Materials Research Proceedings 41 (2024) 1166-1170 https://doi.org/10.21741/9781644903131-129

The plane strain compression test, an alternative to large strain hardening characterization

NEAG Adriana[1,2,a], BALAN Tudor[1,b*]

[1]Arts et Metiers Institute of Technology, Université de Lorraine, LCFC, F-57070 Metz, France

[2]Dept of Materials Science and Engineering, Technical University, Cluj-Napoca 400641, Romania

[a] adriana.neag@ipm.utcluj.ro, [b] tudor.balan@ensam.eu

Keywords: Plane Strain Compression, Characterization, Large Strain

Abstract. Large strain characterization of sheet metals has become increasingly important with the generalization of advanced high strength steels, for which the tensile test provides data over a very reduced strain range. Among the numerous alternative characterization tests, the plane strain compression test (PSCT) requires a small amount of material and classical testing machine and acquisition. PSCT was mainly used for hot forming characterization, but recently it has been proved sufficiently accurate for application in cold metal forming. The aim of this work is to provide an in-depth validation of the PSCT by means of the finite element method. When converting the PSCT force-displacement curve into a stress-strain curve (flow curve), several analytical corrections are applied. The FE simulation of the test was used in order to validate these correction terms and their hypotheses. The originality of the approach is the design of a sequence of test configurations which allow for the individual validation of each and every one of the correction terms concerning the effect of: yield surface; friction; variation of sample width; variation of contact zone length; edge effects. The FE simulations showed that the analytical exploitation of the PSCT provides a very good accuracy. They help identifying the most suitable correction to consider the effects of yield surface shape, friction, edge effects. The traditional correction of the sample width as well as the more recent correction of the effective tool width were validated. The results show that the PSCT provides accurate flow curves and designate the best analytical expressions to be used.

Introduction

Stress-strain curves of sheet metal are crucial for realistic simulations of sheet metal forming. They are traditionally extracted from the uniaxial tensile test, which is limited to the uniform elongation. Thus, alternative methods are required to generate an accurate flow curve. Common alternatives in the literature are the bulge test, the simple shear test, the stack compression test, the in-plane torsion test, and the plane strain compression test. The plane strain compression test (PSCT) is one of the simplest, since it uses a simple test device and a universal tension-compression machine and standard force-displacement acquisition (see Figure 1). Moreover, it requires small amounts of sample material. It is thus an appealing test for industrial application. Traditionally applied for hot rolling simulations, several authors show that the test is sufficiently accurate for the flow curve determination at room temperature [1][2].

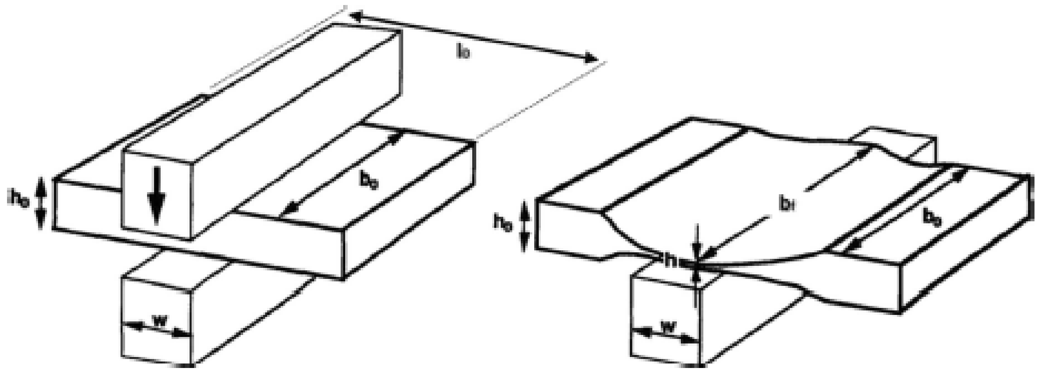

Figure 1. Schematic description of the PSCT test and corresponding notations

The PSCT configuration is simple: a rectangular sample is compressed between two rectangular dies, wider than the part. The displacement of the upper tool is imposed and the force is measured. A stress-strain curve under the plane strain stress state is derived. The tools are lubricated based on graphite, glass, polymer (Teflon), oil… depending on the test temperature. The accuracy of the PSCT-based flow curve is affected by several factors: tool misalignment, stress concentration, heterogeneous strain distribution, friction. Becker and Pöhlandt [1] used a tool with a radius to diminish stress concentration. The effect of factors that cannot be entirely eliminated, like friction, require a correction of the flow curve calculation equation [4].

This paper investigates the various correction terms for PSCT flow curve calculation, by means of finite element simulations. A reference, known material law is selected and PSCT simulations are performed under different conditions. The upper die force is plotted as a function of displacement, and stress-strain curves are calculated by applying the PSCT analytical formulas to these FE-based force-displacement recordings. These curves can be validated with respect to the reference flow curve. Also, simulation allows to decouple the validation of each correction terms separately, which is impossible experimentally. For this, several 2D and 3D test configurations were simulated.

Finite element simulation of the PSCT

The FE simulation of the PSCT is performed using the Forge ® commercial software. The selected FE code must provide a remeshing function since significant element distortion may be induced by the material flow in the area of the die corner. Two-dimensional and three-dimensional simulations allowed to validate the various hypotheses independently. Indeed, 2D simulations respect the plane strain hypothesis utilized in the analytical calculation, thus allowing for the validation of the friction and shear corrections. Then, 3D simulations allowed for the verification of the width increase correction. Figure 2a-b illustrates the increase of the sample width as the plane strain compression proceeds, in particular when large strain levels are reached.

Fine mesh density is required in order to describe the strain gradients that develop in the active area of the sample (see for example Figure 2c). Furthermore, sudden variations in the force evolution are observed when a node loses contact with the die as the lateral flow progresses. As seen in Figure 3, even when the average force evolution curve becomes independent of the mesh size, the amplitude of the force variation due to contact evolution continues du diminish as the mesh size diminishes. An average element size of 0.05 mm was selected in the active area of the sample. Three symmetry planes were used in order to reduce computing time

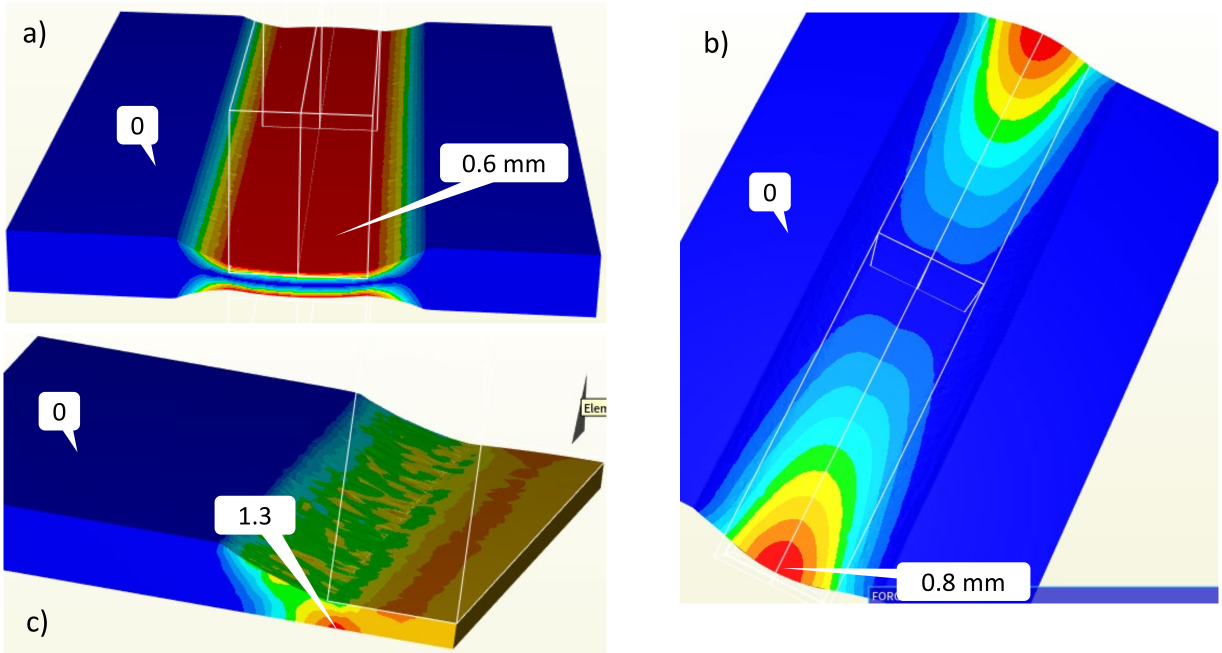

Figure 2. Typical results of 3D PSCT simulations: a) displacement of material points in the punch travel (z) direction; b) displacement in the y direction; c) equivalent strain distribution.

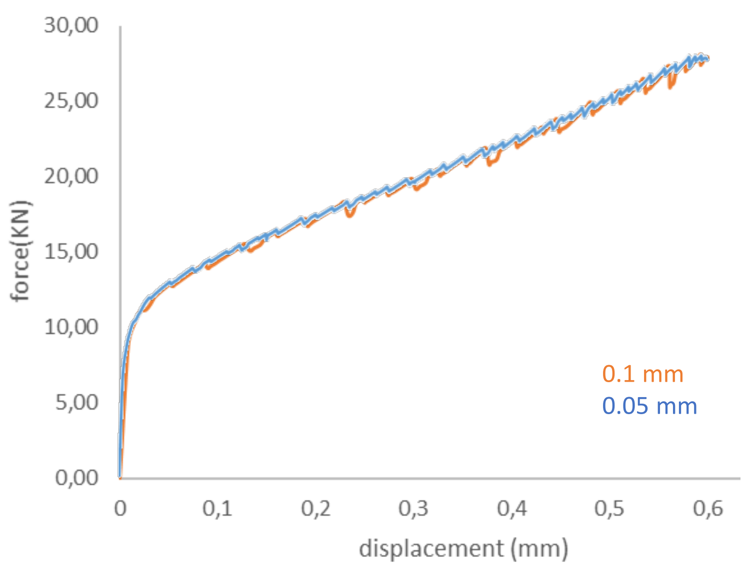

Figure 3. Evolution of the die force for two converged mesh sizes.

Results and discussion

The PSCT flow curve analytical formulas are based on the slab method analysis of the deformation zone. The boundary condition at the die exit surfaces has an influence on the results and was questioned repeatedly in the literature. Becker and Pöhland [1] introduced a so-called shear correction factor in this respect. According to Figure 4, this shear correction slightly improves the flow curve calculation, provided that the friction coefficient (and law) is exactly known, as is the case here. However, when a real experiment is analyzed, this improvement may not be systematically observed.

Another classical correction term aims to take into consideration the increase of the sample width, which induces an increase in the contact surface between dies and sample, thus affecting the calculation of the average normal stress. The simulation of the width increase required a full 3D simulation. Figure 5 shows that this correction term compensates very well the influence of the width increase on the flow curve calculation. The same conclusions were obtained with small to moderate friction conditions. Finally, three different friction correction terms were confronted to each other using both 2D and 3D simulations of the PSCT. In both cases, the friction correction is necessary and the three proposed correction terms are almost identical.

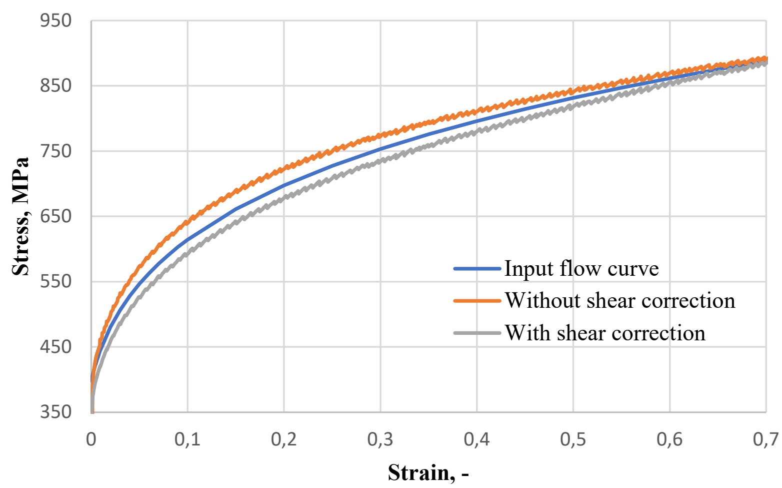

Figure 4. Influence of the shear correction factor on the PSCT-based flow curve.

The influence of a tool misalignment was also investigated using 2D simulations. While no correction term can compensate for an accidental (thus unknown) misalignment, the simulation results show that the error can be neglected for tool misalignments inferior to 0.2 mm. The error approaches 10% when the tool misalignment reaches 0.5 mm for the given sheet and die geometries (Figure 6).

Conclusions

The plane strain compression test can be used as an economical method for the calculation of flow curve for sheet metals at large strains and at room temperature. The flow curve calculation includes several correction factors to compensate for edge effects, friction effects etc. The numerical simulation of the test provides a means for their independent validation, very difficult or even impossible to achieve experimentally. The investigation revealed that the so-called shear correction of the edge effects does not improve significantly the results and can be avoided. In turn, the classical compensation terms for the specimen width increase and the friction influence proved both necessary and accurate. In particular, the performed simulations could not show any difference between the correction terms using Coulomb and Tresca friction laws. In any case, these corrections are only efficient for low to moderate friction conditions, thus friction should be carefully reduced in the experiments.

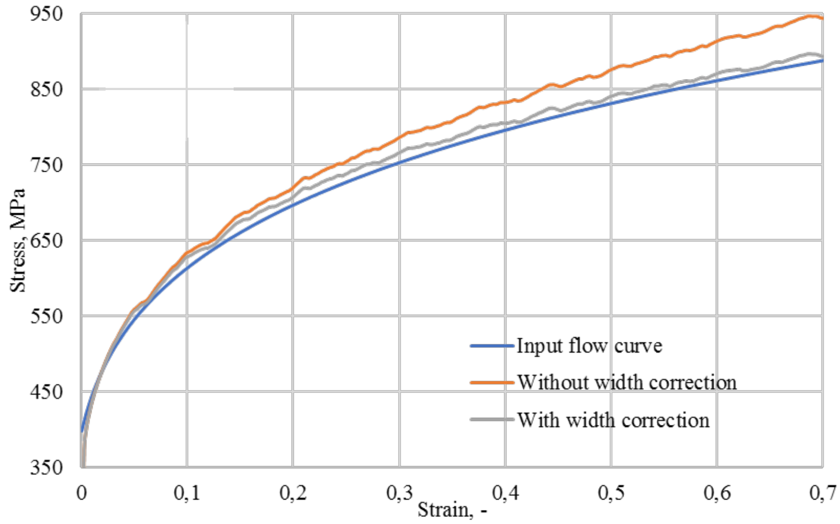

Figure 5. Influence of the width correction factor on the PSCT-based flow curve using 3D simulations of the PSCT test.

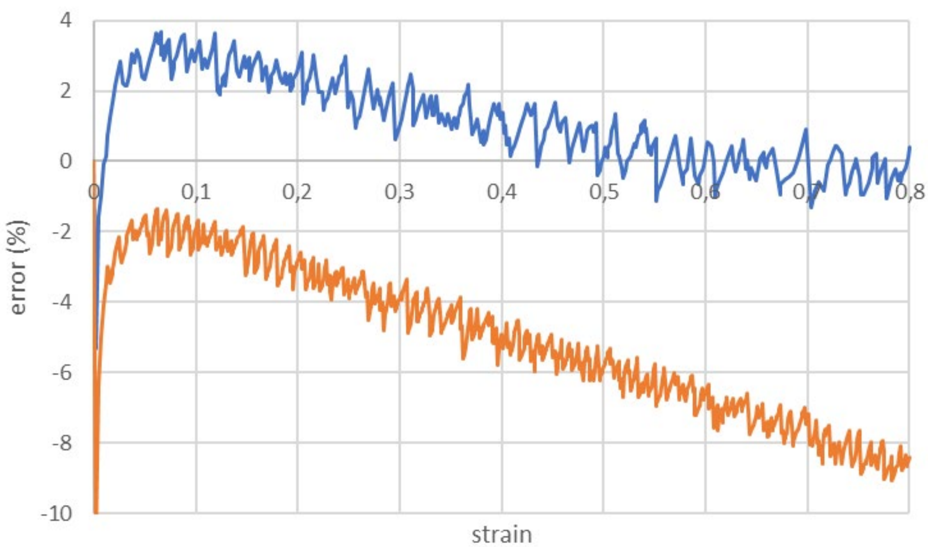

Figure 6. Error in the predicted flow curves for tool misalignment of 0.1 mm (blue) and 0.5 mm (orange).

References

[1] Becker N, Pöhlandt K, Improvement of the plane-strain compression test for determining flow curves. Ann CIRP 38 (1989) 227–230. https://doi.org/10.1016/S0007-8506(07)62691-2

[2] Chermette C, Unruh K, Peshekhodov I, Chottin J, Balan T, A new analytical method for determination of the flow curve for high-strength sheet steels using the PSCT, Int J Material Forming 13 (2020) 269-292. https://doi.org/10.1007/s12289-019-01485-4

[3] Gelin JC, Ghouati O, Shahani R (1994) Modelling the plane strain compression test to obtain constitutive equations of aluminium alloys. Int J Mech Sci 36(9):773–796. https://doi.org/10.1016/0020-7403(94)90009-4

[4] Aksenov S, Kliber J, Puzino Y, Bober S, Processing of PSCT results for investigation of AISI-304 stainless steel constitutive behavior. J Chem Techn Metallurgy 50 (2015) 644–650