MERIT RESEARCH JOURNALS
www.meritresearchjournals.org

Merit Research Journal of Petroleum, Geology and Mining Vol. 1(1) pp. 001-008, August, 2013
Available online http://www.meritresearchjournals.org/pgm/index.htm

Full Length Research Paper

Experimental and simulation analysis of deep drawing cylindrical cup process

Najmeddin Arab

Department of Material science, Branch of Saveh, Azad Islamic University, Saveh, Iran.
E-mail: najarab@yahoo.com; Tel.: 0098 912 6052792

Accepted August 01, 2013

The deep drawing process is one of the most important sheet metal forming processes. The traditional sheet forming techniques used in industry is experimental, expansive and time consuming methods. Prediction of the formability, thickness distribution in deep drawing process will decrease the production cost and time of material to be formed. In this study, a rigid-viscoplastic FEM, using ABAQUES software with anisotropic Hill's non-quadratic yield criterion is applied to analyze the deep drawing of axisymmetric cylindrical cup. The strains in the radial and circumferential directions have been measured. A correlation on the flange thickness variation by taking into account the work hardening with the experimental values has been searched. The optimal process parameters in the sheets obtained in the simulation were compared with experimental results for various forming conditions. With this regard, the numerical simulations were conducted using the finite element method for cup shaped components with flange. Thickness distribution is obtained for entire cup along with flange. The results obtained from this numerical analysis are compared with experimental findings and results of other researchers. Experimentally thickness distribution is obtained by measurement at various locations in half cut cup along with flange region.

Keywords: Deep Drawing, Simulation Sheet Metal Forming, Experimental Analysis

INTRODUCTION

Steel makers test the formability of newly developed materials to evaluate their service performance or to select them for specific applications. Traditionally, they carried out forming experiments with simply shaped small tools, and compensated for insufficient data by referring to past forming results. Conventional procedures produced only qualitative results and were not capable of accurately evaluating materials.

Theoretical analysis of deep drawing of cups was first reported by Hessenberg (Hessenberg, 1954), and Danckert (Danckert, 1995) studied the effect of residual stress in deep drawing of cylindrical cups by process modeling the die profile. The results of the parametric variation of the numerical simulation by Kobayashi and co-workers (Kobayashi and Alton, 1989; Kobayashi, 1978) compared reasonably well with experimental work of Swift and Chung (Swift and Chung, 1951), Yamada and Oshimura (Yamada and Oshimura, 1968), introduced plasticity matrices with elasto-plasto model for analyzing cup drawing.

In recent years, computers have advanced in both hardware and software to the extent that they can now analysis sheet metal forming problems or nonlinear and large-deformation problems that were very difficult to solve due to the complex change in boundary conditions. With the aid of numerical analysis technique, it is appears possible to achieve the optimal forming of sheet metals by combining material properties and forming conditions

Table 1. Chemical composition of steel sheets.

Steel Grade	% C	% P	% Mn	% S
St 14	Max 0.08	Max 0.03	Max 0.4	Max 0.03

Table 2. Mechanical properties of steel sheets.

Steel Grade	Sheet Thickness mm	Mechanical Properties			Parameters of power Function $\sigma = k\varepsilon^n$	
		$\sigma_{0,2}$ MPa	σ_b MPa	*EL%*	*K*	*n*
St 14	2,0	210	350	36	710	0,307

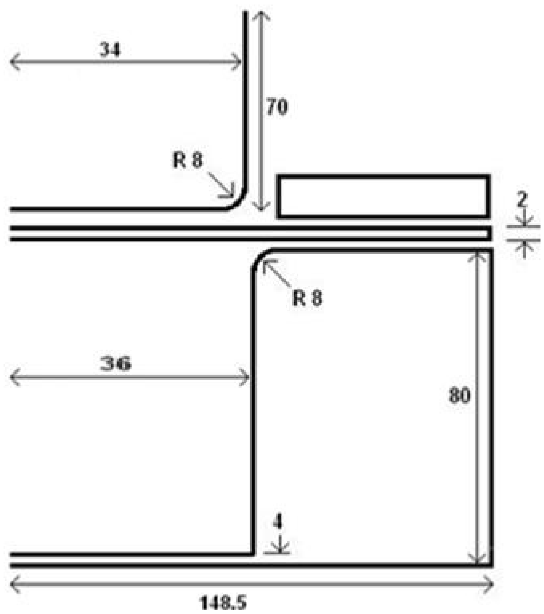

Figure 1. Drawing of cylindrical up used in experiments.

in an appropriate manner (Sattari et al., 2007; Kroplin and Luckey, 1994; Lee et al., 1994).

Cylindrical cup deep drawing and cylindrical punch stretching of sheet metal, the optimal method of forming sheet metals, were analyzed by different software to predicting and evaluating the formability of sheet metals and avoiding the fracture. For axisymmetric cup drawing, the material properties and forming conditions were analyzed for their effects on the strain path of sheet metals, and the fracture limits of sheet metals. For cylindrical punch stretching the limiting dome height was determined from the strain path of fractured portions. The analytical techniques employed were investigated for their agreement with experimental techniques discuss in references (Lang et al., 2001; Yoshida et al., 1995; Jian et al., 2003; Landert and Clyne, 2004; Semenov, 1983).

Experimental procedure

The sheet metal used in this research was 2 mm thick with 148.5 mm diameter carbon steel sheet according to German Standard DIN–EN10130-FePO4-(St14). Chemical composition and mechanical properties of the material are show in Tables 1 and 2.

The die was made from medium carbon steel which the surface of punch and matrix was nitride hardening. Also the polyethylene papers (nylon) used as lubricant.

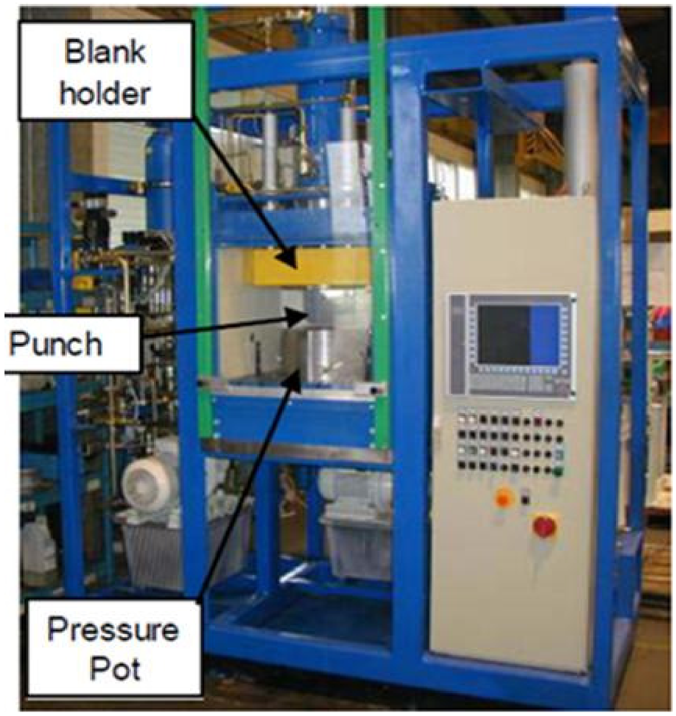

Figure 2. Experimental apparatus and its control system.

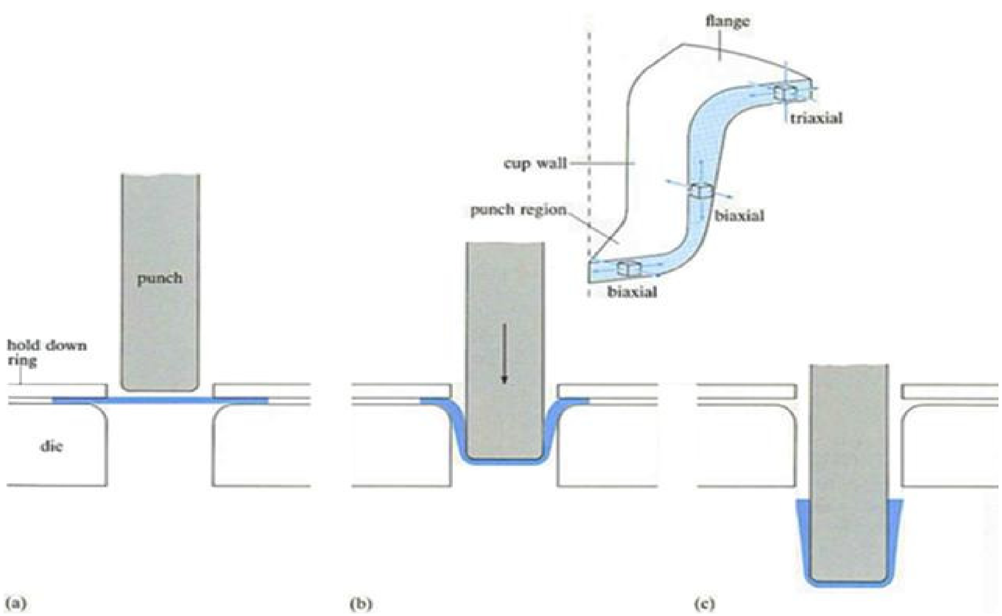

Figure 3. Deep drawing stages and stress situation on different zones of deep drawn cup.

The drawings of die and punch geometry are show in figure 1. The primary sheet size was 148.5 cm diameter that was demarcation the rolling direction. The hydraulic 30 tons press and its control system which show in figure 2 was used to drawn the cups.

To clarify the effects of material properties and forming conditions on the strain path, the *n* and *K* values, friction coefficient, blank shape, and tooling geometry were used as computational parameters. (Figure 1)

The forming sequence can be divided in three stages: (a) the lubricated steel sheet (blank) is placed on the blank holder; (b) the die goes down and tightens the sheet against the blank holder. The joint descent of the die and blank holder causes the starting of the deep

Figure 4. Measuring positions after cutting the drawing cups.

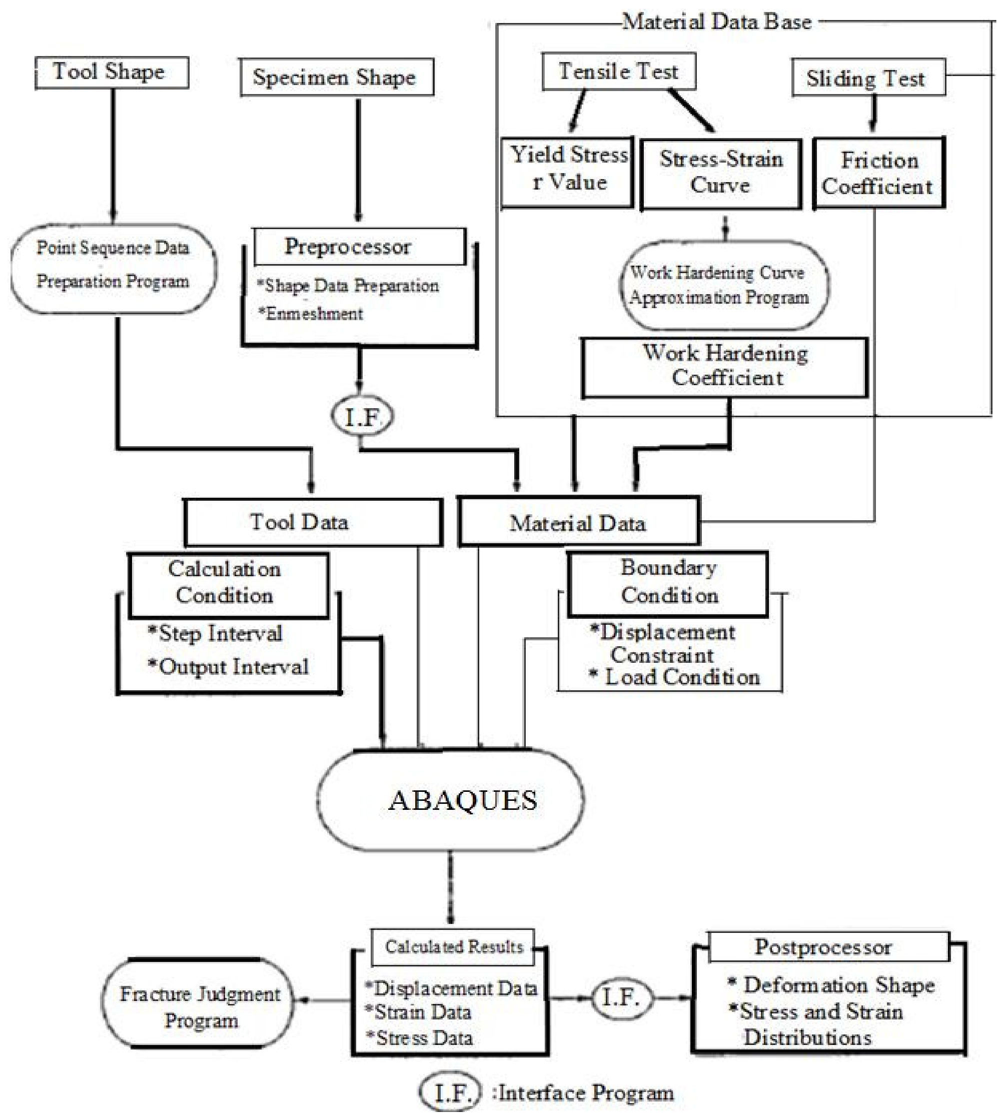

Figure 5. Flow chart of simulation system (Garcia et al., 2006).

drawing and start to draw the sheet on die; (c) Once the lower punch penetration is finished, the moving tools go up and the final part is ejected (Garcia et al., 2006; Hosford, 1993). Figure 3 shows the sheet deformation pattern at stages of this process. Also the figure illustrates the stress situation in drawn cup.

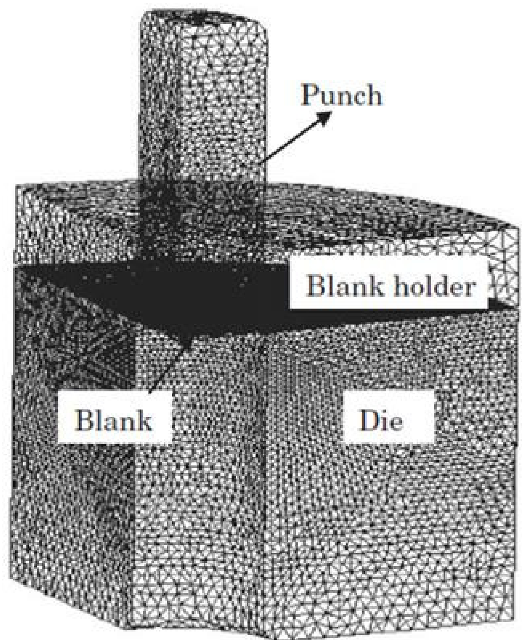

Figure 6. The finite element mesh of cylindrical drawing

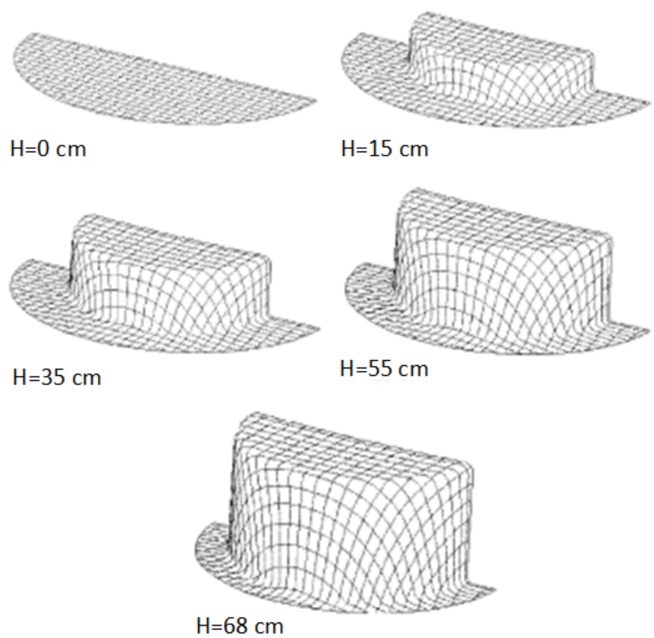

Figure 7. Simulation configuration of deformed cup

After the drawing process, the drawn parts were cut in rolling direction and the thickness was measured according to Figure 4.

Simulation process

Simulations of the process were conducted in FEA software ABAQUES. The configuration of the punch, die, blank and blank holder modeled in the software is shown in Figure 5. Shell type of element was employed to model the blank. Deep drawing quality steel sheet was used as blank material. To predict and evaluate the formability of sheet metals, it is necessary to simulate the whole forming process conditions to predict the fracture, wrinkling, earing or other forming limitations. This can be

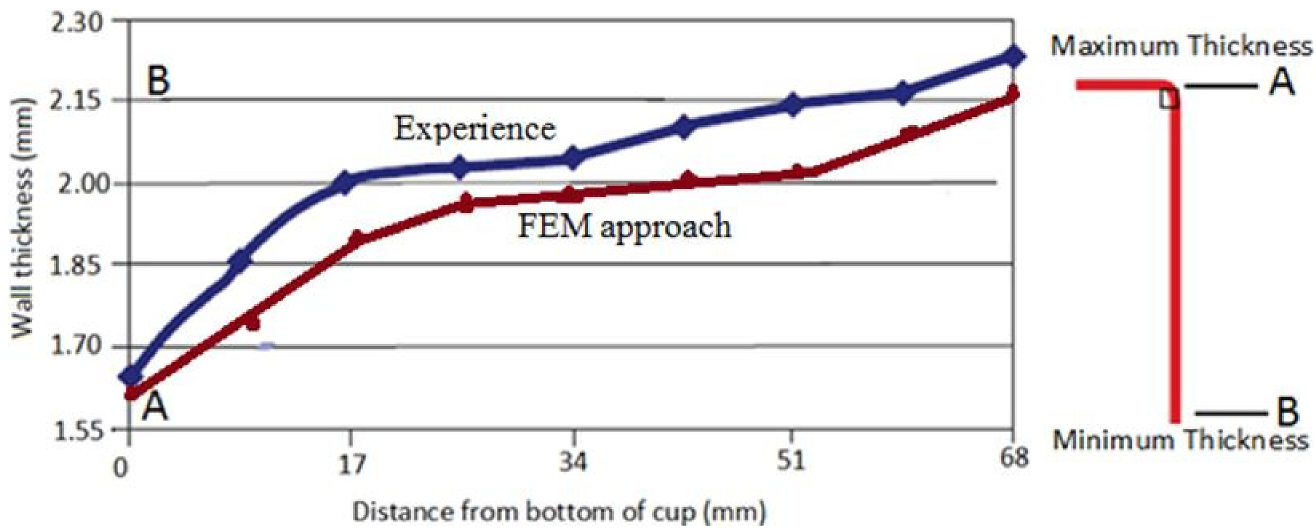

Figure 8. Thickness changes in cup drawing.

accomplished by practical simulation system that combines FEM analysis with fracture estimation. Figure 4 shows the configuration of the forming simulation system. Two or more types of dimensional elastic-plastic programs for the analysis of sheet metal forming are used as FEM solvers. Among them, the ABAQUES is a powerful program using membrane elements and it can solve complex forming conditions without divergence. Computing time can be shortened by carefully selection of meshing procedure of the cup and die parts.

Integrating simulation and the experience of process and tool designers can reduce the sequence development time. Furthermore, simulation helps in designing geometrically more complex parts that would require increased manual design effort and more trial and error. With simulation via FEM, designers can estimate field variables such as strain distribution, stress distribution, material flow and forming defects. This information enhances the design capability and knowhow of an experienced process designer and leads to a reduced number of die-tryout tests.

The applied finite element code is LS-DYNA3D, which is efficient in the simulation of sheet metal forming and popular. The model includes 8259 elements and 7836 nodes. The mesh of process is built with Belytschko-Tsay shell element, the punch, die and blank holder with rigid shell element which only takes account for the elastic deformation. The finite element mesh used in the analysis is shown in Figure 6.

The deformed configurations of the sheet for different punch penetrations are depicted in Figure 7. According to the experiments a blank was drawn at the die in order to clearly showthe deformation patterns experienced to obtain a cylindrical cup.

RESULTS AND DISCUSSION

Experimental results

The thickness measuring results from 6 positions in drawn parts are presented in Figure 8 show maximum thinning and thickening positions in drawn cups.

According to the results of this research, for a blank with 2 mm thickness, the maximum thinning in drawn cups, occur in position 3 and it is 18% of blank thickness. Also the maximum thickening occurs in position 5 and it is 14%of blank thickness. The history plot of the rigid tool contact forces in the Z direction are presented in Figure 9. Two trends are noteworthy: The contact forces are in equilibrium; i.e., the contact force exerted by the punch on the work piece is in equilibrium with the contact forces transferred by the work piece to the holder and die. Note also that as the punch pushes the blank upwards (+Z direction), the predominant tendency is for the sheet to contact the die. However, portions of the sheet separate from the die and make intermittent contact with the holder.

Simulation results

Figure8 compare experiment results with simulated results for wall thickness changes as a function of distance from bottom of cup. As one can see there is good agreement between experiment and simulation results. The equivalent plastic strain contours at the outermost fiber of the work piece and the corresponding equivalent stress contours at the end of the cup forming process. It is noted that maximum plastic strains are of the order of 45% and the peak values occur along the die radius. The portion of the work piece held between the

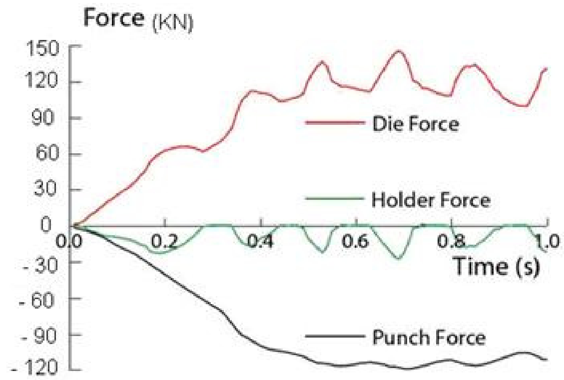

Figure 9. History plot of contact tool forces in Z direction during cup drawing experience.

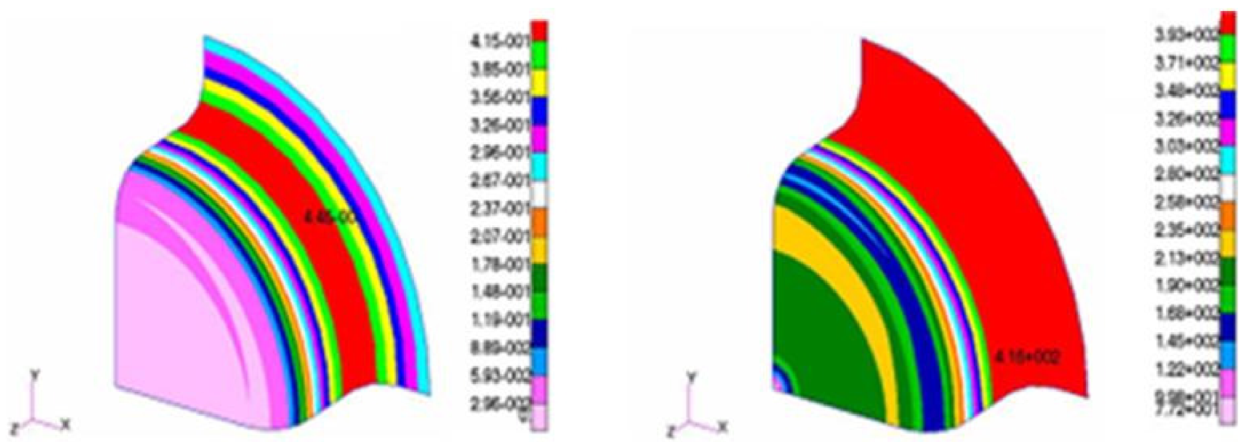

Figure 10. Simulated equivalent plastic strains and equivalent stresses in workpiece at end of cup forming process.

die and the holder is the most highly stressed. Also, the circumferential variation of the quantities is negligible, thereby confirming the axisymmetric nature of the problem being simulated
(Figure 10).

CONCLUSIONS

A finite element modeling of sheet metal forming processes using low carbon standard steel as a blank material has been presented. The performance of the model has been preliminary assessed in the analysis of the deep drawing of a cylindrical cup. A satisfactory experimental validation of the numerical prediction has been achieved for deformation stages and thickness distributions on the sheet. The simulation results corresponding deformations and thickness distributions of the final deformed reasonably agree with the respective experimental values. Although a more complete validation is still desirable, the good performance of this model proves the potential feasibility of its application as a useful tool aimed at improving the design and control of industrial processes. Close cooperation between experienced die designers and FEM engineers makes simulation a practical tool for designing progressive and transfer dies. An excellent alternative, training and experienced designer in the use of FEM codes for simulation

REFERENCES

Danckert J (1995). Reduction of residual stress in deep drawing by modeling the draw die profile, Ann. CIRP 44 (1) 259–262.

Garcia C, Celentano D, Flores F, Ponthot JP, Oliva O (2006). Numerical modelling and experimentalvalidation ofsteel deep drawing processes, Part II: Applications, Journal of Materials Processing Technology 172, 461–471

Hessenberg WC (1954). A Simple Account of Prof. Swift Work on DeepDrawing, BISRA Report

Hosford WF (1993). *The Mechanics of Crystals and Polycrystals*, Oxford University Press, USA, 1993.

Jian N, Shi X, Ngaile G, Altan T, Pax B, Harman B, Homan G (2003). Simulation Confirms Deep Draw Die Design, Metal Forming, November, 32-35.

Kobayashi S (1978). The matrix method for the analysis of metalforming, Advances in Deformation Process, Plenum Press, NewYork

Kobayashi S, Alton T (1989). Metal Forming and Finite Element Method, Oxford University Press, Oxford

Kroplin B, Luckey E (1994). Metal forming process simulation in industry, International Conference and Workshop, Baden-Baden, Germany,28– 30.

Landert M, Clyne TW (2004). Exploration of deep drawing characteristics, University of Cambridge, http://www.msm.cam.ac.uk/mmc

Lang L., Kang D, Wang Z, Yuan S (2001). Numerical Simulation of Failure during Cylindrical Cup Hydrodynamic Deep Drawing, J. Mater. Sci. Technol. 17, 1, 133-134.

Lee JK, Kinzel GL, Wagoner R (1994). Numerical simulation of 3D sheet metal forming processes, verification of simulations with experiments, Third International Conference on NUMISHEET 96, the Ohio State University,September Dearborn, MI. USA.

Sattari H, Sedaghati R, Ganesan R (2007). Analysis and design optimization of deep drawing process. Part 1,Three dimensional finite element and sensitivity analysis, *J. Mater. Process. Technol*. 184, 84-92.

Semenov EI (1983). *Handbook of Sheet Metal Forming*, Machinery-Building, Moscow, Russia,

Swift W, Chung SY (1951). Cup drawing from a flat blank—experimentalinvestigation, Proc. Int. Mech. Eng. 199–211.

Yamada Y, Oshimura N (1968). Plastic stress strain matrix and applicationfor the solution of elasto-plastic problem by FEM, Int. J. Mech. Sci.10 343–354.

Yoshida T, Hashimoto K, Usuda M (1995). 3-D FEM Analysis of Sheet Metal Deep Drawability and Strechability, Application of FEM Analysis to Research Formability of Sheet Metals, Nippon Steel Technical Report No. 67.