PLASTIC ANISOTROPY OF TRIP-AIDED STEEL SHEETS INDUCED BY PRESTRAINIG

ПЛАСТИЧЕСКАЯ АНИЗОТРОПИЯ СТАЛИ *TRIP* ПОСЛЕ ДЕФОРМАЦИИ

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Abstract:
Mechanical anisotropy in terms of texture evolution and transformation hardening of TRIP-aided steel sheets can be caused by plastic pre-straining. The influence of the specimen orientation on anisotropy was studied in two-step tensile tests by reloading tensile specimens oriented at different angles with respect to the initial tensile direction. The texture evolution and plastic strain ratio were determined for different biaxial states of deformation. The results show that the sheets prestrained to 10 % exhibit strongly altered mechanical properties. The anisotropic flow behavior cannot be attributed only to the texture changes, because of the masked influence of the strain-induced retained austenite to martensite transformation on microstructure development in such sheet material.

KEYWORDS: PRESTRAINING, TEXTURE EVOLUTION, MECHANICAL ANISOTROPY, TRIP-AIDED

1. Introduction

Low alloyed TRIP-aided multiphase steels are developed as high-strength thin sheets, particularly suitable for deep drawing applications, because of their high ductility and low planar anisotropy of the mechanical properties ($R_{p0.2}$~ 500 MPa, U.T.S.~1000 MPa, U.E.~25 %) [1-3]. Recent investigations showed that a large pre-strain leads to an orientation sensitivity of properties [1]. During stepwise forming operations with changing strain-paths, a characteristic deformation texture develops and retained austenite transforms to martensite, usually being assumed to control the anisotropic flow behaviour of prestrained TRIP-aided steel sheets. Both effects were investigated in detail by correlation of the microstructural changes with the *r*-values used in practice to characterise sheet anisotropy.

2. Experimental

The microstructure of the investigated cold-rolled TRIP-aided steel sheet (thickness 1.33 mm) consists of a fine grained ferritic-bainitic matrix and about 14 vol. % metastable retained austenite (Fig. 1a), which transforms to martensite during sheet forming [1- 3].

The initial $\{001\}<1\bar{1}0>$ texture of the cold-rolled sheet (Fig. 1a) changes during uniaxial pre-straining to strains ε_1 up to 10% applied in the transverse direction, i.e. ε_1 is perpendicular to the rolling direction of the sheet, Fig. 2a. Apart from the symmetric central peaks of the $\{001\}<1\bar{1}0>$ component, regions of enlarged pole density near $\{332\}<\bar{1}\bar{1}3>$ and $\{772\}<\bar{1}\bar{1}7>$ are detected (Fig. 2b).

From the pre-strained sheet, secondary tensile specimens were cut with their axis inclined 0°, 22.5°, 45°, 67.5° and 90° to the direction of prestraining (Fig. 2a). A mesh grid etched on the specimen surface enabled the determination of the local effective strain after the secondary tensile tests [1]. The deformation texture after secondary deformation was determined for each angle θ for a uniform effective strain of 23 %. The retained austenite to martensite transformation as a function of strain was monitored as reported in [1].

The *r*-values were determined for each specimen as the width-to-thickness strain increment ratio and were compared with those calculated from the texture data by means of the full constraints model with the method described in [4].

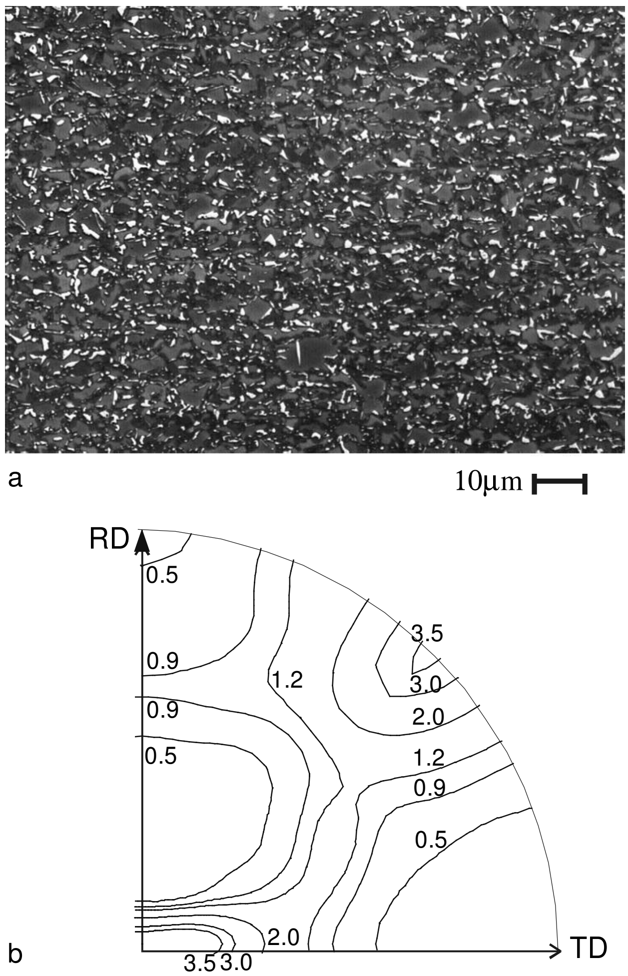

Figure 1. Microstructure of the TRIP-aided steel sheet: ferritic-bainitic matrix (dark) and retained austenite (white) (a). Calculated (002)-pole figure of the as-received material; RD-rolling direction, TD-transversal direction (b).

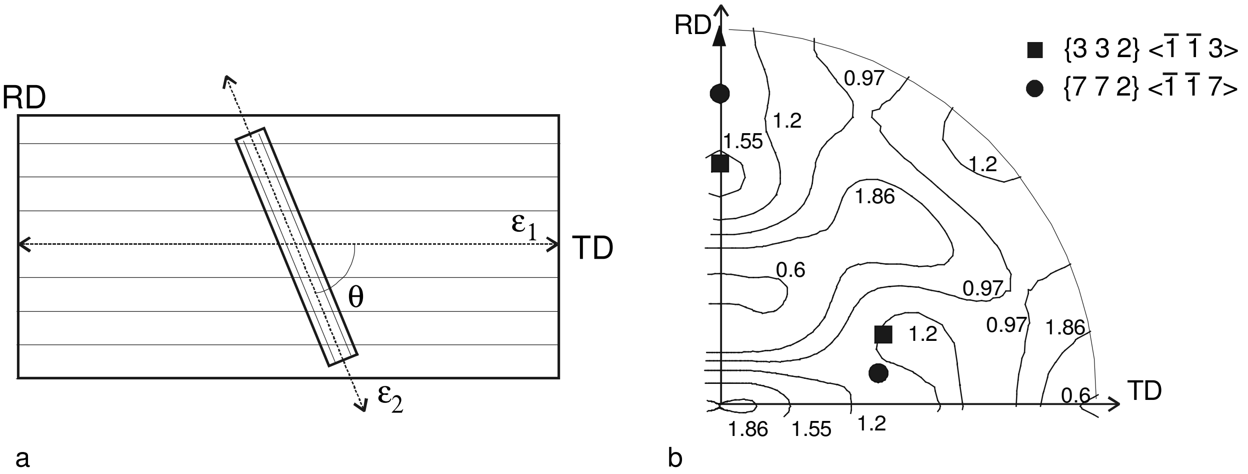

Figure 2. Prestrain direction ε_1 || TD and the orientation of a secondary tensile direction ε_2 (a) with calculated (002)-pole figure for $\varepsilon_1 = 10\%$ (b).

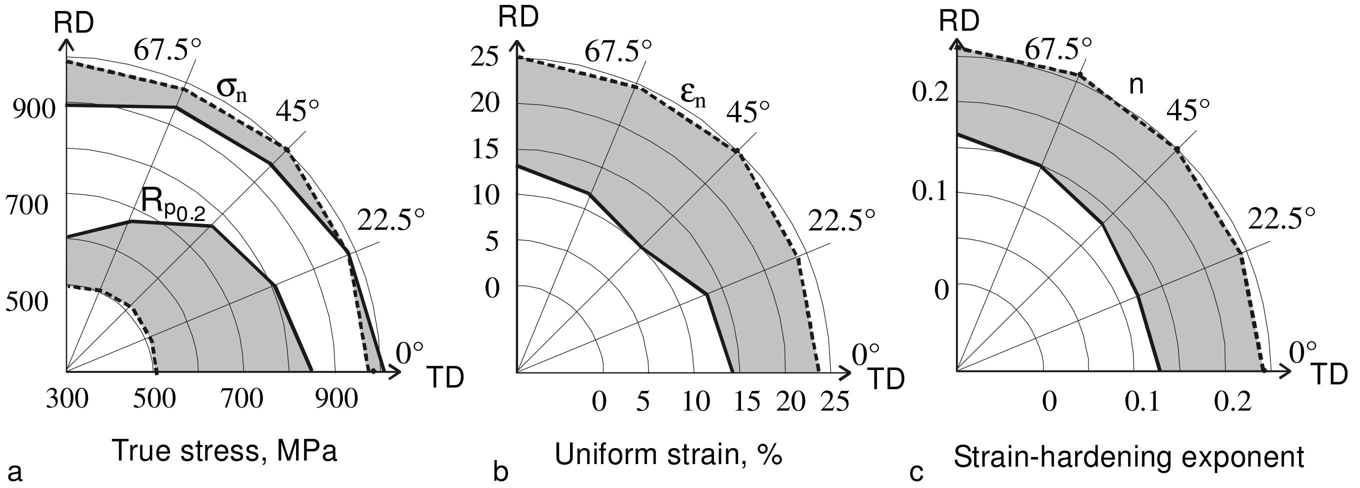

Figure 3. Orientation dependence of the yield stress $R_{p0.2}$ and true ultimate stress σ_n (a), necking strain ε_n (b) and strain-hardening exponent n (c) for the as-received sheet (dotted line) and for the pre-strained sheet (solid line). The shaded regions show the decrement/increment of the respective tensile values.

3. Results and discussion

Figure 3 shows the effect of in-plane uniform straining on the tensile properties of TRIP-aided steel sheet, i.e. a large increase of the yield stress $R_{p0.2}$, a drop of the strain hardening exponent $n_{15\text{-}20}$ and, consequently, a lower uniform elongation U.E. r (θ) – values of 0.8÷1.0 are typical for TRIP-aided steels (Fig. 4). After 10% of prestraining, *r* deviates from the initial values (a solid line) only at $\theta = 0°$ and 90°.

$R_{p0.2}$ reveals the largest orientation sensitivity, probably attributable to the transformation characteristics of the retained austenite, leading to a path strain-dependent dislocation substructure (Fig. 3a). The volume fraction of retained austenite was determined by magnetic measurements as a function of effective plastic strain for each tensile orientation θ (Fig. 5). These results point out the orientation dependence of the amount of retained austenite transformed to strain induced martensite.

In two-step tensile loading to a total effective strain of 23 % different biaxial states of deformation are realized, with grain rotations being a function of the tensile direction. The respective texture analysis is presented in Fig. 6. The orthorhombic texture is preserved during secondary straining with ε_2 // ε_1 and $\varepsilon_2 \perp \varepsilon_1$ ($\theta = 0°$ and 90°, respectively), both textures revealing a strong $\{332\} < \bar{1}\bar{1}3 >$- component. All other orientations of the tensile axis with respect to the direction of pre-straining lead to complicated pole figures, showing approximately the $\{557\} < 0\bar{1}1 >$ texture maxima.

The analysis of orientation distribution functions enables the recalculation of the *r*-values from the texture data (Fig. 7). After 10% prestraining the intensity of the rotated cube ($\{001\}\langle 110\rangle$) texture component, which has detrimental effect on deep-drawability, decreases from × 16 (Fig. 7a) to × 3.2 (Fig. 7b) and equalises with the intensity of the $\{332\}\langle 112\rangle$ component that has positive effect on the r -value.

A model prediction of the r-values based on the texture is shown in Fig. 7c. The texture based model predicts very low r-values for orientations close to RD and TD which differs drastically from the experimental results (cf. Fig. 4) because the transformation induced plasticity effect has a significant contribution to the deformation. The contribution of the above mentioned effects to the plastic anisotropy of the TRIP steels could be better evaluated by means of EBSD measurement.

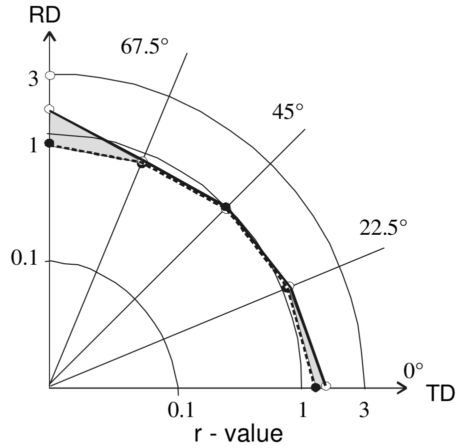

Figure 4. r – value for the as-received sheet (dotted line) and for the 10% pre-strained sheet (solid line).

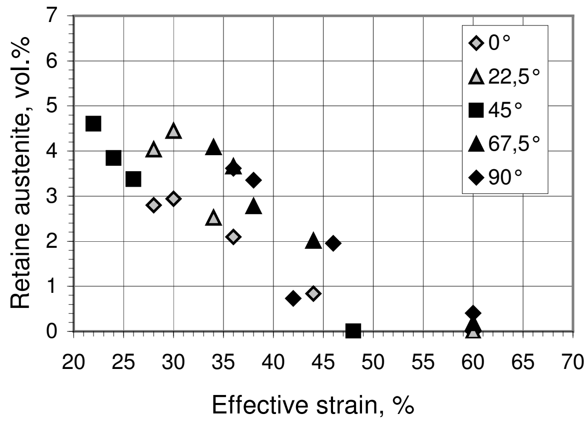

Figure 5. Content of retained austenite as a function of the effective strain for differently oriented secondary tensile specimens.

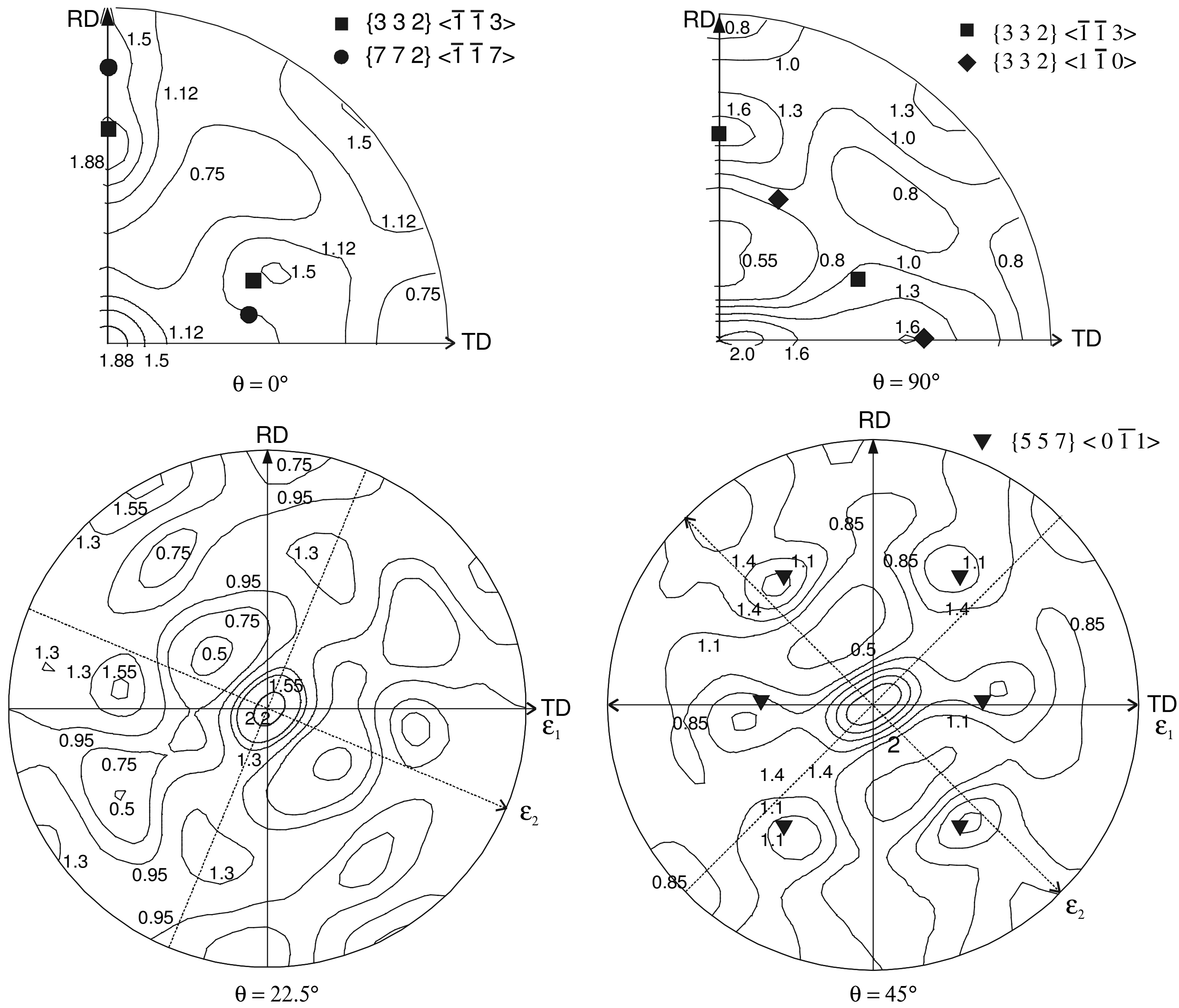

Figure 6. Calculated (200)-pole figures for the same effective strain ε(θ) = 23 %, in dependence of the secondary tensile direction θ.

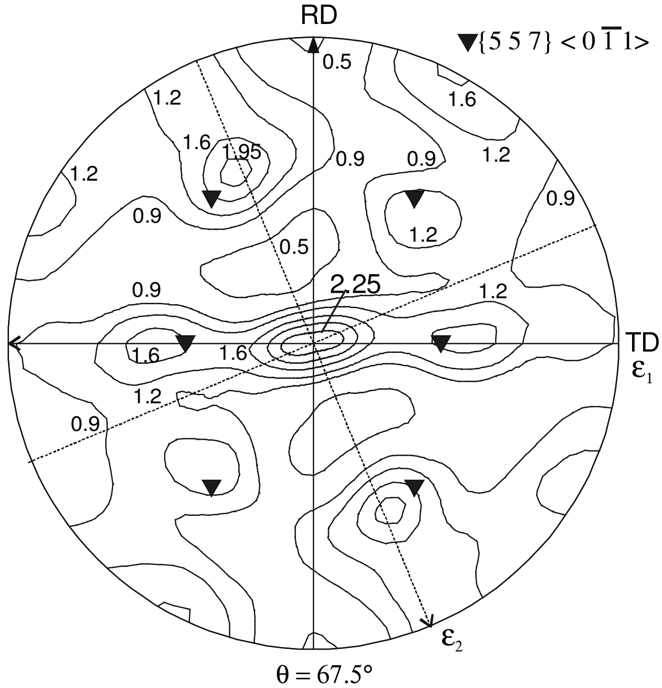

Figure 6. continued.

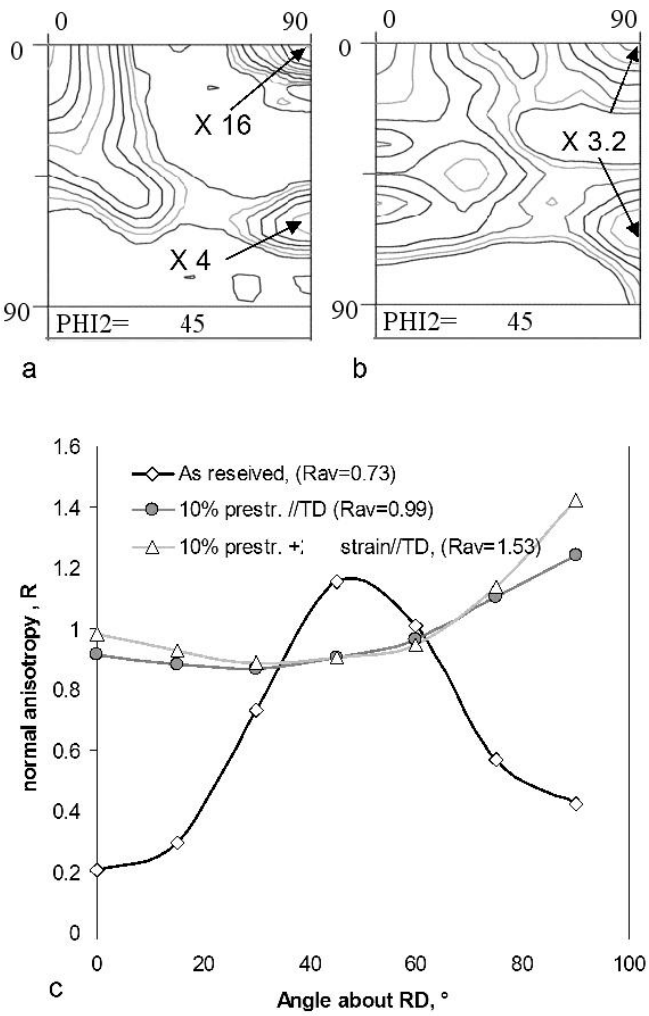

Figure 7. ODF of the as received material (a) and after 10% prestraining //TD (b); (c) Changes in the r-value in the as received and prestrained steel (texture based model prediction)

5. Conclusion

Despite their relatively small r-value of around 1, multiphase TRIP-steels are well suited for deep drawing and stretch forming operations, due to their low mechanical anisotropy. Prestraining of sheets induces an anisotropic flow behaviour caused by the interplay of texture development and strain-induced martensitic transformation. These effects are subject of further investigations [5].

6. Acknowledgements:

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7. References

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