ABSTRACT: Many studies have shown that improvements in the numerical prediction about rolled sheet forming is done through the laws of behaviour increasingly complex, particularly by the combination of isotropic and kinematics hardening (mixed hardening) to take on the Bauschinger effect. But there are several types of test experimental characterization Bauschinger effect: simple shear in one direction and then reverse, tension and compression, bending unbending test... In the case of steel, this paper will answer these two questions: Are these experimental tests are equivalent in terms of Bauschinger effect? What is the impact of these different tests on the identification of parameters of the law of behaviour?

Key words: Bauschinger Effect, Steel, experimental tests, Isotropic and kinematics hardening

1 INTRODUCTION

Increasingly in the forming and in-use properties prediction, we use the complex behaviour laws by introducing a kinematic hardening combined with a hardening isotropic. In rheology, there are several experimental tests to show the Bauschinger effect allowing to determinate the parameters of this type of laws. But what do these various tests define the same characteristic of the Bauschinger effect? In this paper, we will try to answer this question. As a first step, it will be determined what the Bauschinger effect and different experimental tests on characterizing. In a second step, it will be different experimental results on a wide range of steel with a comparison of characterization on different types of tests. Finally, we discuss the implications for the identification.

2 BACKGROUND ON THE BAUSCHINGER EFFECT

2.1 Description

In 1881, J.Bauschinger [1] discovers realizing on a metal, compression test resulting after a first plastic deformation of tensile test, a decrease in the yield stress. Since that day, this is known as Bauschinger effect. The figure below shows what we get in terms of stress-strain in Bauschinger shear test.

Fig. 1. Stress-strain curve for Bauschinger tension-compression test [2].

The Bauschinger effect (see fig. 1) is characterized by two stages. The first stage consists to the transient Bauschinger deformation composed by early re-yielding and workhardening stagnation. The workhardening stagnation appears at a certain range of prestrain. The second stage is the permanent softening defined by stress offset in a region after transient period.
2.2 Quantifications

To quantify the Bauschinger effect, we have got several possibilities. The first is used by A. Aouafi at the last conference ESAFORM [2] (see fig. 2). He quantified the bounds of stagnation region (γ₁ and γ₂ are respectively the beginning and the end of workhardening stagnation). We can add the quantification of the permanent softening.

In the literature, there are others parameters to quantify the Bauschinger effect [3, 4, 5]. Here are some examples about Stress parameters:

\[
X_{1\sigma} = \frac{\sigma^+ - |\sigma|}{2}
\]

(1)

\[
X_{2\sigma} = \frac{|\sigma|}{\sigma^+}
\]

(2)

\[
X_{3\sigma} = \frac{\sigma^+ - |\sigma|}{2\sigma^2} = \frac{X_{1\sigma}}{\sigma^+} = \frac{1}{2}(1 - X_{2\sigma})
\]

(3)

where \(\sigma^+\) denotes the flow stress in forward straining and \(|\sigma|\) the early re-yielding defined at offset given (see fig.3).

Here are examples about Energy parameters:

\[
\beta_{E1\sigma} = \frac{E_1}{E_{predf}}
\]

(4)

\[
\beta_{E2\sigma} = \frac{E_2}{E_{predf}}
\]

(5)

\[
\beta_{E3\sigma} = \frac{E_3}{E_{predf}}
\]

(6)

where \(E_i\) are different area under the curve, defined in the figure 3.

Fig.3. Schematic definition of energy parameters for Bauschinger test.

2.3 Experimental tests

Before applying these quantification parameters, we will list the experimental tests to achieve the Bauschinger effect. For a Bauschinger effect in an experimental test, it is enough to solicit the material in one direction and then in the reverse direction with the possibility of registering a variable linked to stress in function on other variable linked to the strain. The experimental tests the more used are compression-tension [6], tension-compression [5, 7, 8], simple Bauschinger shear test [9, 10, 11, 12] or bending test (3-points [13] or 4-points [14] bending test, cyclic bending tests [15, 16]).

For compression-tension, tension-compression or Bauschinger shear test, we get a direct stress-strain curve. In contrast to the bending test, we have got either force-displacement (3-points or 4-points bending) or moment-angle (cyclic bending). Accordingly for the bending tests, it is not possible define the parameters of Bauschinger effect quantifying and it is necessary to make an identification by inverse method with FEA Code.

The difficulty of tension-compression or compression-tension tests is the buckling; the advantage is to have got directly stress-strain curve on reference axis of hardening about FEA code behaviour implementation.

About shear test the difficulty is the Yield loci parameters influence the hardening parameters identification. The advantage we can attempt large strain.
were carried out in various laboratories of university as LPMTM [3, 9] or M&S [10]. In the framework of ArcelorMittal project, two specimens of steel grade were testing by the compression-tension tests of T.Kuwabara [6].

In the figures 4 to 7, we compared 2 parameters of the Bauschinger effect quantifying identified in the preceding paragraph applied to these Bauschinger shear tests (BS) and compression-tension tests (CT) directed by S.Sadagopan & al [5]. The first parameter (see figures 4 and 6) shows a good correlation between the different types of tests, however the second parameter not (see figures 5 and 7). The Figures 6 and 7 show also the comparison on the same sample of 2 steels grades, 2 parameters for Bauschinger shear tests and compression-tension tests. Only the first parameter shows a concordance of 2 types of tests on the Bauschinger effect.

4 MODELLING

To illustrate the impact of identification, we realize 3 different identifications on the DP steel with non-linear kinematic hardening using Amstrong-Frederick law [17].

\[
\dot{\chi} = C_x (X_{\text{sat}} n - X)^{\lambda}
\]  

(5)

The first identification uses only the Bauschinger shear tests, the second only the compression-tension tests and the last third on 2 types of tests. In figure 8, we find classical result, ie that the first two cases of identification showing a good correlations on the type of test that was used for identification and bad for others type of test and correlation average for the third case. This is due in part because of yield loci (here Von Mises) and partly due to dispersion measurement experimental tests. Figure 9 confirms
that the Lemaître & Chaboche hardening law not
effect the Lemaitre & Chaboche hardening law not
enough to properly describe the “elbow” and
Bauschinger effect of the curves, and the need
models containing doubles kinematics variables.

Fig. 8. Comparison of 3 possibilities of identification

Fig. 9. For identification 1, comparison stress-strain curve
between experimental and model for Bauschinger shear test
and Compression-Tension test

5 CONCLUSIONS

This paper has listed some tests and parameters to
quantify the Bauschinger effect on steels. A
comparison of 2 tests (Bauschinger shear and
compression-tension) has been made in terms of
parameters to quantify the Bauschinger effect and
identification of the kinematic hardening model.

REFERENCES

1. J. Bauschinger, ‘Über die Veranderung der
Elastizitätsgrenze und elastizitätsmodul verschiedener’,
Metal Civiling N.F., 27, (1881) 289-348
2. F. Yoshida, T. Uemori, ‘A model of large-strain cyclic
plasticity and its application to springback simulation’,
3. A. Aoufi, S. Bouvier, M. Gaspérimi, X. Lemoine and O.
Bouaziz ‘Phenomenological Analysis of Kinematic
Hardening of HSLA and IF Steels Using Reverse Simple
Shear Tests’, Proceedings of the Int. Conf

4. J. Yan, ‘Study of Bauschinger Effect in Various Spring
Steels’ Degree of Master of Applied Science, 1999,
Department of Metallurgy and Materials Science,
University of Toronto,
5. S. Sadagopan, D. Urban, ‘Formability Characterization
Of A New Generation Of High Strength Steels’ Final
report of AISI/DOE Technology Roadmap Program,
March 2003
6. T. Kuwabara, Y. Morita, Y. Miyashita, S. Takahashi,
“Elastic-Plastic Behavior of Sheet Metal Subjected to
In-Plane Reverse Loading”, in Tanimura, S. and Khan, A.S.
(eds), Dynamic Plasticity and Structural Behaviors,
(1995) 841-844
diagram and Bauschinger’effect parameters of steel
DP780’ in the test report 148-1G for MATFEM
Partnerschaft Dr. Gese & Oberhofer on behalf of Arcelor
Research S.A., TsPO TEST, Voronezh (2007)
8. W. Schmitt, O. Benevolenski, T. Walde, A. Krasowsky,
‘Material Characterization for simulation of sheet Metal
Forming’, in VIII International Conference on
Computational Plasticity COMPLAS VIII, E. Oñate and
D.R.J. Owen (Eds) © CIMNE, Barcelona, 2005
9. S. Bouvier, V. Tabacaru, M. Banu, C. Maier, C. Girjob,
B. Gardey, H.Haddadi, C. Teodosiu, ‘Selection and
Identification of Elastoplastic Models for the Materials
used in the Benchmarks’, Digital Die Design Systems
(3DS) Contract IMS 1999 00051, 18 Months Progress
10. P. Flores, ‘Development of Experimental Equipment and
Identification Procedures for Sheet Metal Constitutive
Laws’, PhD Thesis of University of Liege, November
2005
11. R. Greze, H. Laurent, P. Y. Manach ‘Springback study
in aluminum alloys based on the Deméri Benchmark
Test: influence of material model’, Proceedings of the
Ferreira Duarte, ‘Hardening Behavior and Structural
Evolutions upon Strain Reversal of Aluminum Alloys’,
13. F. Campmana, L.Cortese, F. Placidi, ‘FEM Evaluation of
Springback after Sheet Metal Forming: Application to
High Strength Steels of a Combined Isotropic-Kinematic
Hardening Model.
du Procédé de Sertissage de Pièces de Carrosserie’ PhD
Thesis of Ecole Nationale Supérieure des Mines de Paris
(2006)
15. M. Brunet, F. Morestien, S. Godereaux, ‘Nonlinear
kinematic hardening identification for anisotropic sheet
metals with bending-unbending tests’, Journal of
Engineering Material and Technology, ASME, 2001,
Vol.123, pp.378-383
pour la Simulation de Procédé Mise en Forme à Froid’,
PhD thesis of Ecole Nationale Supérieure de Cachan
(2002)
representation of the multiaxial Bauschinger effect.