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Effect of σ_b and r_b identification method from bulge tests on aluminium stamping simulation

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Abstract. Anisotropic yield surface description is required to perform numerical simulation of forming processes such as stamping. The BBC2005 criterion, available in AutoForm software, is well adapted for aluminium alloys. This model requires the tuning of 8 parameters including σ_b and r_b, respectively the bulge yield stress and the ratio of strain in the two directions of the sheet plane. Nevertheless, there is not strict consensus on how these values can be identified from bulge test. The different methods that can be found in the literature are reviewed and tested on 8 different aluminium alloys from 5xxx and 6xxx families. Based on numerical simulations of stamping of representative industrial automotive parts, the sensitivity of modelling results to the σ_b and r_b values is shown and the selection of the most appropriate identification method is discussed.

Keywords: BBC2005; Plastic anisotropy; forming simulation; identification from bulge tests

1 Introduction

Autoform is a major and widespread software for stamping simulation and used by many car manufacturers. In this code, the material behavior is defined mainly by an isotropic hardening curve and an anisotropic yield function for which the BBC2005 equation [1][2] is well adapted when simulating stamping processes of aluminium Automotive Body Sheet (ABS) alloys. Autoform software does not allow to input directly the BBC2005 parameters but provides an internal identification process from experimental measurements.

Among them, six parameters are obtained through uniaxial tensile tests: Lankford anisotropy coefficients – also called r-values – and yield stresses in the usual three directions (0°, 45° and 90° from rolling direction RD). The two other ones can be obtained with a bulge test: $\sigma_b$and r_b, respectively the biaxial yield stress and the coefficient of biaxial plastic anisotropy [2]. The last parameter, related to the exponent of the criterion is fixed at m=8 for fcc material such as aluminium alloys.

σ_b and r_b are optional but it has been demonstrated in [2] that they should be accurately measured in order to take full advantage of the BBC2005 criterion.

Several methods can be found in the literature to identify such parameters. Which one is the most suited for ABS aluminium alloys? What is the impact of this choice on stamping simulation results? This paper contributes to answering these questions by applying the methods found in the literature on 8 different aluminium alloys from 5xxx and 6xxx families.

1.1 Material

The materials tested in this study are listed in Table 1.

Table 1. Studied materials.

ID	AA name	Main applications
#1	AA6005	Outer surfaces
#2, #3, #4	AA6016	Outer and inner surfaces
#5, #6	AA6111	Structural parts
#7	AA5182	Inner parts
#8	AA5x54	Inner parts

1.2 Experimental Methods

1.2.1 Uniaxial tensile test

Tensile tests were carried out following the ISO 6892-1:2019 standard using plate type 1 and 2 geometries.

1.2.2 Bulge test

Bulge testing consists in applying a hydraulic pressure loading on the clamped 200-mm-by-200-mm metal sheet. Thus, the equi-biaxial loading is frictionless. The deformation of the blank is captured with a stereo-correlation set-up allowing to measure optically the

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sphere-like curvature of the sample over time and strain mapping the surface. The equi-biaxial stress and the thinning strain at the apex of the dome are obtained according to the ISO 16808:2022 standard. The optical device allows measuring the strain history along X (parallel to RD) and Y directions (perpendicular to RD), called respectively ε_x and ε_y.

1.3 Identification of σ_b and r_b

1.3.1 Bulge yield stress σ_b and k_b ratio

The authors based their work on [3]. A plastic work equivalence is established between bulge and uniaxial tensile tests results. σ_b is evaluated through the ratio number k_b such as:

$$\bar{\sigma} = k_b \, \sigma_u = \sigma_b \tag{1}$$

Where $\bar{\sigma}$ is the effective stress and σ_u is the uniaxial tensile stress. u subscript is relative to uniaxial tensile tests. Four methods were employed:

(M1) Method 1: k_b is evaluated at $\sigma_{u,max}$.

(M2) Method 2: k_b is evaluated at an arbitrary value of plastic work $0 \leq W_u \leq W_{u,max}$. 10% tensile plastic strain was chosen.

(M3) Method 3: k_b is evaluated as the average value on a range of plastic work included in $[0; W_{u,max}]$. 5% tensile plastic strain to necking strain was chosen.

(M4) Method 4: k_b corresponds to the bulge scale parameter defined in ISO 16808:2022 standard. No plastic work equivalency is used here.

1.3.2 Evaluation of r_b

Identification of r_b consists of evaluating the mean value of the ratio $\varepsilon_y/\varepsilon_x$, as proposed by [4]. Three methodologies are evaluated.

(MR1) Method 1: r_b is identified as the mean value for the strain ratio between 8% and 12% of equivalent tensile strain, using plastic work equivalence.

(MR2) Method 2: r_b is identified for the range of 10% to 30% (or maximal strain if lower) of surface strain on rolling direction.

(MR3) Method 3: r_b corresponds to a simple linear fit of the $(\varepsilon_y, \varepsilon_x)$ curve, as proposed in [5].

2 Results

2.1 Identification

The k_b and r_b values obtained using the three methods are given in Fig. 1 and Fig. 2.

For k_b, similar results can be found for M2 and M3, meaning that k_b ratio at 10% tensile plastic strain corresponds to its mean value between 5% tensile plastic strain and necking. Nevertheless, the high difference between M3 and M1 means that k_b tends to increase with strain for, at least for materials #1 to #6 (all 6xxx alloys) contrary to #7 and #8 (5xxx alloys) for which k_b is rather constant over strain.

Scattering is very important for the identification of r_b: for 5 materials out of 8 the gap between values is over 10% between each method.

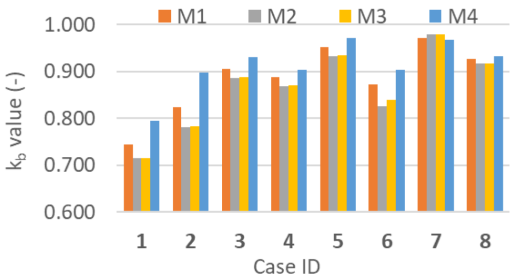

Fig. 1. Identified $\boldsymbol{k_b}$ values for each material.

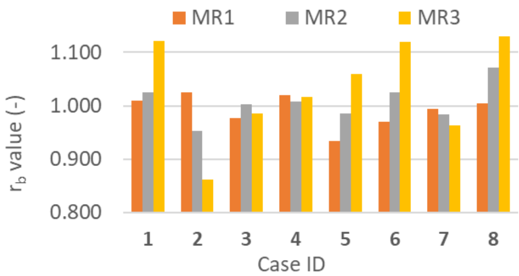

Fig. 2. Identified $\boldsymbol{r_b}$ values for each material.

2.2 Application case

Simulations of the stamping operation of an inner door ring have been done using extremal identified values of k_b and r_b. The computations are not clearly sensitive to r_b but k_b values impact the forming limit diagram (FLD) of the simulations: points are shifted to increased minor true strain values are increase, shifting to the right the FLD points. This increases the number of points in the critical zone for stamping up to a factor 3 for some cases. k_b, thus σ_b, is of first order in the differences between simulations

3 Conclusions

σ_b and r_b values are very sensitive to the selected identification methodology. Methods M1 and MR1 should be considered for further identifications for Autoform simulations.

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