MODELING AND SIMULATION OF METAL COLD-FORMING MANUFACTURING USING DEFORM-2D.

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CD de Monografías 2013

Abstract.

Numerical modeling and simulation of technological processes has proven to be very convenient in the manufacturing industry, helping to increase productivity and reduce economical expenditure on costly shop floor trials and redesign of tooling and processes. Finite element methods have gained popularity in process analysis due to their outstanding capabilities. The present paper reports an investigative study made on the process of metal cold-forming in the manufacturing of gas cylinders using the DEFORM 2D software as a simulation and modeling tool. An analysis of the AISI 1006, AISI 1010 and AISI 1015 steels sheet thickness was carried out examining the effective stresses and strains in meshed elements. The simulation results affirm the accuracy, precision and effectiveness of the software.

Keywords: *Finite element method, cold-forming, Deform 2D.*

1. Introduction

The Finite element method has become a household name in the field of engineering and has forever changed the point of view of engineers in the analysis of complex domains. What we have as present day finite element method groups together ground-breaking mathematics and engineering discoveries that date back to the perfection of the direct stiffness method by Jon Turner between 1950 and 1962. FEM was developed initially, and prospered, as a computer-based simulation method for the analysis of aerospace structures. Then it found its way into both design and analysis of complex structural systems, not only in Aerospace but in Civil and Mechanical Engineering. In the late 1960s it expanded to the simulation of non-structural problems in fluids, thermomechanics and electromagnetics. (Felippa, 2004)

Due to its outstanding abilities such as remarkable robustness and flexibility, it was no surprise as it got integrated into a wider scope of engineering applications such as manufacturing processes. Various software production companies therefore took advantage in designing programs tailor-made to analyze and simulate manufacturing processes. Recent research reflects the betterment of these programs as computer evolution continues to take positive development strides. Among the existent manufacturing processes which have implemented FEM is metal cold-forming which refers to the operation through which a laminated metal sheet is subjected to the force to obtain a hollow final object. (Rossi, 1979)

During the process of cold-forming, due to factors like inadequate lubrication and high values of the punch force, problems like bottom die destruction and variation of thickness in the formed product can occur. This conditions can bring forth undesired consequences such as low quality products or temporary stops in the line of production which incur economical expenses. The possibility of simulating and modeling the process with computer software therefore seems of utter benefit because it allows the detection of problems that can arise in the handling without the consumption of actual materials and the ability to test-drive necessary adjustments in working parameters and analyze their behavior. The DEFORM software has proven to be one of the ideal computer software capable of accurately carrying out FEM based forming modeling.

For instance (Lee *et al.* 2004) carried out experimental and FEM analyses to investigate the elastic characteristics of workpiece and die in the closed-die upsetting for ferrous metal using the DEFORM-2D software, mainly to estimate the elastic strains and stresses of die and the dimensional changes of the workpiece. They validated the FEM results of the estimated strains for the die by comparing them with the measured strains by strain gages attached on the available locations.

Metal cutting operations have also been successfully simulated using the DEFORM-2D in the analysis of serrated chips. (Ceretti *et al*. 1999) employed the FEM program to predict ductile fracture initiation and propagation in serrated chip formation at different cutting conditions in a simple orthogonal cutting operation. The DEFORM-2D program has shown capabilities of analyzing and studying the behavior of variables that are difficult to control such as the influence of friction in cold-forging operations. (Buschhausen *et al*. 1992) proposed and examined a friction test, based on a double backward-extrusion process in order to obtain information on lubrication quality. In this test, the upper punch moves downwards, while the lower punch and the die are stationary. Based on the FEM simulations, calibration curves were established. Using these calibration curves and measuring only the heights of the extruded cups and the punch stroke in experiments enables the quantification of the friction factor and the evaluation of the lubrication conditions under production conditions.

(Quang-Cherng & Rong-Shean, 1997) used a FEM based program to simulate multi-stage cold forging based on pre-defined process condition parameters and tooling geometry. The results of the simulations were then set up for the construction of a neural network model which used the multi-layer network and the back-propagation algorithm to learn the training examples. They were able to successfully decide the optimal process condition parameters like preform punch geometry and preform punch stroke based on the requirement of homogeneous plastic deformation of the cold-forged product.

The proposed method proved to be useful for the shop floor to decide the cold forging process parameters for producing a sound product within the required minimum quantity of the die set.

More than two decades ago studies (Knoerr & Altan, 1992) pointed out the use of the DEFORM program to perform FEM based analyses in 2 dimensions of various forming processes such as cold-forging, making emphasis on aspects like the prediction of flow-induced defects, precision forging of aluminum alloys, investigation of a suck-in type extrusion defect, forging of bevel gears, stress analysis of forging dies, and development of a new test to evaluate lubrication in cold forging.

There is surplus evidence of the achievements of solutions of differential equations by the FEM, its integration into computer software to assemble powerful tools able to simulate processes. A wide range of metal manufacturing process applications clearly bear testimony of the competence of the software package of DEFORM-2D. This influenced the utilization of the above mentioned program in the study and simulation of the cold forming process indicated in this paper.

2. Basic working principles of the DEFORM-2D software

Deform-2D is a finite element method based process simulation system designed to analyze various forming and heat treatment processes used by metal forming and related industries. Widely used applications include, cold-forming, machining and die and stress analysis to mention but a few. Its implementation of the finite element tools grants it the merits of high accuracy, precision and robustness.

Deform is designed specifically for deformation modeling, serving as a very useful aid in production and research facilities with numerous advantages like the reduction of costs and expenses in shop floor trials. The software consists of a system that automatically analyzes optimized meshed models, examining parameters like heat flow, temperature, stress and strain distributions in two-dimensions.

Among the special capabilities of the Deform-2D we can find:

- Self-contact boundary condition with robust remeshing allowing a simulation to continue to completion even after a lap or fold has formed.
- Multiple deforming body capability allows for analysis of multiple deforming workpieces or coupled die stress analysis.
- Fracture initiation and crack propagation models based on well-known damage factors allow modeling of shearing, blanking, piercing, and machining.

General capabilities include:

- Extensive material database for many common alloys including steel, aluminum, titanium, and super-alloys.
- Contour plots of temperature, strain, stress, damage, and other essential variables simplify post processing
- User defined material data input for any material not included in the material database.

The working principle of the program can be broken down into 3 major aspects: pre-processing, running simulation and post processing. The preprocessing aspect deals with the assembly of the data required to run the simulation such as object description, detailing geometry, mesh, material, temperature, etc.

Other important data include specifications of the description of the material behavior under the conditions, the manner in which the objects interact with one another and instructions on the methods DEFORM should use to solve the problem. The running of the simulation consists of an engine that reads the input data and performs actual numerical calculations. The post processing allows the observation of the data upon completion of the simulation, permitting the view of information like stress, strain, temperature, damage, etc.

3. Experimental setup of case–study

DEFORM-2D was used to simulate a cold-forming process of a steel disc of 530 mm diameter and 2.2 mm of thickness to develop the bottom and top components that constitute the body of gas cylinders as shown in figure 1 a), with the dimensions shown on Fig. 1 b). The material properties and geometry of the workpiece were introduced in the pre-processing unit as well as the lubrication conditions, top and bottom die dimensions, mesh type, number of steps, working parameters such as velocity and force of the top die, pressing pressure etc.

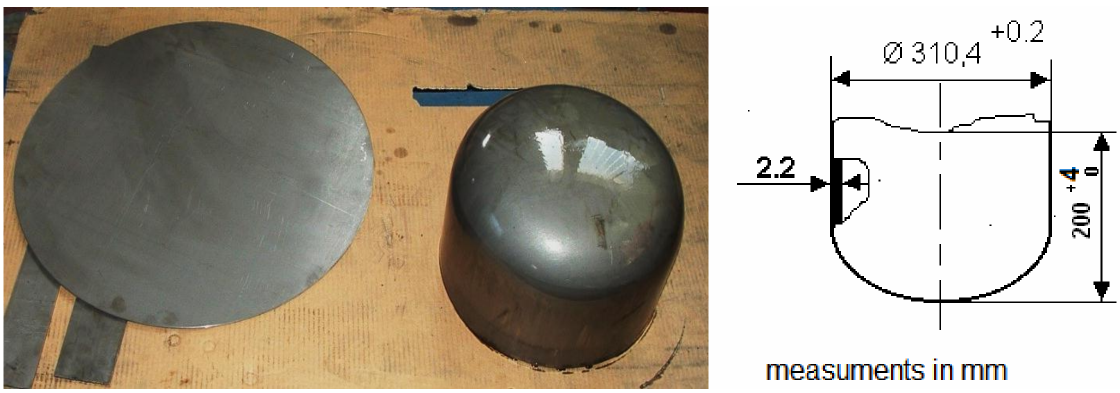


Fig. 1 (a) Workpiece metal disc and formed b) Measurements of formed workpiece

Simulations were carried out using the AISI 1006, AISI 1010 and AISI 1015 steels, inputted from the material library of the software. Table 1 shows the forming parameters introduced to the pre-processor unit of the program to carry out the simulation.

Table 1 Forming parameters of first simulation with the AISI 1006 steel.

Parameter	**Value**
Punch force ((Ton)	96
Pressing force (Ton)	36
Punch velocity (mm/s)	30.3
Punch depth (mm)	200
Lubricant friction coefficient	0.08
Meshing	5 000
Number of steps	200

Fig. 2 shows the assembly and dimensions of the respective dies as they appear in the DEFORM working window. It only shows a 2-dimensional image and only half of the layout, hence what is shown is the symmetrical half of the components.

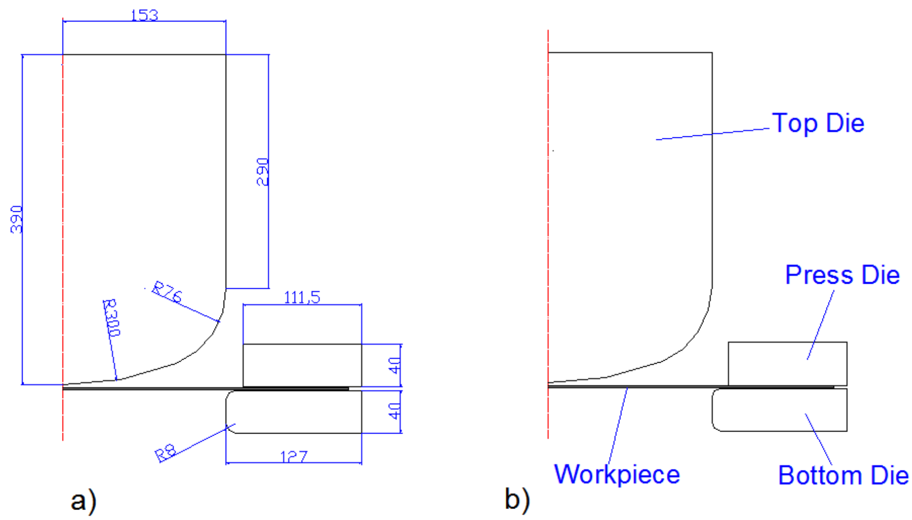


Fig. 2 Geometries and measurements of the dies. (Measurements in mm)

In the following table, values and working parameters of simulations with AISI 1010 and the 1015 steels are shown, with a variation of the top die velocity to a lower value and an increased number of meshed elements, which gives a better approximation.

Table 2 Forming parameters for the simulation with AISI 1010 and 1015

Parameter	**Value**
Punch force ((Ton)	96
Pressing force (Ton)	36
Punch velocity (mm/s)	20.6
Punch depth (mm)	200
Lubricant friction coefficient	0.08
Meshing	10 000
Number of steps	1000

4. Results and discussions

Once the simulations were complete, the relative formed workpiece with all the values of the acquired alterations it went through during the forming process are displayed in the post processing unit of the software in graphical mode, allowing a clear inspection of the workpiece with respect to the strains, stresses, temperature distributions, and damage to mention but a few.

In the first simulation with the AISI 1006 steel at 30.3 mm/s top die velocity the workpiece was successfully deformed with an observed incomplete flow of workpiece material in to the bottom die, part of it remained hung between the coupled pair of the bottom and the press die. Courtesy to the name "cold-forming", the results clearly mark no increase of temperature. A 20 ^{o}C temperature distribution is observed in all parts of the workpiece.

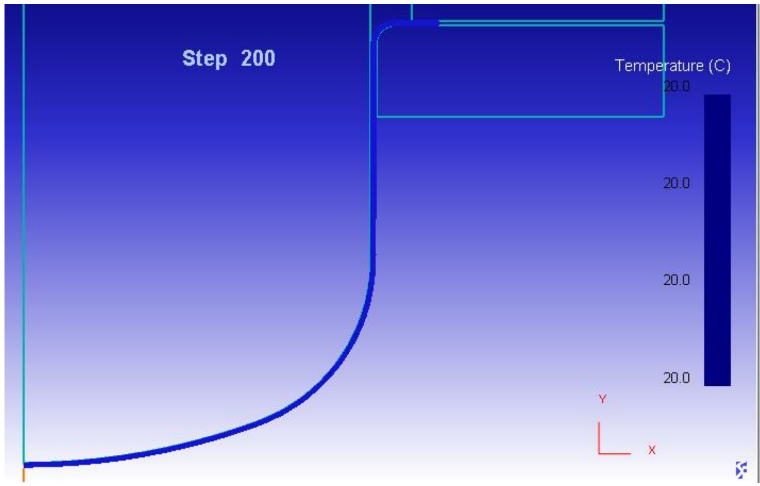


Fig. 3 Temperature distribution AISI 1006 steel.

The vertical movement of the top die is the one that enables it to produce the necessary force to disfigure the metal sheet into the desired geometry at a predetermined velocity. The velocity flow of the workpiece material is shown in fig. 4, with maximum values of 21.5 mm/s are observed where the workpiece has direct contact with the dynamic top die.

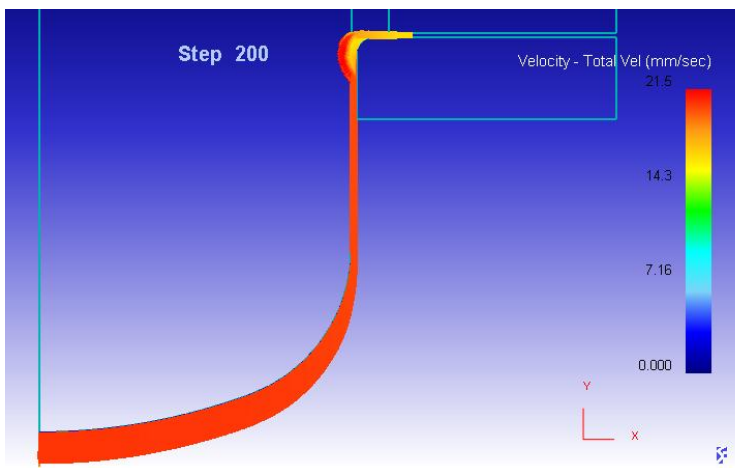
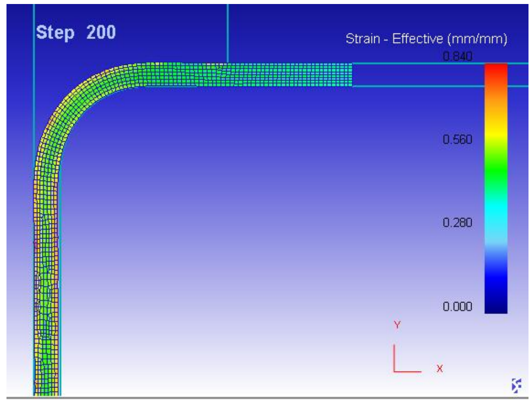
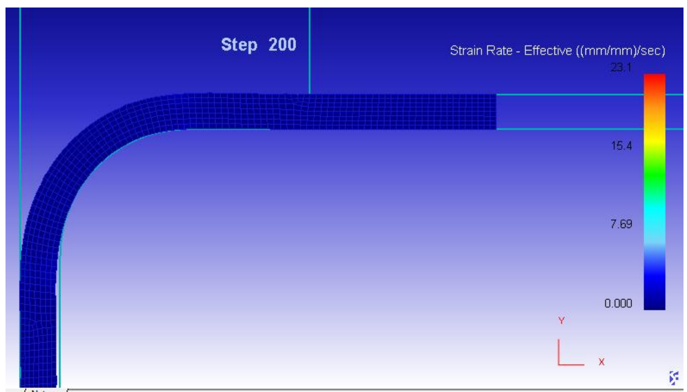


Fig. 4 Total velocity flow AISI 1006 steel.

Fig. 5 a) and b) show the strain and strain rate values respectively, with maximum values of strain reaching 0.840 mm and practically minimum values of strain rate by the end of the process.



a) Effective strain AISI 1006

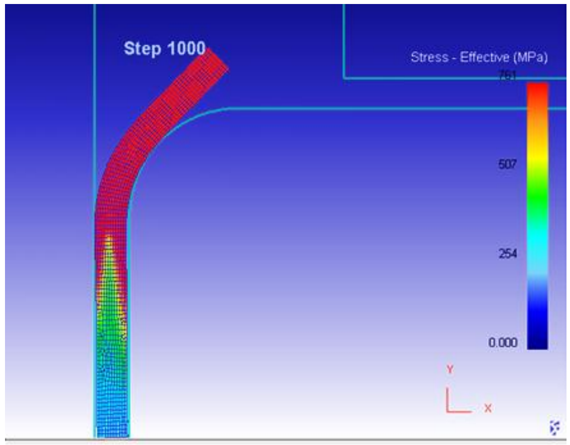


b) Effective strain rate

Fig. 5 Strain of the sheet.

Part of the material was seen beheld by the force between the press die and the bottom die, showing high effective stress rates of 554 MPa around the top edges as shown by fig. 6a). Simulations with the AISI 1015 steel show a better flow of material surpassing the force of the press and bottom die, with registered maximum effective stress values of 761 MPa respectively, as shown in fig. 6b)

a) AISI 1006 steel



b) AISI 1015 steel

Fig. 6 Zones of maximum effective stresses.

Figure 7 a) and b) display the damage undergone by the workpiece metal sheet in the most critical areas. Though the values are very small, the simulation with less velocity of the AISI 1015 steel show higher maximum damage values of 1.01 whereas the AISI 1006 reflect only 0.895 damage maximum value.

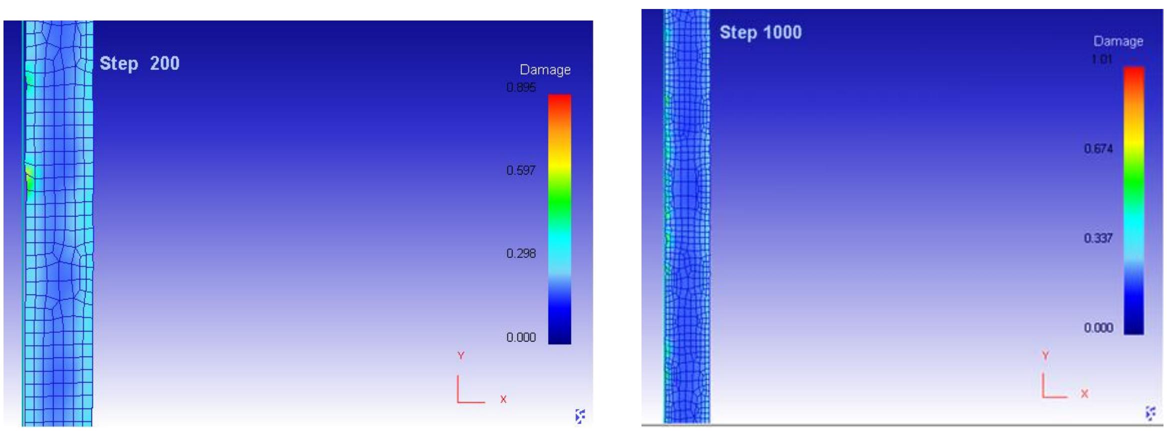


Fig. 7 Damage analysis a) AISI 1006 steel b) AISI 1015 steel

The thickness of the workpiece is a very critical value to monitor because it carries with it, the responsibility of guaranteeing the integrity of the whole formed object to withstand internal and external pressure forces that may be subjected to the workpiece when it carries out its function as a finished object. Fig. 8 shows some critical zone at the dome of the zone where in real life, the thickness of the sheet always tends to vary. This is also proven by the simulation as there is a distinctive variation of the same.

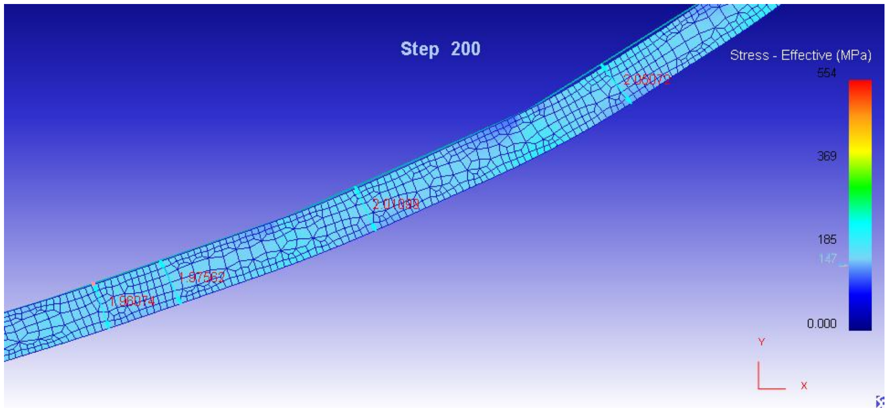


Fig. 8 Thickness at bottom domed zone AISI 1006 steel

5. Conclusion

This study affirms and acknowledges the ability of the DEFROM-2D software to successfully and accurately model and simulate the process of metal cold-forming. The implementation of the software addresses one of the cornerstone objectives in the manufacturing industry; increasing productivity at lower costs, as it eliminates loss of material and frequent stops in the line of production in trial runs. It also serves as a prognostic aid as damages and excessive deformations of either the workpiece material or the working tools can be observed beforehand and necessary measures to resolve the problem can be made.

Bibliografía.

Buschhausen A.; Weinmann K.; Lee J.Y.; Altan T., 1992. Evaluation of lubrication and friction in clod forging using a double backward-extrusion process, *Journal of Materials Processing Technology*, 33(1-3) p. 95-108

Ceretti E.; Lucchi M.; Altan T., 1999. FEM simulation of orthogonal cutting: serrated chip formation, *Journal of Materials Processing Technology*, 95 (1-3) p. 17-26

Felippa C.A., 2004. *Introduction to finite element methods* (First edition), Boulder-Colorado (USA), 626 P

Knoerr M.; Altan T., 1992. Application of the 2D finite element method to simulation of cold-forging processes, *Journal of Materials Processing Technology*, 35 (3-4) p. 275-302

Lee Y.S.; Lee J.H.; Kwon Y.N; Ishikawa T., 2004. Analysis of the elastic characteristics at die and workpiece to improve the dimensional accuracy for cold forged part, *Journal of Materials Processing Technology*, 153-154 p. 1081–1088

Rossi M., 1979. *Estampado en frio de la Chapa* (Ninth edition) Editorial Dossat, Madrid (Spain), 712 P

Quang-Cherng H.; Rong-Shean L., 1997. Cold forging process design based on the induction of analytical knowledge, *Journal of Materials Processing Technology*, 69 (1-3) p. 264–272