FINITE ELEMENT SIMULATION OF SHEET METAL DEEP DRAWING USING EXPLICIT CODE AND RESULT VALIDATION

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Abstract - ***Metal forming process requires lot of trials to arrive at the tool design to produce defect free parts. The design of new forming tools gets more problematic as the geometries get more complicated and the materials less formable. Today, metal forming simulation is an effective technique for predicting the formability of automotive parts. Compared with conventional methods such as the use of try-out tools, metal forming simulation enables a significant increase in the number of tool designs that can be tested before hard tools are manufactured. A significant understanding into the result of the forming operation can be gained as it is possible to use sheet-metal-forming simulation at an early stage of the design process, for instance in the preliminary design stage. This work has been done to study the explicit nonlinear behaviour of sheet metal forming process utilizing the FEA software. This work will help in setting a benchmark for the development of new forming tools.***

The main objective is to avoid cracking and severe wrinkling which may occur in the forming process. The objectives are achieved by studying the sheet metal deep drawing process and the parameters required for defect free finished parts. Further, the LS-DYNA cards of a forming example model have been studied using LS-DYNA KEYWORD & THEORY manuals. Using CATIA V5 R16 software the modelling of the components is done; based on the guidelines set, the meshing of the model and the solver deck is created using pre-processor-Altair Hypermesh v11.0. The solver used is L-S DYNA Version: ls971. The post processing is carried out using Altair Hyperview v11.0.

The simulation results are in concurrence with experimental results. The analysis is helpful for the prediction of thickness variation of the product prior to the carryout of the actual drawing process. The analysis may be used for estimating the critical thickness that might initiate the failure of the product and also to set the minimum clearance between the punch and die. Any changes in the tool design, new ideas can be easily incorporated into the process without extra costs. With the help of simulation results the major parameters that affect a stable forming process were found.

Key Words: *Sheet metal, Explicit analysis, Deep drawing*

1. Importance of virtual tools in design process

Finite element analysis (FEA) has become an integral part of design process in automotive, aviation, civil construction and various consumer and industrial goods industries. Cut throat competition in the market puts tremendous pressure on the corporations to launch reasonably priced products in short time, making them rely more on virtual tools (CAD/CAE) accelerate the design and development of products. FEA tools are being used in analyses of multi-disciplinary problems, including but not limited to structures, thermal and fluid flow, bio-technology, electromagnetism etc.

FEA analysis helps in accelerating design and development of the products by minimizing number of physical tests, thereby reducing cost of prototyping and testing; however FEA has not taken the place of the validation by testing. Many organizations are working hard to achieve 100% virtual validation of the products.

Past few decades have seen an increase in application of CAE for simulation of crash/impact phenomenon particularly due to the development of high computing machines and parallel computing techniques.

In the past, trial and error and operator experience optimized part and die design. Today, computer aided design and finite element modeling are used to create part and die designs and to simulate the deep drawing process, significantly reducing the costs of tooling and labor in the design process.

1.2 Sheet metal deep drawing process

Deep drawing is a manufacturing process that is used extensively in the forming of sheet metal into cup or box like structures Figure-1. Pots and pans for cooking, containers, sinks, automobile parts, such as panels and gas tanks, are among a few of the items manufactured by sheet metal deep drawing.

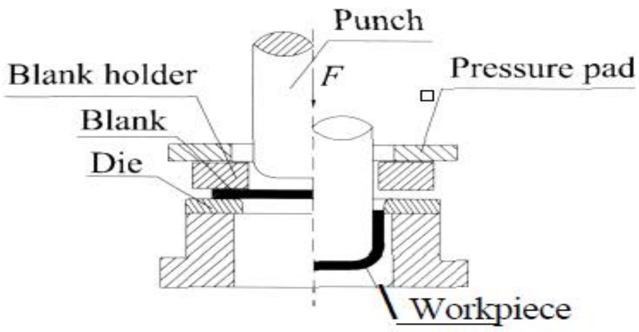


Fig -1: Deep drawing of a plane round sheet plate

Deep drawing involves complex material flow and force distributions Figure-2. There are two main factors which cause the punch in deep drawing to draw the metal into the die cavity, rather than shearing it. One major factor in deep drawing is the die corner radius and the punch corner radius.

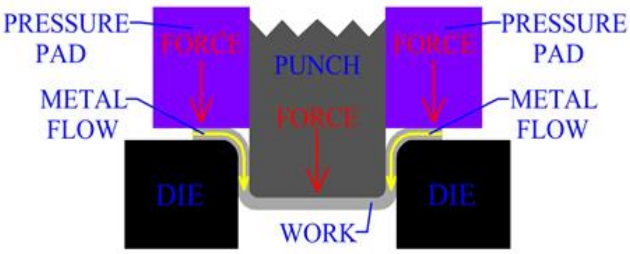


Fig -2: General direction of metal flow

A radius on an edge will change the force distribution and cause the metal to flow over the radius and into the die cavity. However, there are changes in thickness in certain areas, due to the forces involved. Material forming the straight wall is under tensile stress that will naturally cause it to thin. Deep drawing process factors are controlled to mitigate thinning, but some thinning of the sheet metal is unavoidable. Maximum thinning will most likely occur on the side wall, near the base of the part. A correctly drawn part may have up to 25% reduction in thickness in some areas.

2. STATEMENT OF THE PROBLEM

In this paper study is done by taking a deep drawn split rim of an automobile as shown in Figure-3. Split rims are used generally in earth moving machinery, fork lifts, tractors, large trucks etc. A nonlinear analysis is performed. Typical goals of this thesis are to improve the ability to:

•Evaluate manufacturability
•Estimate target geometry, spring back, bulging
•Determine areas of necking (areas with high risk of fracture)
•Find where to put draw beads, choose lubrication.
•Evaluate tool wear
•Decrease costs and shorten time
•Optimize shape and reduce residual stresses

Fig -3: Split Rim

3. EXPLICIT ANALYSIS & IMPLICIT ANALYSIS

In simple terms a numerical stepping scheme is called explicit when a direct computation of the next, unknown, time step is made, using only already known quantities from previous time steps. This is in contrast with the implicit method, which solves the equation by involving the current state, as well as the later one, which is unknown. It is clear that the implicit method takes more effort to calculate and also may be harder to implement. When solving with the implicit method, the inversion of the stiffness matrix is required. Thus, for problems with large deformations, this matrix will be very large and hence very expensive to compute. However, the implicit method has some advantages over the explicit.

Figure-4 shows the graphical representation of the computational cost in terms of CPU time and speed v/s model size, physical complexity due to material models. [12]

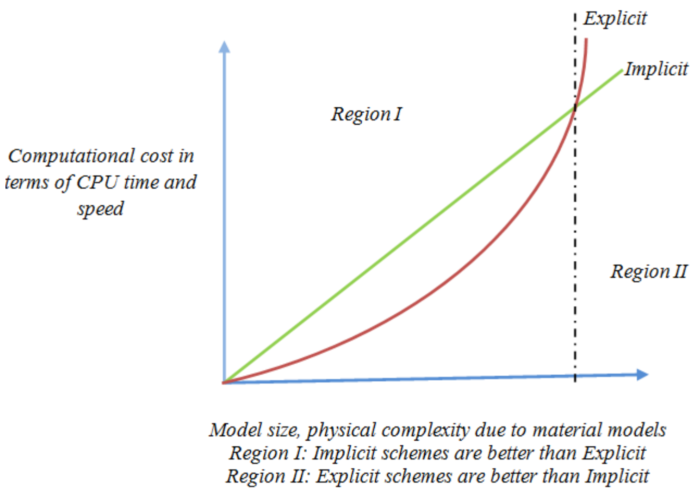


Fig -4: Implicit and Explicit regions

4. GEOMETRICAL AND FINITE ELEMENT MODELLING - Phase-I & Phase-II

Phase-I: The sheet metal deep drawing process and the parameters required for defect free finished parts are studied. Further, the explicit solver cards of a deep drawn model have been studied; guidelines and methodology has been set for the proposed project which is mentioned in phase-II.

Phase-II: The material used for the deep drawing of split rim (Figure-5) is Hot rolled carbon steel sheet, grade - DD-1079.

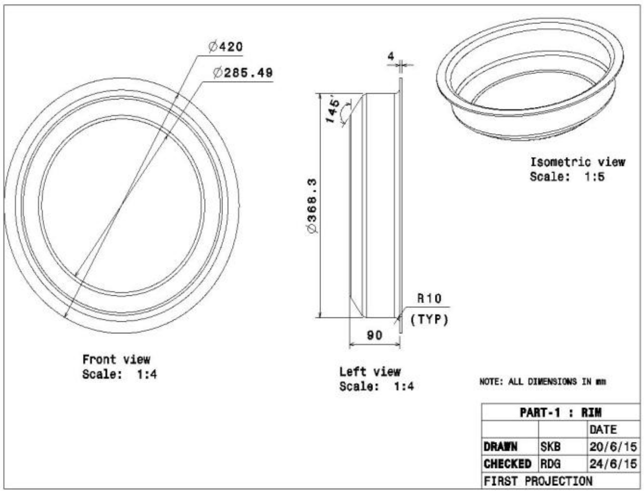


Fig -5: 2D drawing of split rim

Using 2D shell element of 5mm a fine mesh is created so as to capture all the geometric features. The material and properties are assigned. Contacts and load curves are defined

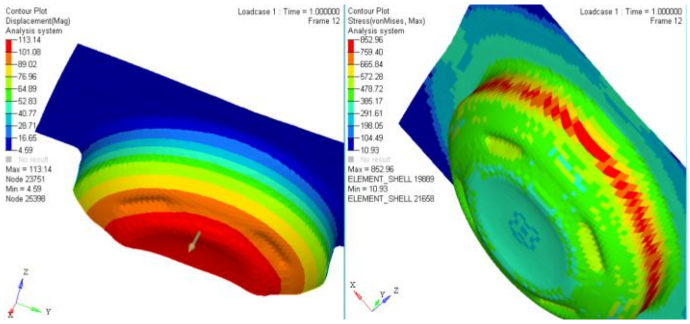
5. RESULTS & DISCUSSIONS

Simulation is the process of product validation where the product is tested with defined boundary conditions and assumed parameters. It is basically getting information about how something will behave without actually testing it in real life. Simulation is an important feature in engineering systems or any system that involves many processes. Simulations are preferred when mathematical models are complex or not reliable.

5.1 Simulation Optimization

In explicit forming simulations, run time can be greatly decreased using mass scaling and/or artificially high tool velocity. Both these methods introduce artificial dynamic effects, which must be minimized to reasonable levels in an engineering sense. Improper mass scaling will give inaccurate results. Figure-6 illustrate the effects of mass scaling.

(a)



(b)

(c)

Fig-6: Effects of mass scaling (a) without mass scaling - simulation run time is more. (b)Improper mass scaling (c) Optimum mass scaling reduces the simulation time

5.2 Effects of Blank holder force (BHF) and blank holder pressure (BHP) (Figure-7)

Blank holder force plays an important role during deep drawing process and it has to be selected very carefully. Blank holder force controls metal flow, it also affects thickness variation, stress & strain path and wrinkling behaviour.

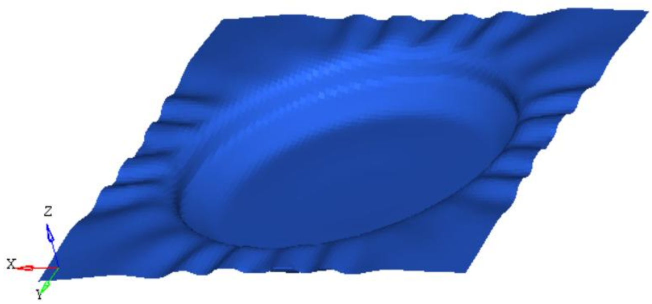


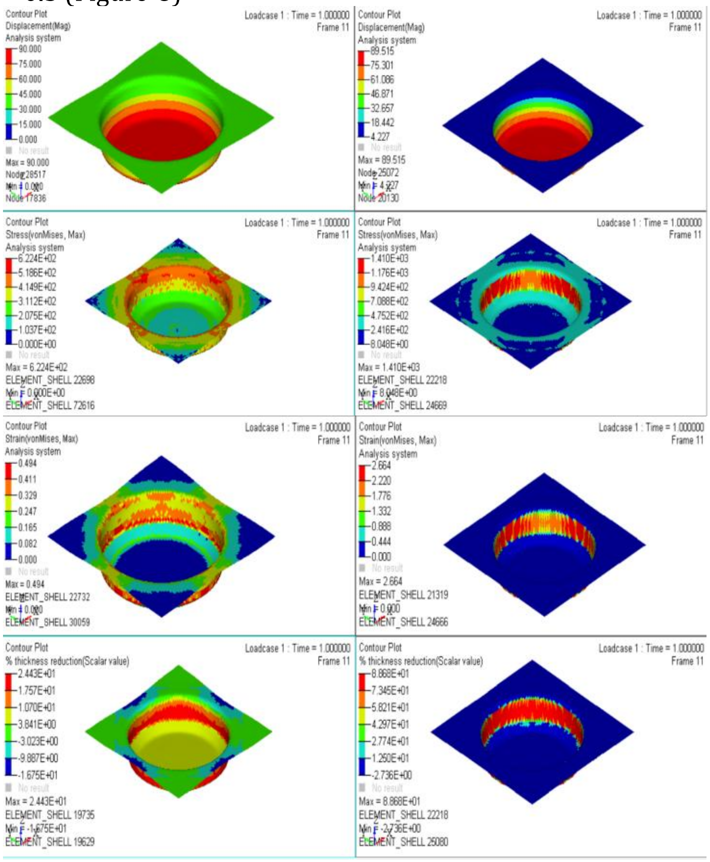
Fig-7: Wrinkling due to improper blank holder pressure

5.3 Effects of friction

Friction is one of the most influential parameter in drawing process. Thickness distribution is affected due to friction. Drawability of metal sheet increases as coefficient of friction increases. Coefficient of friction increases with increasing test specimen strain, increases with increasing local contact pressure, and decreases with increasing stretching speed, i.e. strain rate.

In case of lubricated friction, for steel on steel, the static coefficient of friction = 0.15 & dynamic coefficient of friction = 0.15

In case of dry friction, for steel on steel, the static coefficient of friction = 0.7 & dynamic coefficient of friction = 0.5 (Figure-8)



(a) (b)

Fig-8: Effects of friction in drawing process (a) Lubricated condition (b) Dry condition

From the results, tabulated in Table-1, it is clear that there is obstruction in the flow of metal and sever thinning is observed in dry condition and better results can be achieved with optimum lubrication if coefficient of friction is in the range of 0.15 – 0.3

Table-1: Effect of friction

	Lubricated condition	Dry condition
Max Displacement (mm)	90	89.51
Max Stress (MPa)	6.224E+02	1.410E+03
Max Strain	0.494	2.664
Max %thickness reduction	2.443E+01	8.868E+01
Min thickness (mm)	3.469	0.452

5.4 Results

- Displacement contour plot of the full model is shown in the Figure-9

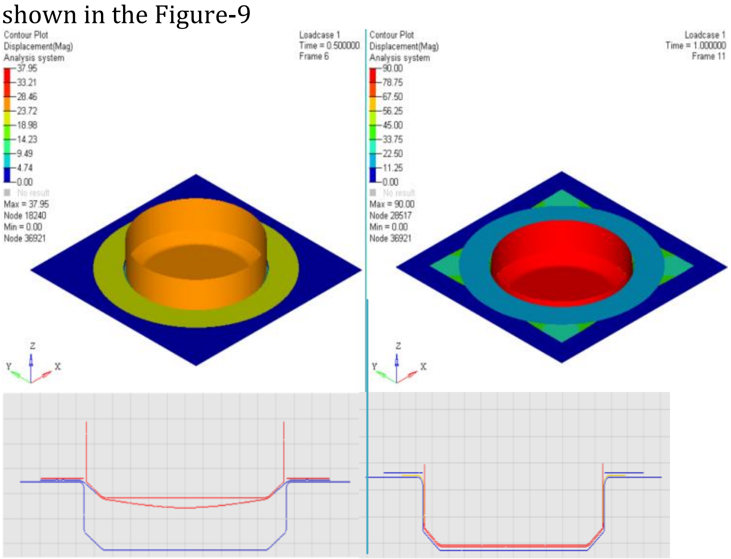


Fig-9: Displacement contour plot of the full model

The simulation is run for 1 sec to a depth of 90mm. The line diagram shows the behavior of the blank at 0.5sec and 1sec. Figure-10 shows the displacement contour of the blank at 90mm depth. The intended depth is achieved without any defects like wrinkling or severe thinning.

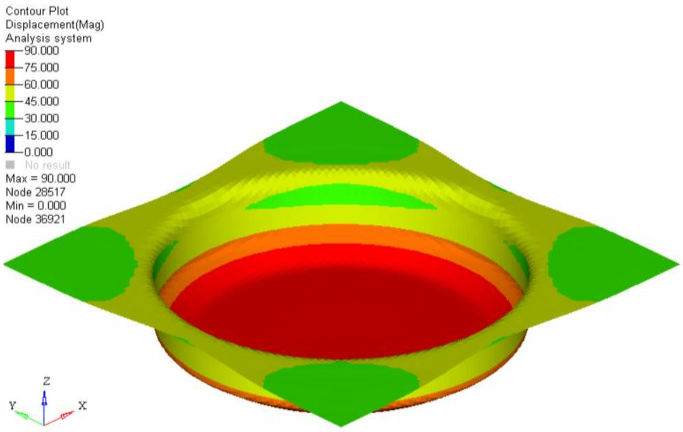


Fig-10: Displacement contour of the blank

- Stress and strain contour plot (Figure-11).

The maximum vonMises stress = 559.6 MPa and the maximum strain = 0.46. The contour shows the maximum stress at the die radius. The stress concentration is mainly observed at the fillets of the die and punch and hence sharp corners should be avoided by providing proper fillet

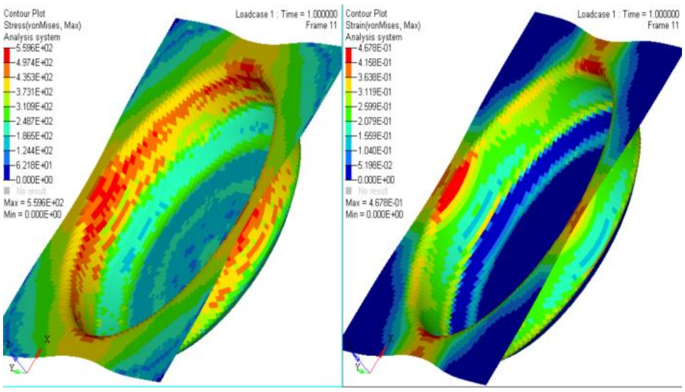


Fig-11: Stress and strain contour plots

radius. Thus failures can be minimized and stress distribution can be controlled.

- Percentage thickness reduction (Figure-12)

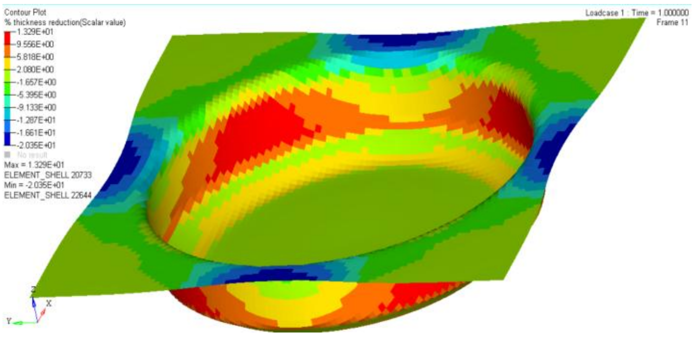


Fig-12: Percentage thickness reduction

There is 13% thickness reduction at the wall section of the rim as shown in above figure. The blue contour shows a 20% increase in thickness.

- Importance of Blank shape - Blank shape is one of the important parameter in deep drawing process as the quality of deep drawn product, forming limits, thickness distribution, minimizing the defects can be achieved by having optimum blank shape, and also material cost of product reduces if proper blank shape is selected. Optimum blank shape reduces forming load, increases forming limits and reduces possibilities of wrinkling and tearing. [12]. Figure-13 shows the metal flow in case of round shape blank. Figure-14 shows the comparison between the blank shapes. It is clear that round shape blank is preferred over square shape blank for circular draw as the stress plot of the blanks show uniform stress distribution and comparatively low stress = 509.09 MPa is induced where as in square shape blank induced stress = 559.61 MPa . Also the thickness distribution is uniform in round shape blank.

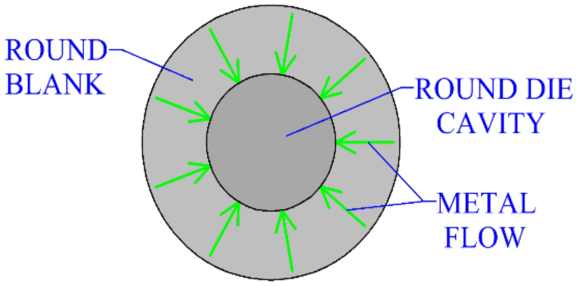
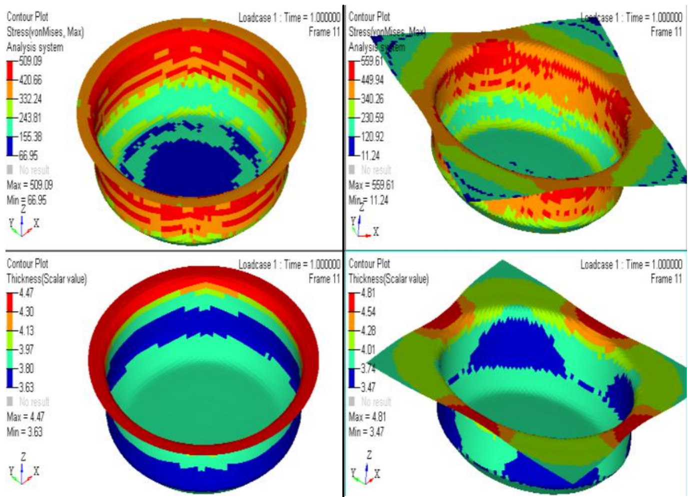


Fig-13: Metal flow in deep drawing of a round shape blank



(a)Round Shape Blank | (b) Square Shape Blank

Fig-14: vonMises stress & thickness variation

In the Figure-15, the direction and trace of metal flow of quarter section of the square shape blank is shown. The blank stretching observed at the corners is minimum compared to the sides. A circular blank shape would be optimum to get uniform stress and metal flow.

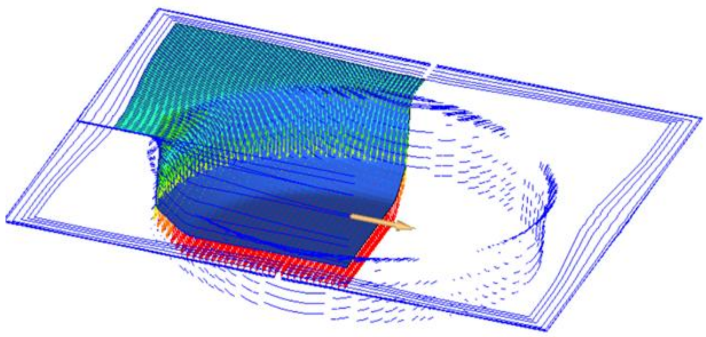


Fig-15: Metal flow direction in deep drawing of square shape blank

5.5 Validation

In this section attempt has been made to validate the results obtained from simulation with experimental results and theoretical calculation.

1. The thickness measuring results show maximum thinning and thickness positions in rim. Figure 16 shows

the thickness measurement of a square shape (525X525) mm sheet metal blank carried out using (0-25mm) micrometer. The thickness values varied at the rim face from (4.72 - 4.12)mm and rim flange (wall of the rim) from (4.01 – 3.50) mm. The rim base thickness was (3.90 – 4.00) mm, a minimum variation from the actual sheet metal blank thickness of 4mm.

Fig-16: Thickness measurement of the drawn rim

Figure-17 shows the thickness contour plot of FE simulated rim.

The max thickness was observed at the rim face = 4.80 mm and min thickness was observed at the rim flange (wall) = 3.5 mm.

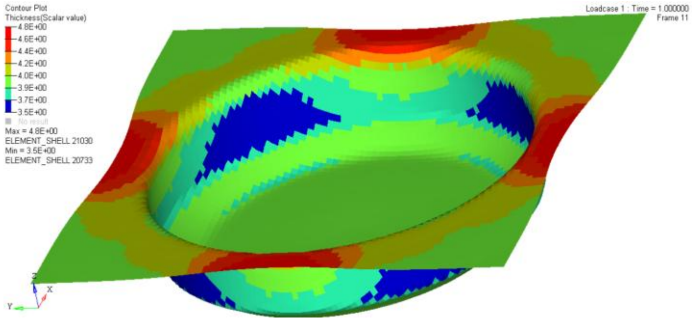


Fig-17: Thickness contour plot

2. Punch force: The punch force varies with the stroke of the punch. It is very difficult to predict the punch force in deep drawing. However, an expression for maximum punch force is given by [21]

$$F_{max} = \pi D_p t_o \, UTS \left(\frac{D_o}{D_p} - 0.7\right)$$

where,
Dp= Punch diameter = 305.16 mm
to= blank thickness = 4 mm
UTS = ultimate tensile stress = 270 MPa
Do = blank diameter = 525 mm
The maximum punch force, Fmax = 1.0565 X 106 N

The simulated force v/s time graph is shown in Figure 18, the value Fmax = 1.16 X 106 N

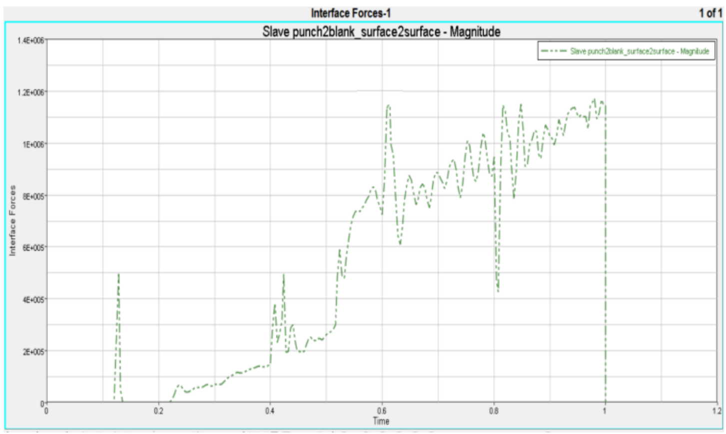


Fig-18: Punch Force (N) v/s Time (sec)

The results are tabulated in the table 2

Table 2: Results

Parameter	Experimental data	Simulation data	Error (%)
Thickness in mm	3.50 - 4.72	3.50 - 4.80	2.00
Punch Force in N	1.0565 X 106	1.1600 X 106	9.48

6. CONCLUSIONS

The simulation results are in agreement with experimental results. The analysis is useful for the prediction of thickness variation of the product prior to the carryout of the actual drawing process. The analysis may be used to estimate the critical thickness that initiates the failure of the product and also to set the minimum clearance between the die and punch. With the help of simulation results the major parameters that affect a stable forming process were found. The main conclusions that can be drawn from this project are

- A complete knowledge of all factors affecting the process is a must for successful execution of deep drawing manufacturing process.
- The blank holder force controls metal flow. By maintaining an optimum blank holder pressure, precise thickness variation can be obtained, as well as strain path and wrinkling can be controlled.
- Friction is one of the most influential parameter in deep drawing process. Friction affects relative thickness distribution.
- Blank shape influences material flow, forming load, and possibility of defects.
- An important aspect that was learned during this project is that if one encounters problems during the forming process, small design changes can be easily incorporated in the process with the help of simulation results to solve the issues.
- Designing complicated forming tools without simulation software compels the design engineer to work within very narrow boundaries and only use ideas that have previously been tested.
- Simulation software is a must if the company wants to be a leading company specialized on forming tools.

Further work

Optimize the simulation time by reducing the elements in the model and increasing the tool velocity without changing the results.

The simulations give alot of data that would be hard to measure on the real material. A study to see how to improve the quantitative analysis by using the simulation data can be made to guide the lab measurements.

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