.45
8	14	17.80
9	17	9.55
10	5	9.37
11	13	5.97
12	19	3.79
13	4	2.59
14	11	1.76
15	22	-0.84
16	24	-6.06
16	18	-19.44
18	3	-19.52
19	23	-21.65
20	8	-24.26
21	2	-32.22
22	21	-32.81
23	20	-33.16
24	10	-36.43

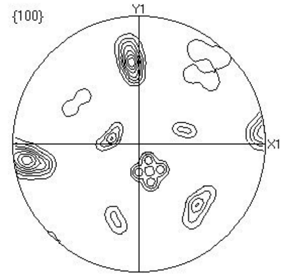
Predicted and measured pole figures for martensite





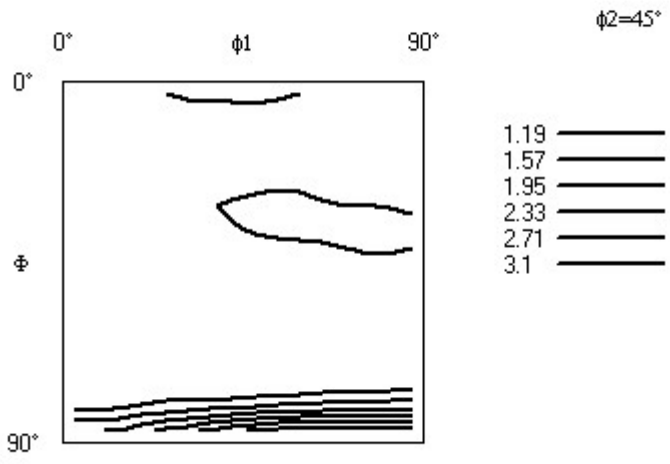


24 V



14 V

ODF- Calculations
Initial texture of austenite

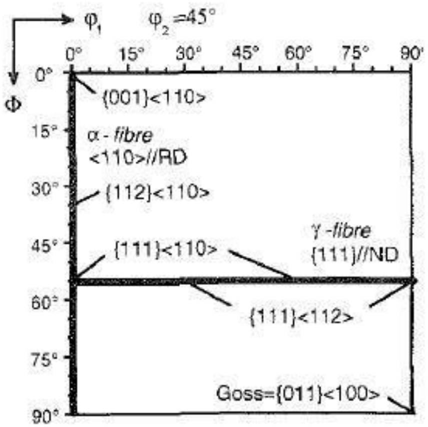


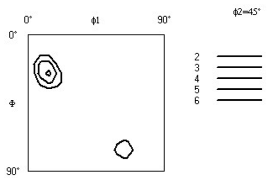
Main components: Goss (110)[001]; Brass (110) ; Cube (001[100]; and, Copper (112)[11].

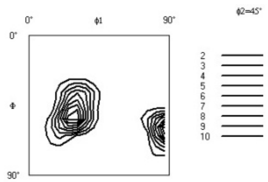
Calculated volume fraction for each orientation: 0.42 for Goss; 0.42 for Brass; 0.08 for Cube; and, 0.08 for Copper.

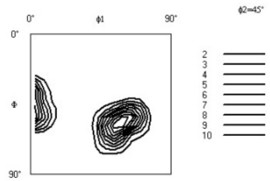
Number of variants with positive energy (U) for each austenite orientation

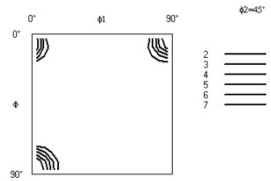
	Copper	Brass	Goss	Cube
Tension	12	14	8	8
Rolling	10	10	8	12





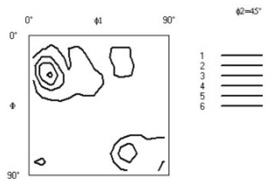


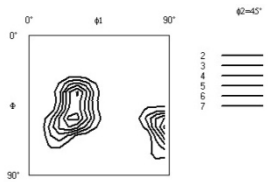


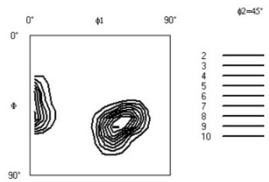


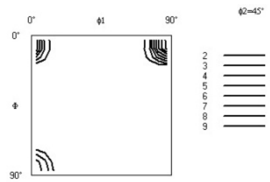
Tension test

Copper Brass Goss Cube



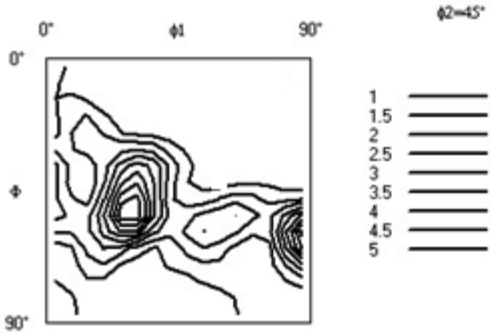


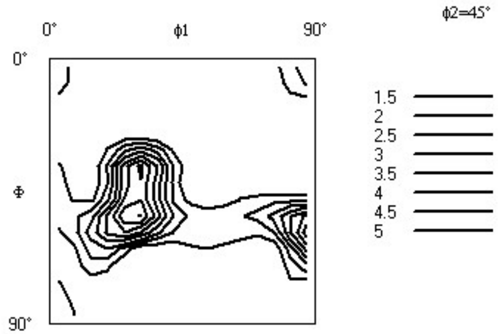




Cold rolled

Comparison between simulated and calculated from measured pole figures ODF´s

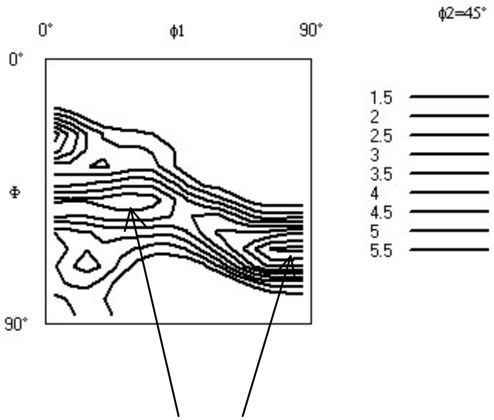




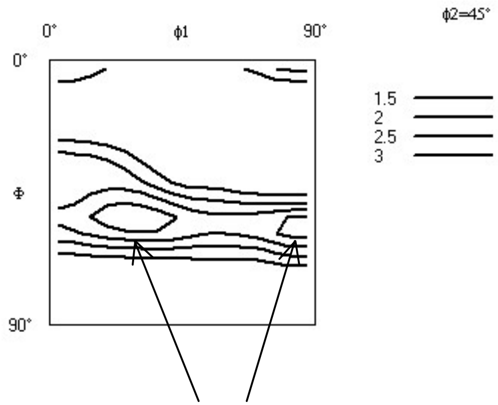
Predicted

Tension test

Cold rolled



{111} <112>



{111} <112>

Measured

Conclusion

- Transformation texture prediction following the phenomenological theory of martensite crystallography (PTMC) assuming cold rolled condition has been done. Variant selection was predicted following Paten and Cohen´s theory. Results concur with results published by Kundu that this theory works not only in uniaxial load but also in more complex loading conditions.

Acknowledgements

- We are grateful to the support from CNPq (National Council for Scientific and Technological Development), Project (301702/2008-0 and 450747/2010-7) and FUNCAP (Fundação Cearense de Apoio ao Desenvolvimento Científico e Tecnológico). We also would like to thanks to Sourabh Kundu from Tata Steel for his help with his software.