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Identification of material parameters using a bi-axial test machine

P. Flores, P. de Montleau, V. Mathonet, P. Moureaux, A.-M. Habraken

Mechanical and Civil Engineering Institute
M&S Department, University of Liege – Chemin des chevreuils 1, 4000 Liege, Belgium
URL: www.ulg.ac.be/matstruc *e-mail: Paulo.Flores@ulg.ac.be*

ABSTRACT: Experimental testing equipment is built in order to identify material parameters of complex phenomenological constitutive laws. This equipment consists in a bi-axial test machine able to perform plane strain and simple shear tests separately or simultaneously and a Miyauchi simple shear test device; an optical extensometer is used to identify the strain field. The article focus on the validation of the results of this new equipment by comparing with results obtained by standard machines and/or by using FEM simulations of already identified materials. The first results show that the bi-axial machine performs the plane strain test optimally and some modifications are proposed in order to improve the results for the simple shear test. Miyauchi device shows a good performance and the experimental results are compared with a FEM simulation.

Key words: Bi-axial machine, validation tests, identification.

1 INTRODUCTION

The material characterization of metals is an important task in order to improve the prediction of metal forming processes.

Several constitutive laws that take into account material anisotropy have been developed lately in order to model the sheet metal behaviour. These laws are based on experimental observations, and depend on material parameters.

The number of material parameters and the required identification tests depend on the complexity of the law. The choice of the law depends upon, among other things, the process, the required accuracy, the experimental constraints and the used finite element code.

This work deals with the set-up of the experimental equipment required to identify anisotropic yield functions and a microstructure based hardening law.

The next section describes the equipment and section 3 shows the first experimental results. In section 4 the anisotropic yield function is identified and a numerical simulation of a simple shear test is compared with experimental data. Conclusions and future work are established in section 5.

The used material is the dual phase steel DP600.

2 EXPERIMENTAL EQUIPMENT

2.1 *Miyauchi test device*

This simple shear test was proposed by Miyauchi [1] and is used to study the Bauschinger effect by reversing the test, to reach high deformation levels and to pre-strain the material for further deformations. To accomplish this last task, the M&S Laboratory built a Miyauchi device that can be adapted to a tensile test machine as shown in figure 1.

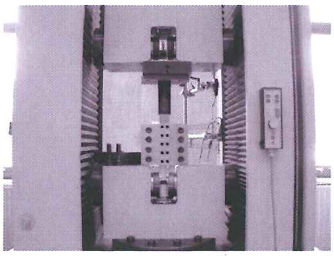

Fig. 1. Miyauchi device in a tensile test machine

The specimen geometry is 200x230 mm with two gauges zones of 200x40 mm from which smaller specimens can be cut off. A deformed specimen can be seen in figure 7.
Some examples of Miyauchi devices can be found in [2].

2.2 Bi-axial test machine

This test was developed at the University of Twente [3]. It consists in a bi-axial machine, able to combine simple shear with plane strain deformation. The main advantages of using a bi-axial machine are that it is possible to test sheet material behaviour under multi-axial and non-proportional loads, as well as allows the study of the path changing effect without removing the test piece. The machine built at the M&S Laboratory is shown in figure 2.

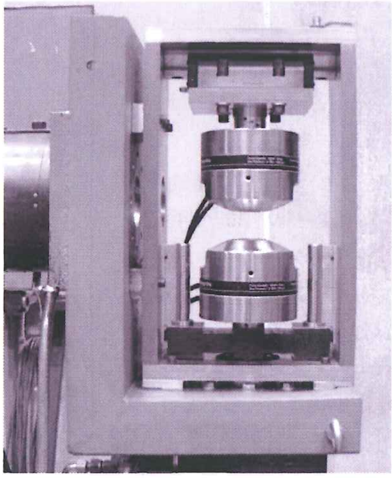

Fig. 2. Bi-axial test machine

The test piece used in this machine is shown in figure 3. On this specimen, plain strain (monotonic) and simple shear (monotonic or cyclic) tests can be carried out, separately or simultaneously. This specimen can out be cut from the Miyauchi specimen.

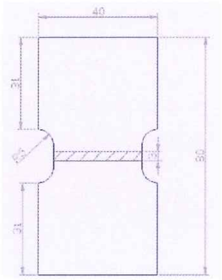

Fig. 3. Bi-axial test specimen, hatched zone is the measurable area

2.3 Tensile test machine

The tensile test machine has a capacity of 20 kN (cell load capacity) and uses self-locking mechanical wedge grips. A Zwick Multisens ® analog extensometer is set in to measure desplacements.

2.4 ARAMIS ® Optical extensometer

The deformation measuring system ARAMIS records an object under load using CCD cameras. For each stage of load, the 3D coordinates of the object surface are calculated on the basis of digital image processing. The computation of strains is based on the deformation gradient **F** obtained from the coordinates of the specimen surface.

3 VALIDATION OF TEST MACHINES RESULTS

3.1 Optical extensometer

The strains measured using the Aramis system while performing a tensile test, are compared with the ones obtained using the analogue extensometer. These results are shown in figure 4.

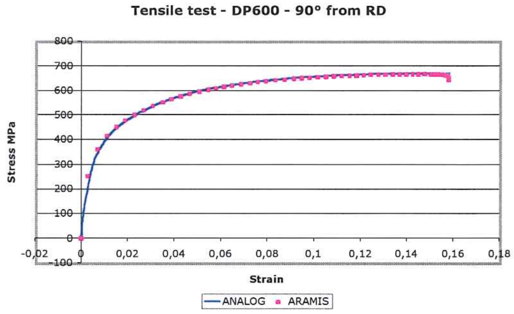

Fig. 4. Tensile test results obtained with two extensometers

These results validate the use of the optical extensometer over the other tests.

3.2 Plane strain test

Several plane strain tests performed by the bi-axial machine are compared with the ones done with the tensile machine. The results are satisfactory as shown in the example of figure 5.

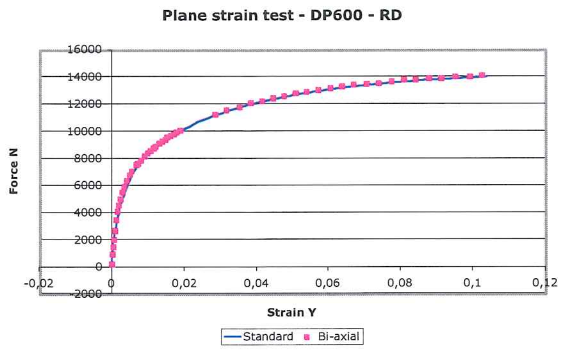

Fig. 5. Plane strain test at rolling direction (RD)

3.3 *Simple shear test*

Two problems are identified after the first tests: parasite displacement and an inadequate grip clamping. The first one is due to the lower grip ("fixed grip") movement while imposing a displacement at the upper grip. To solve this problem, a metal block is placed in a way that it blocks the horizontal displacement of the grip. The force – displacement curve is drawn in figure 6.

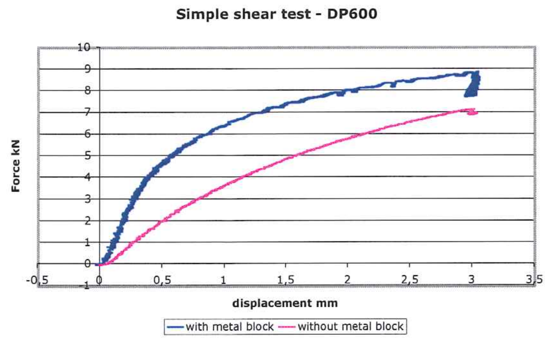

Fig. 6. Simple shear test using bi-axial machine

The second problem is observed after the deformation measurements. The first lines of wedges' teeth (the closest to the measurable zone) don't clamp the specimen, increasing the heigth of the measurable zone. To solve this problem the wedges will be machined.

Even if the results are improved by using the block they are still unsatisfactory. A more accurate and better adapted metal block is under construction. Results using this metal block and the machined wedges will be obtained soon.

3.4 *Miyauchi test*

Several tests are done in order to obtain optimal deformations on the Miyauchi specimen.

Figure 7a shows the undeformed specimen.

To prevent the deformation out of the plane and the friction between the additional device and the specimen deformation zones, some sliding Teflon ® sheets are used. Figure 7b, shows the result obtained for a test without the sliding sheets, while figure 7c shows the result using them. The result is not satisfactory due to the fact that some plastic deformation appears around the bolt holes. It is thought that this phenomenon occurs due to the lack of friction between the clamping zones. To solve this problem, these zones are sanded to increase the friction coefficient. The results are satisfactory as shown in figure 7d and subsection 4.3. The force-displacement curve is depicted in figure 8.

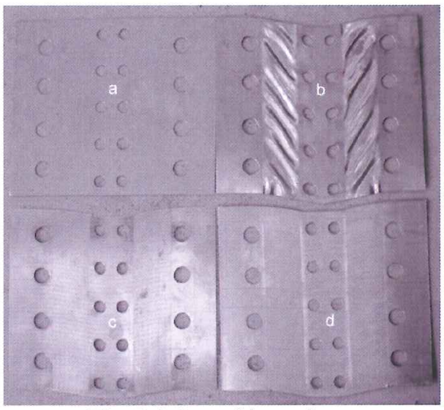

Fig. 7. Miyauchi specimen

4 MATERIAL PARAMETERS IDENTIFICATION

4.1 *Constitutive law*

4.1.a Hill 1948 yield function

Mathematically Hill's yield criterion takes the following form with respect to the principal axes of anisotropy *1, 2* and *3*:

$$\underbrace{F(\boldsymbol{\sigma}) = \frac{1}{2}\left\{\left[H(\sigma_{11}-\sigma_{22})^2 + G(\sigma_{11}-\sigma_{33})^2 + F(\sigma_{33}-\sigma_{22})^2\right]\ldots \ldots + 2\left(N\sigma_{12}^2 + L\sigma_{23}^2 + M\sigma_{31}^2\right)\right\}}_{\bar{\sigma}} = \sigma_Y^2 \quad (1)$$

where *F, G, H, L, M* and *N* are the material constants characterizing the current state of anisotropic yield behaviour and σ_Y is the initial yield stress in the *1* principal direction.

4.1.b Hardening model

Teodosiu and Hu have developed the model summarized hereafter [4]. The model takes into account the intergranular heterogeneity of the microstructure due to the evolution of dislocation structures, in addition to the isotropic and non-linear kinematic hardening. It depends on four state variables and 13 material parameters. Four different types of tests along the rolling direction are required to fit the 13 material parameters of this law. These are: a tensile test, a shear test, a Bauschinger test (reverse shear test) and an orthogonal test. Actually, three Bauschinger test at different amount of pre-strain are recommended (10%, 20% and 30%). For more details about the law see references [4, 5].

4.2 *Material parameters*

Elasticity is assumed isotropic. After performing several tensile tests, the following parameters are obtained: Young's modulus E=212360 MPa, Poisson's coefficient ν=0.28 and initial yield stress (0.2%) σ_Y=283 MPa.

Hill parameters are determined using the plastic anisotropy parameter r obtained from tensile tests in directions 0°, 45° and 90° with respect to the rolling direction (RD). The relationship between r values and Hill's constants are defined as:

$$\begin{aligned} r_0 &= \frac{d\varepsilon_y}{d\varepsilon_z} = \frac{H}{G} \\ r_{90} &= \frac{d\varepsilon_y}{d\varepsilon_z} = \frac{H}{F} \\ r_{45} &= \frac{d\varepsilon_y}{d\varepsilon_z} = \frac{2N - F - G}{2(F + G)} \end{aligned} \qquad (2)$$

assuming H+G=2 and N=M=L.

Hill parameters became: F=0.898, G=1.143, H=0.857 and N=M=L=3.06.

4.3 *Numerical simulation*

Due to the unfeasibility of performing all the required tests to identify hardening parameters, those are taken from [5] where they are identified for the same steel. Using these parameters in addition with those identified in the former subsection, a finite element simulation of a Miayuchi test is done. The simulation is done using *Lagamine* (code developed at the M&S Department of the University of Liege). Figure 8 shows a good agreement between the simulated results and the experimental ones.

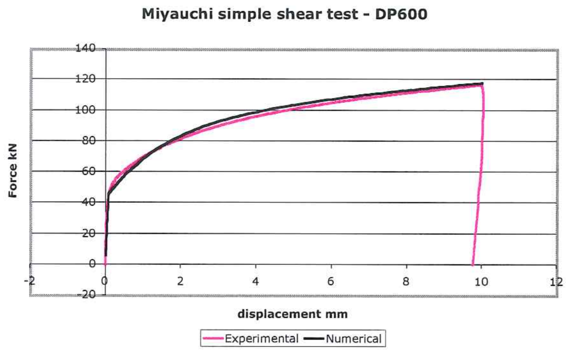

Fig. 8. Simple shear test using Miyauchi device

5 CONCLUSIONS

The experimental equipment built by the M&S Laboratory is tested, showing good results at performing plane strain test and simple shear test using the Miyauchi device. The bi-axial machine is being improved in order to obtain better results for the simple shear test.

The optical system gives satisfactory results.

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