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# TEXTURE AND YIELD LOCUS EVOLUTION IN 70/30 BRASS UNDER DIFFERENT DEFORMATION PATHS

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## ABSTRACT

Texture development and yield loci of 70/30 brass sheets deformed along different strain paths are calculated using a polycrystalline viscoplastic selfconsistent (VPSC) model. The VPSC model can be adjusted to obtain a single slip deformation pattern in polycrystal's grains. The comparison between predicted and experimental data makes possible to find the best choice for the CRSS of {111}<1$\bar{1}$0> slip systems and {111}<11$\bar{2}$> twinning systems. All samples exhibit an approximately isotropic plastic behavior and the shape of the calculated Polycrystal Yield Surface (PCYS) is closer to a von Mises ellipse than to a Tresca hexagon. Finally, the connection between calculated PCYS and the corresponding Forming Limit Diagrams (FLD) is discussed.

## INTRODUCTION

A great deal of research has been devoted to the analysis of the plastic behavior of fcc materials with low SFE and the origin of brass-type texture. Wasserman [1] explained the formation of brass-type texture as starting by a copper component which in a later stage rotates by twinning to the final Goss position. Based on an extensive analysis of the relation between texture and microstructure, Leffers and Juul Jensen [2] established that twinning plays an outstanding role as predominant microstructure feature in fcc materials with low SFE; they pointed out that when twin lamellae form at low and intermediate strains they are heterogeneously distributed forming clusters ("bundles") [3] that consist of a composite of twin lamellae and untwinned matrix. Generally, these bundles are parallel to a given {111} plane, so the grains containing bundles predominantly deform by slip on one single slip plane, the one parallel to the bundles. Based on this evidence, Leffers [4] was able to calculate a brass-type texture with a using a "modified Sachs" model. In the present work, texture development and plastic behavior of materials having a single slip deformation pattern are calculated using a selfconsistent (SC) formulation.

## DETAILS OF THE CALCULATION

Selfconsistent models had been originally conceived to deal with plastically anisotropic materials, for which Taylor hypothesis of equal strain in every grain did not apply. A fully anisotropic viscoplastic selfconsistent (VPSC) model have been recently proposed [5]. The fundamental relation of the VPSC model is the *interaction equation*:

$$\tilde{\dot{\epsilon}} = -\tilde{\mathbf{M}}\ \tilde{\sigma}' \qquad (1)$$

where $\tilde{\dot{\epsilon}} = \dot{\epsilon} - \dot{E}$ and $\tilde{\sigma}' = \sigma' - \Sigma'$ are the strain rate and stress deviations in a given grain with respect to the corresponding macroscopic magnitudes; $\dot{\epsilon}$, $\sigma'$ and $\dot{E}$, $\Sigma'$ are strain rate and deviatoric stress in the grain and in the polycrystal, respectively. The *interaction tensor* $\tilde{\mathbf{M}}$ is obtained through the expression:

$$\tilde{\mathbf{M}} = n\ (I - S)^{-1} S\ \mathbf{M}^{(sec)} \qquad (2)$$

where S is the *viscoplastic Eshelby tensor* [5] $\mathbf{M}^{(sec)}$ is the *polycrystal secant modulus* and "n" (>>1) is the viscoplastic exponent, an adjustable parameter of the rate sensitive equation which describes the shear rate in each deformation system as a power of the resolved shear stress in such system. It is evident from equations (1-2) that for a high "n", the stress deviation diminishes and the model predicts a plastic behavior close to the lower-bound. In another context, Molinari et al. [6] have used an *external* adjustable parameter to vary the strength of the grain-matrix interaction. Nevertheless, in our case the viscoplastic exponent is an *intrinsic* parameter of the interaction equation.

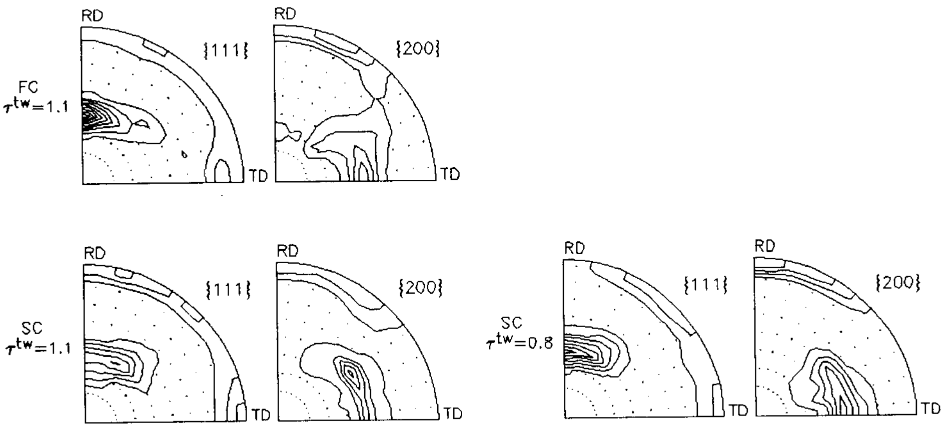


Figure 1: Calculated rolling textures (86% thickness reduction) of a fcc material. FC and SC cases (with VFT scheme) for different sets of critical stresses for {111}<1$\bar{1}$0> slip and {111}<11$\bar{2}$> twinning. Lines: multiples of random distribution (mrd). Points: region bellow 1 mrd

Calculations of texture development in materials that exhibit twinning activity (as in the case of brass) also require an appropriate model for dealing with crystal reorientations associated with twin formation. Twinning reorientation is treated in this work by means of the Volume Fraction Transfer (VFT) [7] scheme which allows to keep track of the exact twinned volume by keeping constant the number of orientations along the calculation.

Predictions for brass rolled up to 86% thickness reduction can be seen in figure 1. The best agreement with brass-type texture is obtained calculating with VPSC model (n=47) using the set of critical stresses: $\tau^{slip} = 1.0$, $\tau^{twin} = 1.1$. Neither the FC calculation nor the use of the VPSC model with a different set of CRSS ($\tau^{twin}/\ \tau^{slip} = 0.8$, employed by van Houtte [8]) give acceptable results. If the texture of a given sample is known, a polycrystalline model for texture development can be adapted to the calculation of the PCYS (Canova et al. [9]). In the next section, texture development and PCYS of 70/30 brass samples deformed along different strain paths are calculated using the VPSC formulation.

## RESULTS AND DISCUSSION

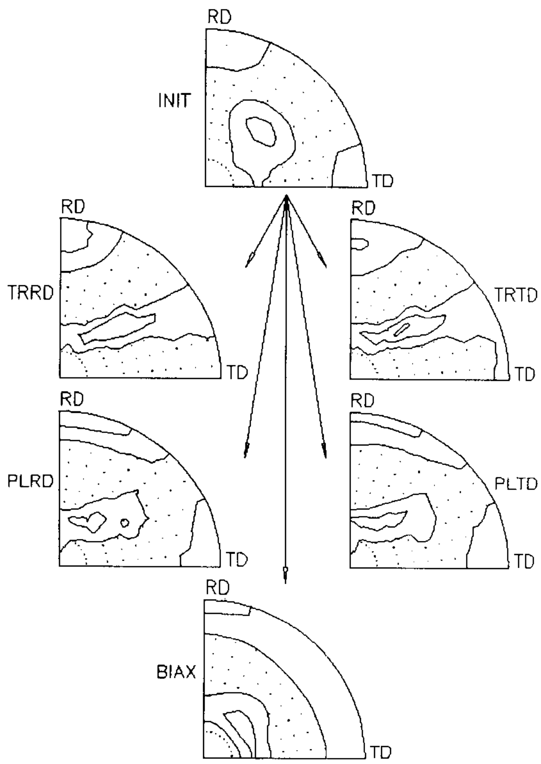


**Figure 2: Predicted {111} poles figures for 70/30 brass samples deformed along different strain-paths, starting from an annealed sheet (INIT). VPSC model is used with $\tau^{twin}$ / $\tau^{slip} = 1.1$. Lines: multiples of random distribution (mrd). Points: region below 1 mrd.**

Starting from an annealed sheet (INIT), 5 samples were deformed –between 22% and 26% true strain– under: uniaxial tension along RD (TRTD) and TD (TRTD), plain-strain tension along RD (PLRD) and TD (PLTD) and biaxial tension (BIAX). The crystallographic textures of these samples were measured by neutron diffraction [10]. figure 2 shows the {111} pole figures obtained with the VPSC model. Experimental and predicted and results show good agreement.

The PCYS of the annealed sample (INIT) is calculated using the FC and VPSC models for different sets of CRSS's (figure 3). The theoretical results are compared with some measured points (X: yield stress (YS) in a TRTD test, Y: YS in a TRTD test and B: YS in a BIAX test) and tangent lines (R: YS in a PLRD test) and (T: YS in a PLTD test) of the yield loci [10]. The curves in figure 3 are normalized and to a value of 1 for the YS in a TRRD test.

It can be seen that: a) the experimental yield locus is approximately isotropic, closer to the Tresca than to the von Mises criterion; b) predictions for $\tau^{tw} = 0.8$ do not agree with experimental data, specially in the FC case; c) the best agreement between predicted and experimental data (X, Y and B) is given by the SC case for $\tau^{tw} = 1.1$. In this case, the predicted PCYS is close to an isotropic Von Mises ellipse. d) For plain-strain tension (lines R and T) predicted results (even in the best SC case) do not agree with experimental data.

Assuming that the best agreement between predicted and experimental results for texture development and PCYS is obtained with the SC model for set of critical stresses: $\tau^{slip} = 1.0$, $\tau^{twin} = 1.1$, the PCYS of the five deformed samples are calculated with this model and parameters. Figure 4 shows that all the predicted PCYS are quite similar, the greatest difference is observed between TRRD and TRTD, while the others yield surfaces fall in between. Table 1 shows the characteristic points of the predicted PCYS. Regarding points X and Y for TRRD and TRTD samples in table 1, it can be seen that X/Y(TRRD)>1 and X/Y(TRTD)<1. This means that, for both cases, a *geometric hardening* is predicted as a consequence of texture development.

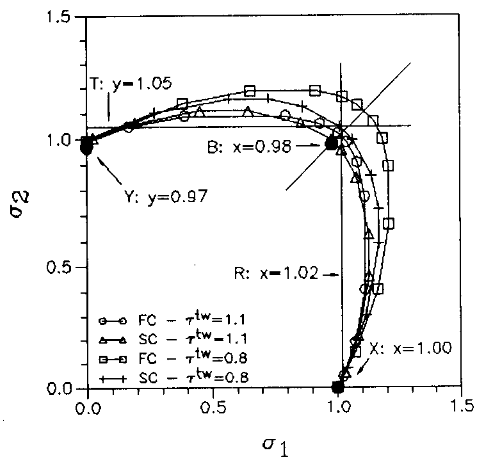


Figure 3: PCYS for the annealed sample (INIT) calculated under FC and VPSC model, with $\tau^{twin} / \tau^{slip} = 1.1$ and $\tau^{twin} / \tau^{slip} = 0.8$. Experimental data are superposed.

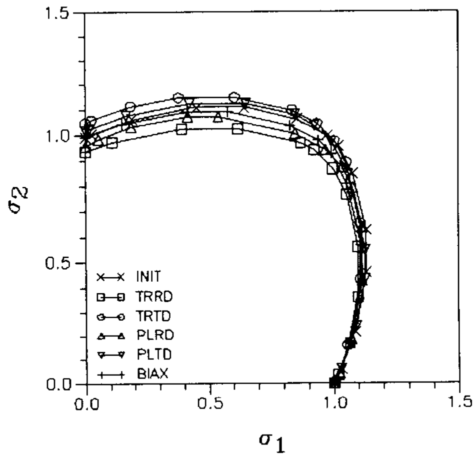


Figure 4: PCYS for brass samples deformed along different stain-paths, calculated under VPSC model, with $\tau^{twin} / \tau^{slip} = 1.1$.

| | INIT | TRRD | TRTD | PLRD | PLTD | BIAX |
|---|---|---|---|---|---|---|
| X | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Y | 0.99 | 0.94 | 1.05 | 0.96 | 1.02 | 0.99 |
| R | 1.13 | 1.10 | 1.11 | 1.11 | 1.13 | 1.11 |
| T | 1.11 | 1.03 | 1.15 | 1.07 | 1.12 | 1.10 |
| B | 0.99 | 0.93 | 0.99 | 0.96 | 0.98 | 0.96 |

Table 1: Characteristic points of the predicted PCYS of brass samples deformed along different strain paths

As in the annealed case, the calculated PCYS of deformed brass samples look like Von Mises ellipses. Table 2 shows the relative values of predicted and experimental [10] yield stresses: R/X, T/Y and B/X for PLRD, PLTD and BIAX samples, similar ratios for the Tresca and Von Mises criteria are included.

| | PREDICTED | EXPERIMENTAL | VON MISES | TRESCA |
|---|---|---|---|---|
| R/X | 1.11 | 1.03 | 1.15 | 1.00 |
| T/Y | 1.11 | 1.06 | 1.15 | 1.00 |
| B/X | 0.96 | 0.98 | 1.00 | 1.00 |

Table 2: Predicted and experimental relationships between yield stresses

It is interesting to discuss the connection between the PCYS predictions and the associated Forming Limit Diagrams (FLD). The Marciniak-Kuczynsky (MK) model [11] is extensively used for FLD calculations in the region of positive deformations. The MK prediction are very dependent of the the yield locus. In a previous work [10] the Hosford equation [12] has been used for the calculation of FLD with the MK model:

$$\sigma_1^a + \sigma_2^a + R(\sigma_1 - \sigma_2)^a = (R+1)\sigma_{eq}^a \qquad (3)$$

where R is the average Lankford coefficient, $\sigma_{eq}$ is the equivalent stress and "a" is an adjustable exponent. Hosford's equation reduces to von Mises for a=2 and R=1 and it approaches Tresca for high values of "a". Vial-Edwards and Penelle [10] have shown that the best agreement between predicted and experimental FLD for annealed brass was obtained with a=8 in Hosford's equation. In other words, the actual material behaves close to Tresca criterion that to von Mises. On the contrary, it is evident (figure 4 and tables 1 and 2) that the calculations based on polycrystalline models systematically predict PCYS closer to a Von Mises ellipse than to a Tresca hexagon.

## CONCLUSIONS

1) Better agreement between predicted and experimental data, concerning both texture development and PCYS calculations, was obtained when VPSC model was used to obtain a single slip deformation pattern, with a high value of the viscoplastic parameter "n".

2) The predicted PCYS of brass samples deformed along different strain-paths showed little changes with respect to the initial annealed sheet. Samples tested in tension along TD and RD are limit cases. A geometric hardening is predicted in both cases.

3) Predicted PCYS obtained by means of polycrystalline models have elliptical shapes, equivalent to a low "a" exponent in Hosford equation. This fact do not coincides with the better agreement between experimental and predicted FLD when the MK model is used together with a Hosford's yield criterion employing a high "a" exponent.

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