11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

Finite Element Analysis of Wrinkling During Cup Drawing

Diogo M. Neto[1], Pedro D. Barros[1], Marta C. Oliveira[1], José L. Alves[2] and Luís F. Menezes[1]*

[1] CEMUC – Department of Mechanical Engineering, University of Coimbra,
Rua Luís Reis Santos, Pinhal de Marrocos, 3030-788 Coimbra, Portugal
e-mail: {diogo.neto, pedro.barros, marta.oliveira, luis.menezes}@dem.uc.pt,
http://www2.dem.uc.pt/cemuc/

[2] CT2M – Department of Mechanical Engineering, University of Minho,
Campus de Azurém, Guimarães, 4800-058, Portugal
e-mail: jlalves@dem.uminho.pt, http://www.ct2m.uminho.pt/

Key Words: *wrinkling, in-plane mesh refinement, yield criteria, DD3IMP.*

Sheet metal forming is one of the manufacturing processes where the use of finite element analysis (FEA) had the largest impact in the design stage, driven by the strong demands on high precision and high value-added products imposed by sectors such as the automotive industry, aircraft industry and can industry. FEA allows reducing process development time and to obtain high precision products, since it allows the prediction of defects and design modifications at the design stage. The major defects in sheet metal forming processes are tearing, springback and other geometric surface defects, including wrinkling. Nowadays, thin high strength sheet metals are being used on various types of automotive parts. On the other hand, the improvements on can manufacturing technology and cost control efforts have resulted in a consistent reduction of the net metal weight and cost which led to beverage cans with thinner sidewalls, reduced neck diameters and smaller base diameters [1]. However, small diameter cans and light gauge material increases the likelihood of wrinkling during sheet metal forming. Thus, wrinkling is becoming a more prevalent failure mode. Wrinkling is a kind of local buckling of sheet metal which is formed by excessive compressive stresses, i.e. it results from instability under compressive stresses [2]. Manufacturing experience suggests that wrinkling is influenced by various factors such as mechanical properties of the aluminium sheet, tooling geometry, contact conditions including the effects of lubrication, and process boundary conditions [1]. Thus, unlike the fracture limit that can be estimated using strain or stress values, the wrinkling limit will also be highly influenced by geometry and contact conditions. In fact, the initiation and growth of wrinkles are influenced by many factors such as the stress ratio, the mechanical properties of the sheet material, the blank geometry and the contact conditions. The effects of all these factors are very complex and the studies of wrinkling behaviour may show a wide scattering of data for small deviations in factors, as is common in instability phenomena [3]. In fact, small variations of the parameters can result in widely different wrinkling behaviours [1].

The two main categories of wrinkling that may occur during deep drawing are flange and wall wrinkles [4], which are basically originated from the compressive circunferential stresses. However, wall wrinkling occurs far more easily than the wrinkling on the flat flange since the wall is relatively unsupported by the tool. Also, the suppression of wall wrinkles is more difficult than the suppression of flange wrinkles, which can be controlled by increasing the

blank holder force, i.e. by changing the radial tensile stress component [2]. However, in order to improve the productivity and the quality of products, wrinkling must be suppressed.
This work focuses on the analysis of the NUMISHEET 2014 Benchmark 4 – Wrinkling during cup drawing, which had as objective to investigate the effects of geometry and the materials model on a dome wrinkling (puckering) behaviour. Two different punch geometries were proposed and two materials were selected: an aluminium alloy, AA5042, and a mild steel, AKDQ. The mechanical behaviour of both materials is described using a Voce type isotropic work-hardening law combined with two yield criteria: Hill’48 and Cazacu and Barlat 2001. The numerical simulations were performed with DD3IMP in-house code, which is a fully implicit solver that has been developed to simulate sheet metal forming processes [5]. The contact with friction algorithm and the in-plane mesh refinement have been previously identified as numerical parameters that strongly influence wrinkling prediction [3]. In this study, the circular blank is discretized with 8-node hexahedron solid finite elements, allowing the accurate evaluation of the contact forces through an accurate description of contact evolution and thickness change, associated to the simultaneous contact on both sides of the sheet, which is treated with an Augmented Lagrangian method. The study highlights the influence of the in-plane mesh refinement and of the yield criterion adopted. The comparison between the numerical results and the experimental ones is presented to evaluate the effectiveness of the yield criterion selected as well as the identification strategy adopted. Following the benchmark description, the main process parameters studied are the punch force evolution and the cup radial coordinate *versus* the angle from rolling direction after the drawing process, for three different planes [1]. The results show that accurate wrinkling prediction requires a good selection of the in-plane mesh refinement but also an accurate description of the orthotropic behaviour of the material.

Acknowledgements
This research work is sponsored by national funds from the Portuguese Foundation for Science and Technology (FCT) via the projects PTDC/EMS-TEC/1805/2012 and PEst-C/EME/UI0285/2013 and by FEDER funds through the program COMPETE – Programa Operacional Factores de Competitividade, under the project CENTRO -07-0224 -FEDER -002001 (MT4MOBI). The first author is also grateful to the FCT for the PhD grant SFRH/BD/69140/2010.

REFERENCES

[1] R. Dick, R. Cardoso, M. Paulino and J.W. Yoon, Benchmark 4 –Wrinkling During Cup Drawing, *AIP Conf. Proc.* Vol. **1567**, 262-327, 2013.
[2] M.A. Shafaat, M. Abbasi and M. Ketabchi, Investigation into wall wrinkling in deep drawing process of conical cups, *J. Mater. Process. Tech.* Vol. **211**, 1783-1795, 2011.
[3] J.B. Kim, J.W. Yoon and D.Y. Yang, Investigation into the wrinkling behaviour of thin sheets in the cylindrical cup deep drawing process using bifurcation theory, *Int. J. Numer. Meth. Engng.* Vol. **56**, 1673–1705, 2003.
[4] C.T. Wang, G. Kinzel, T. Altan, Wrinkling criterion for an anisotropic shell with compound curvatures in sheet forming, *Int. J. Mech. Sci.* Vol. **36**, 945–960, 1994.
[5] L.F. Menezes and C. Teodosiu, Three-dimensional numerical simulation of the deep-drawing process using solid finite elements. *J. Mater. Process. Tech.* Vol. **97**, pp. 100-106, (2000).