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The effect of texture in modeling deformation processes of bcc steel sheets

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ABSTRACT

In textured polycrystals, combinations of averaging the direction cosines of crystals (CADCC) were found which define interdependences between the crystallographic texture and the anisotropy of the kinetic and elastic properties of a steel sheet. It was shown that in case of bcc materials, three of these parameters exist which can be calculated using the orientation distribution function (ODF).

Based on the ODF, the CADCC were calculated for dual-phase steel DP600 sheets before and after annealing at 220 °C and subsequent deformation by tension to 3%, 6% and 10%. Additionally, damage development was analyzed in this study.

1. Introduction

Before the material is destroyed, micro-defects [1] such as micro cracks and micro voids are initiated and developed during elastic and plastic deformation.

This primarily concerns conditions of material after small degrees of deformation, such as in processes of sheet metal forming, when the sheet deformation is in the range from 3% to 10% or above. As considered in [2] the formation of damage was generalized to a range of strains over 30%. In this paper the damage is assessed at small degrees of deformation when the damage occurs uniformly over the entire volume, the localization of deformation can be ignored, and the elements of damage are very small in size (nano and scale level of micro structure).

The damage coefficient in [2] is defined as the ratio of the damage area of a certain cross section to the area of the undamaged cross section:

$$d = \frac{dS(\vec{n}) - dS^*(\vec{n})}{dS(\vec{n})} \tag{1}$$

with $dS(\vec{n})$ element of area, ($\vec{n}$ – Normal of area to plane dS) ideal solid material (defect free), and $dS^*(\vec{n})$ – of the same element, but where the damage ($dS(\vec{n}) > dS^*(\vec{n})$) was formed. This damage is interpreted in [3] as a decrease in the elastic reaction of a solid body because of the reduced effective area of its components, which is caused by the formation and development of a scattered field of micro-defects.

For this reason, no statements can be made about the extent of micro damages in the material based on the change of elastic properties caused by external effects [2].

If $\tilde{E} = E(1-D)$ is the effective Young's modulus of the damaged material and ($\tilde{E}$) of the undamaged material, the damage coefficient is:

$$D = 1 - \frac{\tilde{E}}{E} \tag{2}$$

The elastic moduli (Young's modulus, shear modulus) are properties of the fourth tensor dimension and indicate anisotropy in materials with a cubic lattice. For this reason they are sensitive to the texture of the examined objects. In [4] it was shown that the presentation of textures as orientation distribution functions (ODF) makes it possible to correlate materials tensoric properties in the polycrystalline and monocrystalline state. Hence, the formation of ODF in the deformed (damaged) state and undeformed state allows an evaluation of the damage in polycrystalline materials.

Textures of polycrystalline bodies can be completely described by means of the ODF. ODF carry information on the effect of texture on the anisotropy of properties [5–7]. To estimate the anisotropy of textured objects it is necessary to extract from ODF parts (parameters) that are sufficient to evaluate the anisotropy of the

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properties. These parameters can serve our proposed combination of averaging the direction cosines of crystals (CADCC) for sheets of cubic metals and alloys. An appearance of the CADCC can be obtained from the anisotropic properties, which can be described as tensors.

CADCC give the possibility to determine the properties in directions difficult to measure directly, for example the Young's modulus in a direction normal to the plane of the sheet (E_{NRD}):

$$\frac{1}{E_{NRD}} = s_{11} - k(1 - \Im_4),\ \text{where}\ \Im_4 = \langle a_{33}^4 \rangle = \Im_1 + \Im_2 + 2\Im_3 - 1 \tag{16}$$

CADCC values are used for calculating the damage in the metal sheet and the known elastic monocrystal properties:

$$D(\varphi) = 1 - \frac{s_{11} - k\left[1 - \left(\Im_1^0 \cos^4\varphi + \Im_2^0 \sin^4\varphi + 1.5\Im_3^0 \sin^2 2\varphi\right)\right]}{s_{11} - k\left[1 - \left(\Im_1^1 \cos^4\varphi + \Im_2^1 \sin^4\varphi + 1.5\Im_3^1 \sin^2 2\varphi\right)\right]} \tag{17}$$

where $\Im_i^0$– CADCC of the sheets in annealed (undamaged) state, $\Im_i^1$ – CADCC of the sheets after deformation.

The purpose of this paper is to study the process of formation and change of texture of dual-phase steel DP600 sheets under tensile strain and the influence of texture on the anisotropy of Young's modulus and the degree of damage of the material after annealing.

2. Material and methods

Sheets of 2 mm thick dual-phase DP600 steel were studied. The sheets in the delivery state were subjected to annealing at 220 °C for 48 h in nitrogen gas. Samples were cut for mechanical testing from the annealed steel sheets in the rolling direction (RD), RD+15°, RD+30°, RD+45°, RD+60°, RD+75° and transverse direction (TD). These samples were subjected to a uniform tensile strain on the test machine Zwick Z100 (100 kN), up to 3%, 6% and 10%. Square patterns of dimensions $10 \times 10\ \mathrm{mm}^2$ were cut from the working parts of annealed (undeformed) and deformed specimens for metallographic analysis of damage after ion slope cutting of the samples using Met Etch Model 683 (Gatan) and X-ray studies of texture on the diffractometer Bruker Discover D8. The textures of alloy sheets were studied with X-ray methods with the construction of direct pole figures (PF) for the main planes of the bcc crystal. The experimental incomplete pole figures {110}, {200}, {211}, {222} were obtained by program for calculating the orientation distribution function (ODF) by Bunge's method [4] with "on reflection" method [8]. The complete PF and CADCC were then calculated with S(11)–S(13) from the ODF, which are necessary for analysis by method of standard projections.

3. Results and discussion

An analysis by PF using the method of overlapping standard projections [8] shows, that during tensile deformation of the annealed DP600 steel sheet the texture orientation of the planar shape modification overlaps the annealed texture of the bcc metals [9] and the orientations (111) [UVW], which do not correspond to the slip orientations in bcc metals.

Based on S(9), the data in Table 1 was used for determining the anisotropy of the Young's modulus of steel sheets after annealing at a temperature of 220 °C and subsequent tensile deformation up to 3%, 6% and 10%. The values for Armco iron monocrystals [10] were used as resilience constants. The results are shown in Fig. 1.

For all treatments, the minimal Young's modulus of the steel sheets corresponds to the rolling direction. For the annealed sheets, the maximum value was found in the direction of RD+60°, and after a tensile deformation of 3% and 6%, the maximum came closer to the RD. At higher deformation a tendency towards RD+60° can be observed. This anisotropy is characteristic for recrystallized bcc metal sheets because of the {100} <uvw> and (112) [$\bar{1}$10] orientations. These are the most anisotropic of the present orientations.

Tensile load reduces the values of these properties in all directions of the sheet, so the mean of Young's modulus decreases at increasing deformation strain. This decrease is not caused by changes in the texture. The formation of anisotropy is caused rather by the strain of orientations in the plane (111), which lies in the plane of the sheet. Hence the observed decrease of the Young's modulus in all directions is characteristic for the damage caused by the processes of plastic deformation and strain.

Table 1
CADCC steel sheet DP600 after annealing and deformation.

CADCC	Averaging the direction cosines			
	Tensile deformation [%]			
	Annealing at 220 °C	3%	6%	10%
$\Im_1$	0.5515827	0.5646524	0.557791	0.5710654
$\Im_2$	0.5196041	0.5233493	0.5317916	0.5432002
$\Im_3$	0.1709358	0.1747263	0.1766876	0.1762911

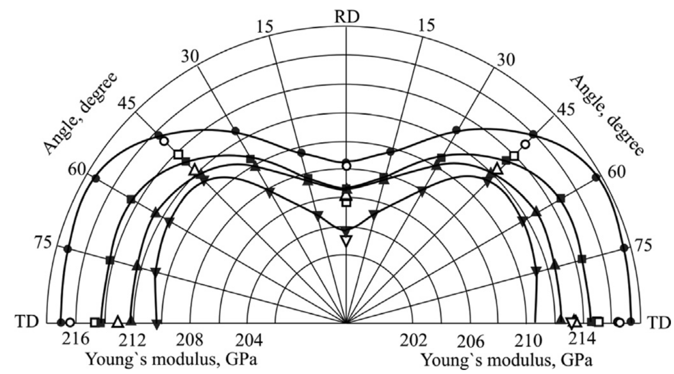

Fig. 1. The Young's modulus anisotropy in the DP600 steel sheet: ● – after annealing at 220 °C, ■ – subsequent tensile deformation of 3%, ▲ – 6%, ▼ – 10%, ○, Δ, ∇ – control measurements of Young's modulus.

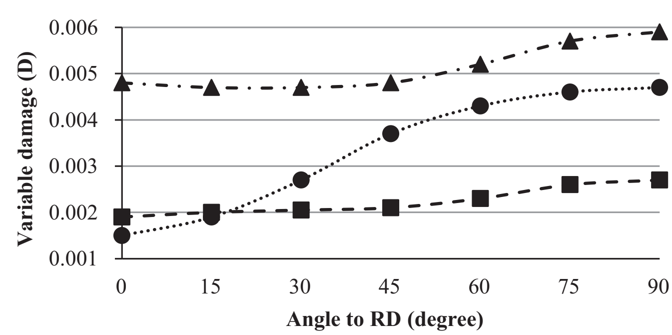

Fig. 2. Damage coefficient anisotropy of DP600 steel sheets after long time annealing and subsequent tensile deformation up to: ● – 3%, ■ – 6% and ▲ – 10% deformation.