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Mechanical properties determination of dual-phase steels using uniaxial tensile and hydraulic bulge test

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Abstract

Numerical simulations of sheet metal forming processes need the establishment of highly reliable results, which in turn need the accurate identification of mechanical properties. In this paper a study is presented on the choice of the characterization function of flow stress-strain curve of sheet metal materials, as well as the selection of the best yield locus, based on experimental uniaxial tensile and biaxial hydraulic bulge tests performed on dual-phase steels of industrial interest. To obtain a better characterization of the hardening curve, a combination is made using the uniaxial tensile test data with biaxial hydraulic bulge test results, since bulge test covers a larger range of plastic strain when compared to tensile test. Since the two flow curves have different strain paths, they can't be directly compared or combined. Therefore, it is necessary a transformation of flow stress-strain curve provided from biaxial bulge test into equivalent stress-strain curve. Different methodologies were applied to transform biaxial stress-strain curve to an equivalent one and the different results are compared and evaluated.

Keywords: Sheet metal forming; dual-phase steels; flow curve; biaxial hydraulic bulge; yield locus.

1. Introduction

The accuracy of the results obtained by numerical simulation depends, among other factors, on the characterization of mechanical properties of materials and particularly on its hardening curve. The selection of the constitutive model, which better reproduces the material behaviour, has an important influence in such accuracy of results. The uniaxial tensile test is the most common method to obtain the characterization of the material and corresponding flow stress-strain curve is expressed in a state of uniaxial stress. However, this type of test has the limitations of uniaxial loading, corresponding to lower values of uniform and maximum fracture strains when compared to those obtained by other types of loadings, which are included in most of sheet metal forming processes. Therefore, these results need to be extrapolated when modelling material hardening behaviour, e.g., when using numerical simulation. One possible approach to obtain higher strain information for metallic material behaviour and its hardening curve is to use the hydraulic bulge test [1-3], since it allows higher values of plastic deformation. Some authors are also using a viscous material instead of hydraulic fluid [4,5]. In this paper, it is proposed a methodology to obtain the hardening curve of dual-phase steels (DP500, DP600 and DP780) based on the combination of two parts. The first part of the data is obtained by the uniaxial tensile test, characterizing the material to lower values of deformation, and the second part corresponds to the biaxial equivalent stress-strain curve obtained from hydraulic bulge test. Making use of the experimental results it will be also selected the yield locus that

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better reproduces the behaviour of the materials under study.

2. Mechanical Characterization

2.1. Uniaxial tensile test

The uniaxial tensile tests were performed at room temperature with grip speed of 5 mm/s, corresponding to a strain rate of 0.0016 s^{-1}. The samples, with a thickness of 0.8 mm, were obtained by machining, according to ASTM E 8M-04, for three different directions relative to the rolling direction (0°, 45° and 90°). In order to ensure the repeatability of the results, several experiments were performed for each direction and material. The respective true stress-strain curves for the selected materials and directions are shown in Fig. 1.

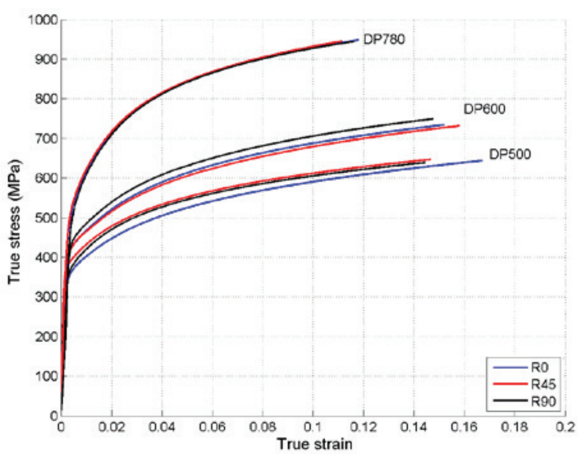

Fig. 1. Flow stress-strain curve obtained from uniaxial tensile test for selected dual-phase steels, according to different directions relative to the rolling direction.

Table 1 presents some mechanical properties obtained from flow stress-strain curves, such as the yield stress ($R_{P0,2}$), ultimate tensile strength (R_m), elongation at yield point (e_0), uniform elongation (e_u) and total elongation (e_t).

Table 1. Mechanical properties of different materials, obtained from uniaxial tensile test (rolling direction).

Material	$R_{p0,2}$ (MPa)	R_m (MPa)	e_0 (%)	e_u (%)	e_t (%)
DP500	356.53	544.84	0.34	18.18	29.52
DP600	416.05	630.85	0.37	16.40	27.14
DP780	526.18	843.10	0.47	12.53	17.96

2.2. Hydraulic bulge test (biaxial)

The experimental system to perform the hydraulic bulge test is composed of a set of tools, a hydraulic pump and a mechanical device, which gets the relevant data for material characterization (Fig. 2).

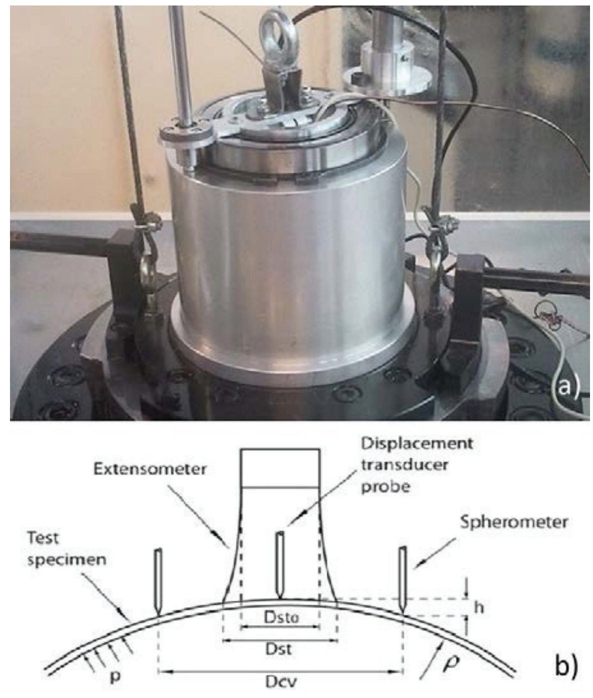

Fig. 2. a) Measuring system, b) variables used to determine the stress and biaxial strain.

The set of tools contains a circular die, with a nominal diameter of 150 mm, a die radius of 13 mm and a blank holder with a drawbead, which restricts the sample and avoids any oil leakage during the test. The measuring system is calibrated before each test in order to ensure accuracy and reproducibility of the measured values. The bulge test is performed with a pressure increment of 1 bar/s and the circular samples have a 250 mm diameter. The experimental system allows the continuous acquisition of hydraulic pressure (p), as well as the variables provided by the measuring system: radius of curvature (ρ) and biaxial strain (ε). The ratio blank diameter/thickness permits the application of the membrane theory and the biaxial stress (σ) is calculated by Eq. 1 while biaxial strain uses Eq. 2.

$$\sigma = \frac{p \cdot \rho}{2 \cdot t} \tag{1}$$

$$\varepsilon_t = 2 \cdot \ln\left(\frac{D_{st}}{D_{st_0}}\right) \tag{2}$$