

Large-strain Bauschinger effect in austenitic stainless steel sheet

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ABSTRACT

Large-strain Bauschinger effect in cold-rolled austenitic stainless steel sheet is investigated after large amounts of prestrain. The material is prestrained in uniaxial tension, and the tensile properties of the prestrained material are measured in different angles with respect to the prestraining direction. By comparing the differences in the yield stresses in different orientations, the effect of prestraining on material anisotropy is studied. The method is applied to AISI 304-type stainless steel sheet. The test results are analyzed using a combined isotropic–kinematic hardening model. The results indicate that this kind of material shows a considerable Bauschinger effect. Transient and permanent softening is observed in the experiments. The experimental Young's modulus also seems to decrease with prestrain.

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1. Introduction

Austenitic stainless steels are finding new applications in telecommunication and mobile devices. The components are fabricated from cold-rolled precision-strip sheets using progressive dies and transfer presses. In the process, the work-piece material may experience strain-reversals. Consequently, numerical simulation of these complex stamping processes requires accurate modeling of stress–strain responses during stress reversal [1,2]. Therefore, there is a need for information on large-strain cyclic behavior of thin cold-rolled austenitic stainless steel sheet metal.

Despite the great interest to cyclic plasticity of metals, most of the discussion deals with the small strain behavior of bulk materials. Information on large-strain behavior of sheet metals, and especially on austenitic stainless steels, is scarce. In the present work, large-strain Bauschinger effect in cold-rolled austenitic stainless steel sheet is studied. In the experimental procedure, first proposed by Szczepinski and Miatkowski [3], the material is prestrained in uniaxial tension using wide tensile test specimens. After prestraining and unloading, the tensile properties of the prestrained material are measured in different angles with respect to the original prestraining direction. By comparing the differences in the uniaxial tensile yield stresses in different orientations in the prestrained materials, the effect of prestraining on material

anisotropy can be studied. The test method is not limited to small strains, and it is applicable also to thin precision-strip samples. An AISI 304-type austenitic stainless steel sheet is considered in the present study.

2. Experimental

The test material was AISI 304-type austenitic stainless steel sheet with a commercial name Outokumpu 4301. The surface finish grade of was 2B, sheet thickness 1.24 mm and the ASTM grain size number was 8. The chemical composition of the tested material is given in Table 1.

The test procedure consisted of two distinct phases. First large samples of the test material were prestrained in uniaxial tension in the rolling direction to four different elongation values ranging from 3% to 20%. The achieved prestrain was determined using an etched circular grid having a diameter of 8 mm. After prestraining, uniaxial tensile tests were conducted to determine the stress–strain curves in the rolling (RD) and transverse (TD) directions. The average of two or three measurements was used as a representative value for each prestrain. Both prestraining and the tensile tests were conducted according to the specifications of EN10002 using the straining rate of 0.5%/min. A plasma cutting method was used in the preparation of both the wide prestraining specimens and the test pieces. Natural (Hencky) strain was used for measuring the strain and Cauchy stress values for measuring the stress.

For materials, which do not exhibit a sharp knee at yield, the definition of plastic yield is troublesome as different yield surfaces

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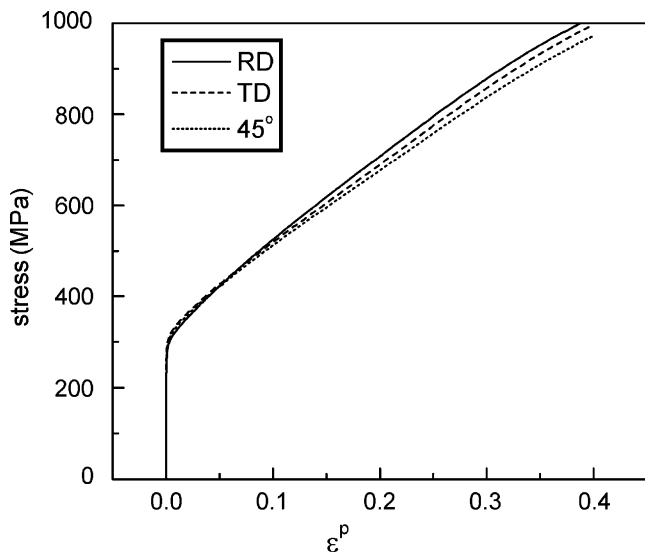


Fig. 1. Tensile test results in the initial state.

Table 1
Chemical composition of the tested material (wt.%)

Cr	Ni	Mn	Si	C	N
18.20	8.20	1.50	0.45	0.04	0.02

result from different definitions [4]. In the present work, the definition of yield was based on the plastic offset strains of 0.1% and 0.2%.

3. Results

The tensile test results measured in the initial state are shown in Fig. 1. The stress–strain curves exhibit a smooth transition from the elastic region to the elastoplastic region, which is characteristic to austenitic stainless steels. The scatter diagram in Fig. 2 shows that there is a strong linear correlation between the flow stress val-

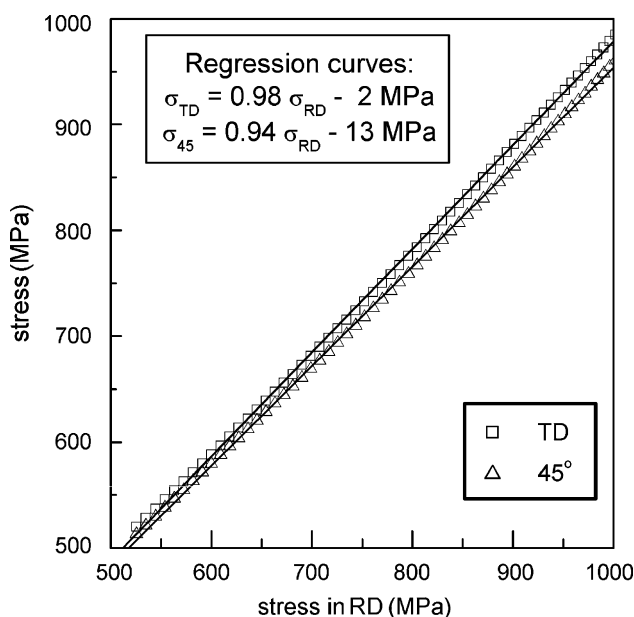


Fig. 2. Scatter diagram of tensile test results in the initial state. Lower part, influenced by the initial transient, is removed.

Table 2
Proof stress values (MPa) and r -values measured in the initial state

	Rp0,1	Rp0,2	Rp1,0	Rp2,0	r
RD	275	292	322	345	0.89
TD	293	304	332	353	0.88
45°	286	298	328	350	1.04

ues measured in different directions. The proof stress values given in Table 2, however, do not reflect the overall trend in Fig. 2. Consequently, the proof stress values are poor indicators of the mild anisotropy of the material in the as-received state.

Results for the prestrained material in Fig. 3 show typical transient Bauschinger effect [5] with transient and permanent softening. After prestraining in the RD, the yield stress is lower in the TD than in the RD. Furthermore, the early yielding with smooth elastic–plastic transition is followed by rapid work hardening. It is also observed the stress–strain curves in the TD do not saturate to the monotonic loading curve, leaving a permanent offset. The offset, called permanent softening, evidently depends on the equivalent plastic strain. The size of the permanent softening $\Delta\sigma$ can be approximately described with the parabola

$$\Delta\sigma = -\frac{C\bar{\epsilon}^p}{0.09}(\bar{\epsilon}^p - 0.6), \quad \bar{\epsilon}^p \leq 0.4, \quad (1)$$

where $\bar{\epsilon}^p$ is the equivalent plastic strain. The peak value C , attained at $\bar{\epsilon}^p = 0.3$, equals to $C = 55 \pm 5$ MPa. It is also worth noting that no signs of work hardening stagnation [5] are visible.

Close examination of the stress–strain curves suggests that prestrain also affects the experimental Young's modulus. The experimental Young's modulus values, determined using a chord line method in the reloading phase, decrease with prestrain. For prestrains larger than 5%, however, the Young's modulus remains at the saturated value of $E = 185$ GPa, which is 10% lower than that of the as-received material. The decrease seems to be independent of strain-path. Similar results have been obtained by Yoshida et al. for low-carbon steels [2].

A scatter diagram of proof stresses measured in the RD and in the TD after prestraining is shown in Fig. 4. The proof stress values fall in straight lines, each line corresponding to certain value of plastic strain offset $\bar{\epsilon}_{\text{off}}^p$. For plastic strain offsets of 1% and 2% all points fall in the same straight line. This indicates that the work hardening rate in the TD remains approximately constant between 1% and 2% of plastic strain.

A closer analysis of the data shows that the slope m and intercept b of the lines in Fig. 4 can be described using linear plateau-

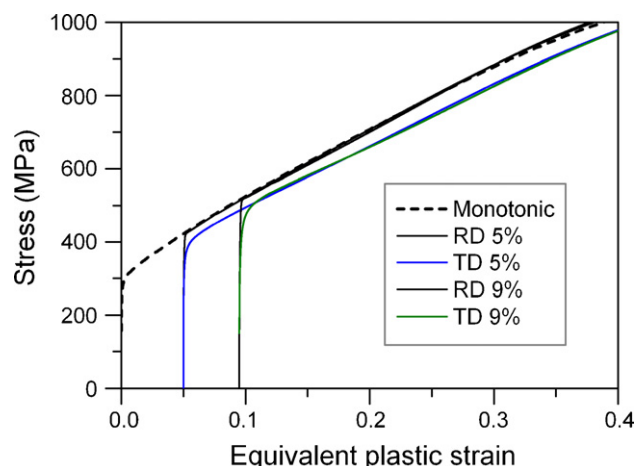


Fig. 3. Stress–strain curves obtained for the material prestrained in the RD.

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