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TEXTURE EVOLUTION AND YIELD LOCI IN FERRITIC STEELS

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INTRODUCTION

Changes induced by different deformation paths in the texture and consequently, in the Yield Loci of ferritic steels are studied in this work. Crystalline rotations were predicted by using the classical Taylor Model assuming pencil glide deformations in grains (TPG)[1] and the viscoplastic model with {110}<111>, {112}<111> and {123}<111> crystallographic slip systems under the full constraints (VFC) and the relaxed constrains (VRC) Taylor assumptions[2].

Texture evolution and the corresponding Yield Loci were predicted for different deformation paths: rolling and rolling combined with equibiaxial expansion, plane tensile deformations, pure shear and uniaxial tensile tests. In the latter case, calculations take into account the plastic anisotropy of the steels, described by the contraction coefficient $q= -(E_{22}/E_{11})$.

TEXTURE PREDICTIONS

Texture evolution predictions for different deformation paths were performed considering:

- An initial isotropic set of 552 orientations for rolling simulation. In the case of combined paths, the rolling texture used in calculations was that corresponding to a deformation E=1.

- Viscoplastic texture simulations were performed using a strain rate sensitivity value m=0.05, which gives a low-rate sensitivity solution to the single crystal constitutive equation and minimizes the computation effort[3].

- Isotropic hardening in grains was assumed for texture and Yield Loci evolutions predictions.

RESULTS

Texture simulations show that VRC and TPG models give the best aggreement with experimental pole figures, which are obtained from our experiments (Al killed steel and AISI 409 stainles steel) and from literature. The most important results obtained in our calculations can be summarized as follows:

Rolling: Fig. 1 shows the calculated {110} Pole Figures (PF) for a thick reduction of 60% (E=1) using the TPG, VFC and VRC formulations. They are in agreement with the experimental {110} PF, Fig. 1.d, corresponding to an Al Killed Steel (AKS). Calculated texture can be associated to the {111}<uvw> and the {hkl}<110> fibers, presenting reinforcements around the orientations {111}<110>, {111}<112>, {100}<110> and {112}<110>. VRC presents the best agreeement with experimental PF. TPG formulation predicts an important reinforcement of the {111}<110> component, while the VFC description tends to reinforce the {112}<110> component (not observed in experimental PF). The latter description also has difficulties for the description of texture secondary components. Our VRC predictions are in agreement with those of Gilormini[4], even if we have obtained a less sharper distribution of orientations.

Rolling + Uniaxial Tensile Tests: Calculations were performed considering tensile tests along the rolling and transverse directions and the corresponding contraction coefficient values (q) associated to the stress states. Our experimental determinations of these coefficients show that, in the studied steels, their values can be considered as constants during the tensile test. Calculated and experimental textures present a good agreement, as it can be observed in Fig. 2.a-b for an AKS sample after a deformation of E=0.12 along the rolling direction of the sheet. PF were predicted using the TPG model. Related to rolling texture, a reinforcement of the {111}<110> texture component is observed. In the case of a tensile test along TD (E=0.33), the {111}<112> component is reinforced in the predicted PF (VRC formulation), Fig. 2.c.. This result is coincident with that corresponding to Arminjon[5].

Rolling + Biaxial Expansion: Comparing with rolling textures, predictions of texture evolution after a biaxial expansion test (E=0.25) show a reinforcement of the {111}<uvw> fiber component, specially around the {111}<112> orientation, and a diminution of the {hkl}<110> fiber, except for orientations placed near the {111}<110> and {100}<110> components. TPG model calculations give the sharpest values of the calculated pole densities[6].

Rolling + Uniaxial Compression: Calculations were performed considering a compression test along the rolling direction with a contraction coefficient q=0.6 and a total deformation E=0.33. Predictions indicate a reinforcement of the fiber {111}<uvw>, specially around the components {111}<112>. Particularly, the VRC model also predicts the existence of {hkl}<110> components placed near the {112}<110> orientation, Fig. 3.a.

Rolling + Pure Shear: Texture calculation for pure shear (q=1, E=0.25, rolling direction) shows a development of the {111}<uvw> fiber, specially in the case of TPG predictions, where a reinforcement of the {111}<110> and {111}<112> components can be observed, Fig. 3.b.

YIELD LOCI EVOLUTIONS

Fig. 4 shows the yield loci calculated using: a) the rolling texture simulated by using the VRC model (522 orientations) and b) the texture description of an AKS sheet given by the Orientation Distribution Function, which is obtained from experimental pole figures. These loci are in good agreement with experimental points and tangents obtained from tensile, compression and biaxial expansion tests[6].

Taking into account the isotropic hardening hypothesis, texture evolution can only alter the loci shape. Then, yield loci can be directly superposed in a κ representation in order to determine texture effects. In general, small changes in Yield Loci shape were determined for different deformation paths as biaxial expansion (E=0.25 and E=0.5) and uniaxial tensile and compression tests along the rolling and the transverse directions. As an example, Fig. 5.a shows the shape changes introduced by an uniaxial compression test along the rolling direction (E=0.33), which is related to the development of the fiber {hkl}<110> predicted by the VRC.

Another interesting case is that corresponding to the loci changes induced by pure shear deformation. In this case, Fig. 5.b, an increment of yield stresses in the first quadrant, specially for the region associated to q=0 (E_{22}=0) can be observed. This change in the locus shape, associated to the reinforcement of the {111}<uvw> texture components, benefits the performance during deep drawing operations[6].

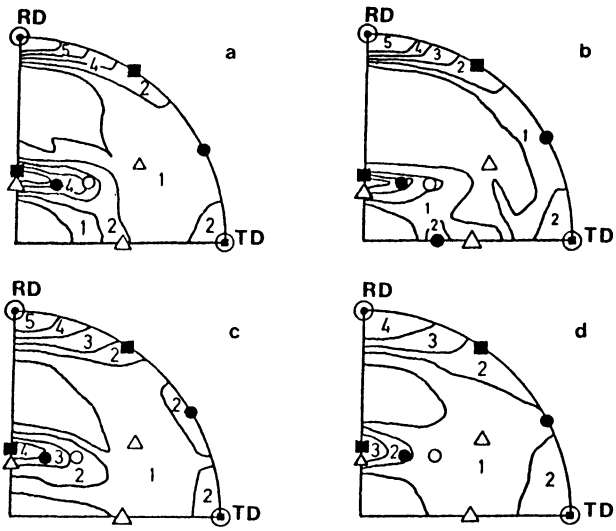
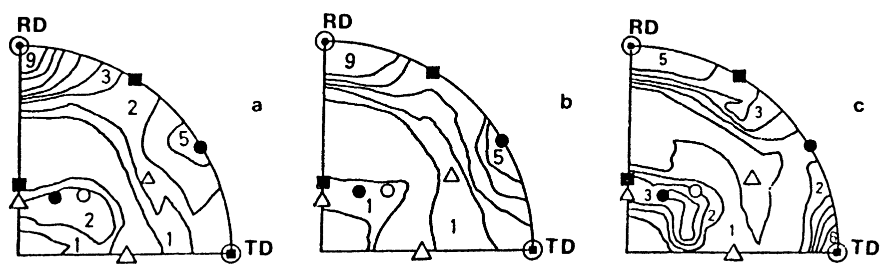


Figure 1: {110} Pole Figures for rolling (E=1), calculated using (a) VRC, (b) VFC, (c) TPG and (d) experimental (AKS).



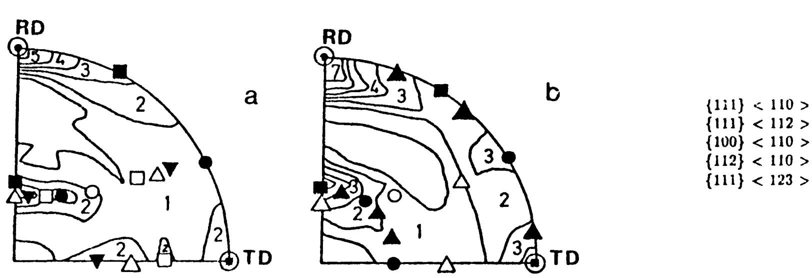


Figure 2: {110} P.F. for rolling (E=1) + uniaxial tensile test (a) along RD (E=0.12), TPG predictions and (b) experimental (AKS); (c) along TD (E=0.33) predicted by VRC.

Figure 3: {110} P.F. calculated for rolling (E=1) + uniaxial compression along RD (E=0.33 - VRC) and (b) rolling + pure shear (E=0.25 - TPG).

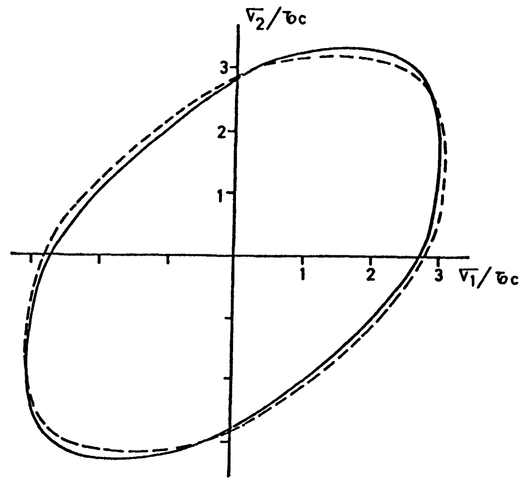


Figure 4: Yield loci (a) —— Calculated from rolling texture simulated by using VCR model (E=1), (b) ---- Calculated from the experimental rolling texture of an Al killed Steel.

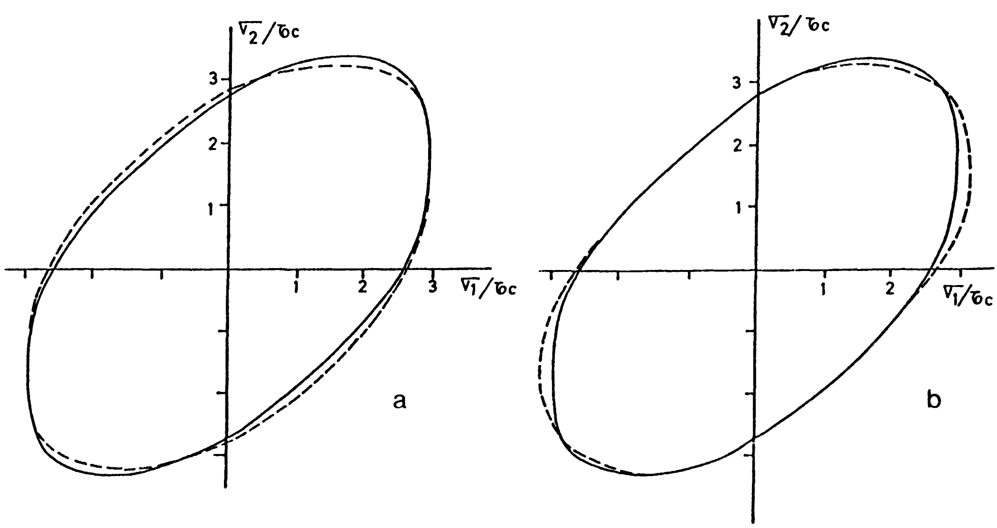


Figure 5: Yield loci evolutions related to rolling —— (VCR model E=1) (a) Compression along RD (E=0.33, VCR model), (b) pure shear (E=0.25, TPG model).

DISCUSSION

As it was mentioned above, texture evolution described by VRC and TPG presents the best agreement with experiments. Particularly, for heavy rolling reductions (E>1.), it was shown that the VRC model presents the best agreement[8]. A detailed study of the possible active slip systems and the activity on each one shows that in high strained grains the possible slip planes determined by the TPG tend to coincide with the crystallographic planes {123}, {112} and {110}, which are used in the VCR descriptions. As the activation of slip systems is low dependent of the strain rate sensitivity, the boundary conditions impossed in grains by the VCC model are responsible of the best texture predictions.

The fact that texture evolution under different deformation paths does not introduce significant changes in the shape of the predicted Yield Loci can be related: 1) to the facility for the accommodation of plastic deformation in grains by means of the {123}<111>, {112}<111> and {110}<111> slip systems (VRC model) or {hkl}<111> pencil glide (TPG description); 2) to the isotropic hardening of the analysed materials. Results of uniaxial tensile and compression tests in different directions of the sheet as well as those corresponding to equibiaxial expansion tests performed in the Al killed and the AISI 409 stainless steel show that the strain hardening coefficients present similar values.

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