EVOLUTION OF ANISOTROPIC STRESS FACTORS WITH TEXTURE IN THE BIAXIAL DEFORMATION OF HSLA50 STEEL

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ABSTRACT The effects of crystallographic texture produced by biaxial deformation on the diffraction elastic constants (DEC) are discussed. Predictions of DEC values from established and new models of grain interactions are compared with experimental data. The effect of preferred orientation on the DEC is discussed in terms of the ODF intensity and single grain stress factors along these orientation fibers.

INTRODUCTION: X-ray diffraction measurement of applied stress during biaxial deformation offers the possibility to determine stress-strain curves for different biaxial strains and strain paths that are of great interest to the forming community. However, a diffraction stress measurement is contingent upon the diffraction elastic constants (DEC) that relate the measured lattice strains to the applied macroscopic stress. It was found that for steels no existing theory or experimental data set was sufficiently accurate in describing these elastic constants which, because of preferred orientation, depend critically both on the direction and on the magnitude of plastic strain. This problem was solved through a three-pronged effort: Measurement of DEC, measurement of preferred orientation, and modeling of DEC using the texture data.

PROCEDURES, RESULTS AND DISCUSSION: For biaxial deformations ranging from 10% to 30 % strain that included balanced biaxial, plane strain in RD and plane strain in TD; tensile samples were cut from the deformed sheet in a RD and a TD orientation. Diffraction elastic constants were then measured over a tilt range of ±45° at azimuth angles of 0° (tilt in ND-RD plane) and 90°(tilt in ND-TD plane), and for different applied stresses. This allowed the determination of the stress factors which are the slopes (linear dependence) of the lattice strain vs. applied macro-stress curves for a specific azimuth and tilt angle. Preferred orientation was measured for each deformation stage using the BT8 diffractometer at the NIST Center for Neutron Research. The results in the form of complete pole figures were used to determine the orientation distribution function (ODF) which is needed to calculate weighted averages of the diffraction elastic constants (DEC). The (211) lattice spacings are shown for different levels of applied stress in Fig. 1, left. Fig. 1, right shows how the stress factors are obtained for a fixed tilt angle ψ by determining the slope $(d-d_0)/d_0$ over the applied stress.

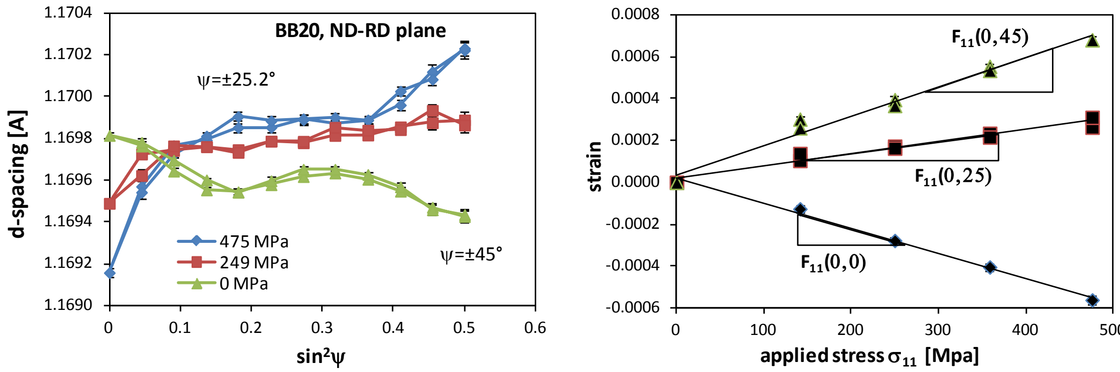

Fig. 1. Left: lattice spacings d vs. $\sin^2\psi$ for a sheet previously strained to 20 % in equi-biaxial mode. Right: Stress factors for different tilt angles in the ND-RD plane.

The non-linear $d(\sin^2\psi)$ in Figure 1, left, is caused by elastic anisotropy and it represents a stark contrast to the classic assumption of linear dependence of the lattice spacing on $\sin^2\psi$ even when subtracting the effects of intergranular strains expressed through $d(\sin^2\psi)$ at zero stress. This is not to be confused with the stress factors in Figure 1, right, which are derived from linear elastic strain-stress behavior. The overall behavior of the DEC for HSLA50 is compiled in Figure 2.

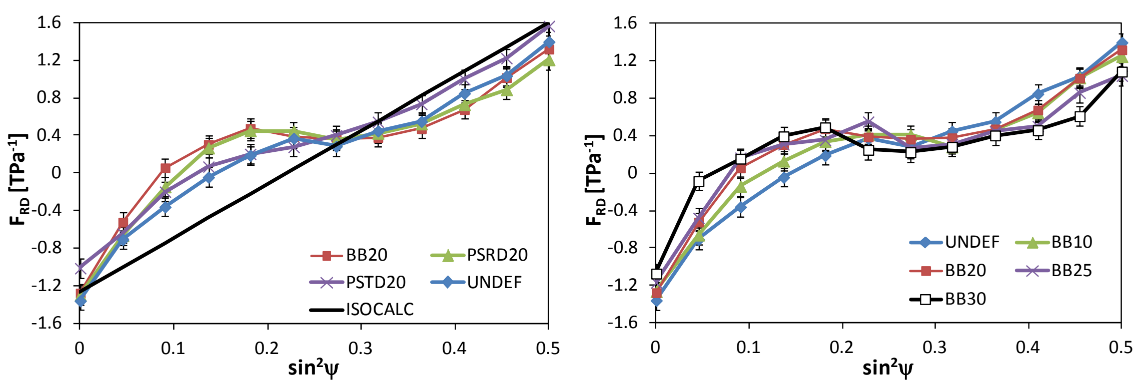

Fig. 2. Stress factors $F_{11}=F_{RD}$ for different modes of biaxial deformation at 20 % strain (left) including plane strain along RD (PSRD20), along TD (PSRD20) and in equi-biaxial mode (BB20). Right: Stress factors $F_{11}=F_{RD}$ for increasing levels of strain in equi-biaxial mode (right) ranging from as received (UNDEF), 10 % strain (BB10) to 30 % strain (BB30). The label ISOCALC refers to a calculated isotropic-elastic model without preferred orientation.

While the overall changes follow qualitatively the same trend for the plane strain modes and equi-biaxial modes (Figure 2, left) it is also clear that increasing magnitudes of plastic strain amplify certain characteristics in $F_{11}(\sin^2\psi)$. What these characteristics are can be gleaned from the ODF intensities along the orientation fibers **m** || [hkl] with **m** as the direction of the measurement in the sample system and [hkl] as the lattice plane normal. The ODF was obtained using the MTEX package [Hielscher & Schaeben, 2008]. The comparison with the linear model (ISOCALC) shows that the tilt angles ψ=0°, ψ=25°, and ψ=40° are the most suitable directions for the comparison shown in Figure 3.

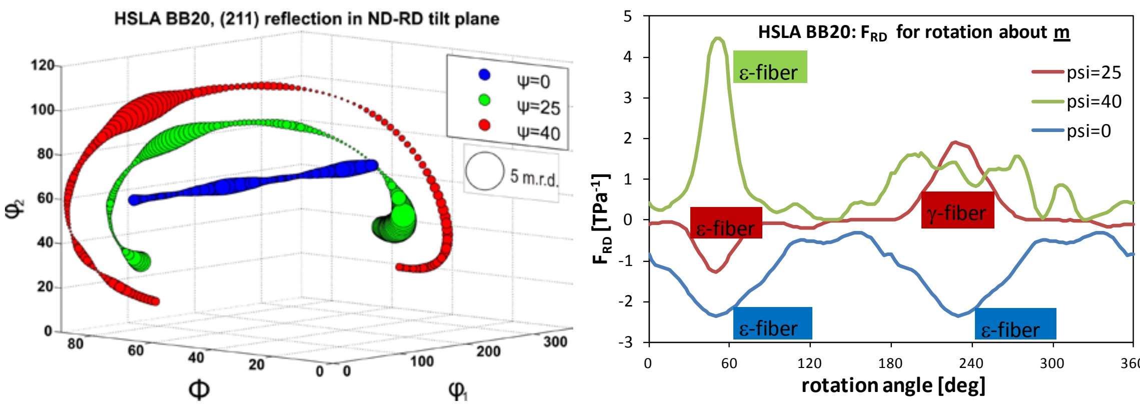

Fig. 3. Left: OD intensity along fibers **m** || [211] for **m**=[φ=0,ψ=0], **m**=[φ=0,ψ=25] and **m**=[φ=0,ψ=40]. Right: Weighted single grain stress factors for the orientations [φ_1,Φ,φ_2] given on the left but here expressed as rotation angle about [hkl] using the inverse Kröner model in the IsoDEC program [Gnäupel-Herold *et al.* 2011a, 2011b].

The two prominent texture components appearing in the stress factors are the ε- and γ-fibers. This is true for all sample investigated here because the combinations of tilt and azimuth angles are the same for all samples. As seen in the peaks of the weighted single grain stress factor curves (Figure 3, right), both the relative strength and the sharpness in Euler space of the ε- and γ-fibers matter. These parameters vary depending on the deformation mode, thus affecting the average over the single grain stress factors. This average, in turn, corresponds to the measured stress factors shown in Figure 1 and 2.

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