NUMERICAL SIMULATIONS OF OBTAINING A BLANK SHAPE OF SHEET METAL FORMING PROCESSES BASED ON THE FINITE ELEMENT ANALYSIS

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ABSTRACT

The present work aims to determine the optimum blank shape design for deep drawing of arbitrary shaped cups with a uniform trim allowance at the flange, i.e., cups without ears. The earring, or non-uniform flange, is caused by non-uniform material flow and planar anisotropy in the sheet. In this research, a new method for optimum blank shape design using finite element analysis is proposed. The deformation process is first divided into multiple steps. A shape error metric is defined to measure the amount of earring and to compare the deformed shape and target shape set for each stage of the analysis. This error metric is then used to decide whether the blank needs to be modified. The blank geometry change is based on material flow. The cycle is repeated until the converged results are achieved. This iterative design process leads to blank shape. To test the proposed method, three examples of cup drawing are presented. The proposed systematic method for blank design is found to be further applied to other sheet metal forming application such as stamping processes.

1.1 INTRODUCTION

Metal formed by an industrial process into thin, flat pieces. It is one of the fundamental forms used in metalworking and it can be cut and bent into a variety of shapes. Countless everyday objects are constructed with sheet metal. Thicknesses can vary significantly; extremely thin thicknesses are considered foil or leaf, and pieces thicker than 6 mm (0.25 in) are considered plate.

Sheet metal is available in flat pieces or coiled strips. The coils are formed by running a continuous sheet of metal through a roll slitter.

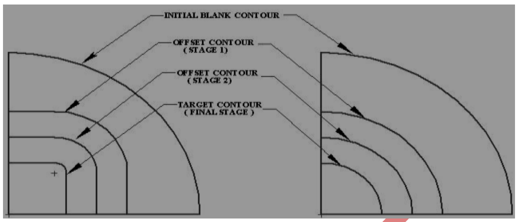
The thickness of sheet metal is commonly specified by a traditional, non-linear measure known as its gauge. The larger the gauge number, the thinner the metal. Commonly used steel sheet metal ranges from 30 gauges to about 8 gauges. Gauge differs between ferrous (iron based)metals and nonferrous metals such as aluminium or copper; copper thickness, for example is measured in ounces There are many different metals that can be made into sheet metal, such as aluminium , brass, copper, steel, tin, nickel and titanium. For decorative uses, important sheet metals include silver, gold, and platinum (platinum sheet metal is also utilized as a catalyst.)

Sheet metal is used for car bodies, airplane wings, medical tables, roofs for buildings (architecture) and many other applications. Sheet metal of iron and other materials with high magnetic permeability, also known as laminated steel cores, has applications in transformers and electric machines. Historically, an important use of sheet metal was in plate worn by cavalry, and sheet metal continues to have many decorative uses, including in horse tack.

II. METHODOLOGY

2.1 Various Stages For Fe Analysis

In this work blank shape that upon deep drawing process produces a cup of required depth having a uniform trimming allowance at the flange. Finite element analysis software ANSYS is used to simulate the process. This process of obtaining a blank shape has been split up into multiple numbers of stages as shown in Fig.1. All stages have got it is on target contour, which is the offset contour to the final target contour of the flange of the required cup. These stages lie in between the initial blank contour and the final target contour. The final target contour is considered as the final stage of the process.



Square cup **cylindrical cup**

Fig.1 Stages for FE analysis

Two advantages of dividing the optimization process into stages. if there would be any defect in the chosen parameters for simulation, that can be known in the first stage itself since it is reached to the final target contour gradually after confirming all the target contours of earlier stages. This helps us in saving a lot of time in case of any defect. the blank is modified to have some specific desired shape at the flange in each stage, so after confirming the target contour of first stage when we go to second stage, the deformed contour of the flange shows comparatively less deviation from the second stage target contour as compared to if we directly comes to second stage from the initial contour. At the end of each stage, a different blank shape will be achieved which will further act as the starting blank for the next stage.

This is considered as the Zeroth stage of the process. The modified blank obtained is now further used for the first stage.

2.2 Error

Error, μ_{error}, is defined as the absolute mean of the shape difference between the deformed contour of the flange and target contour. It is calculated by taking the mean of the absolute values of the distances between the nodal points of the deformed contour of the flange and the corresponding nodal points supposed to be on the target contour.

$$\mu_{error} = \frac{1}{n}\sum_{i=1}^{n} |d_i| \qquad (1)$$

Where

di = distance between the nodal point of the deformed contour of the flange and the target contour along the direction of material flow in the last deformation step .

n = total number of nodes located on the boundary of the blank.

The basic idea used in the modification of a blank is that the material is added from the current blank wherever it has been found less or more, respectively, by comparing the deformed contour of the flange and the target contour. The material flow direction of a node on the boundary of the blank. Since metal forming is a non-linear deformation process, so the node will move along a non-linear deformation path during deformation. The material direction will be changed time to time during deformation and therefore final direction will be different from initial direction of the material flow. A small variation of the initial position results in a different final position. The fact that the desired shape after forming is achieved means that every node on the boundary is on the target contour after deformation. In order to make the nodes lie on the target contour, the initial position of the node should be repositioned considering the amount of shape error and material flow direction [15]

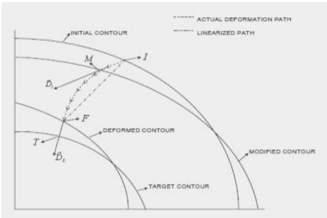


Fig.2 Temporary offset contour

The value of C is calculated by using the following relation:

$$c = \frac{X\,(D - h)}{h} \qquad (2)$$

This temporary offset contour is compared with the deformed contour and the blank is modified which will be further used for the final stage.

We get accurate results, the selection of an appropriate material model is considered as the most important part of the simulation. The selected material model should have the capability to take care of the deformation process considering each and every material property as per the requirement. In the present study, the anisotropic plastic material model "MAT_ANISOTROPIC_PLASTIC" is used and it requires the input of various material properties such as mass density, young's modulus of elasticity,

Poison's ratio, initial yield stress, R1, R40 and R80. The material, mild steel, is used for the analysis. The detailed material properties are given in Table.1

Table.1 Material properties of blank sheet

Property	Value
Sheet material	**Mild steel**
Young's modulus(GPa)	**210**
Mass density(gm/cc)	**8.80**
Poisson's ratio	**0.20**
Initial yield stress(MPa)	**276**
R01	**1.15**
R40	**0.78**
R80	**1.43**
Coulomb coefficient of friction	**0.10**

The final shape of the flange obtained as a result of the deformation of the optimal blank shape up to a depth of 38mm is shown in Fig. 3. The whole process takes a total of eight-deformation analysis or iterations and five modifications to reach to the optimal blank shape. The final shape error has been found to be 0.07mm.The progression of shape error through all the iterations is shown in Fig. 4.

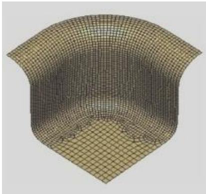


Fig. 3 Blank of a square cup

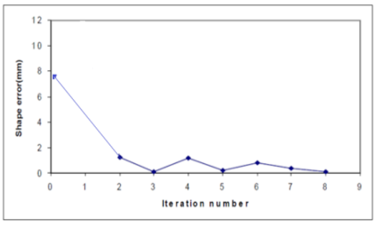


Fig. 4 Shape error from all the iterations for a square cup using multiple stage analysis

A total of six iterations and five modifications to reach to the blank shape. The final shape error has been found to be 0.9mm. The progression of shape error through all the iterations is shown in Fig. 5.

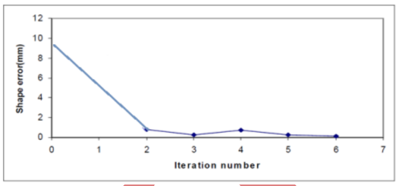


Fig.5 Shape error of all the iterations for a square cup using single stage analysis

The results of each iteration for single stage as well as for multi stage analysis in terms of shape error and CPU time cost is summarized in Table.2

Table. 2. Shape error and CPU time history in progression of blank design for square cup single stage and multiple stage analysis.

Iteration No.	For n = 3		For n =1	
	Shape error	CPU time	Shape error	CPU time
1	8.79	22m 32s	9.79	23m 32s
2	0.26	8m 25s	0.83	22m 43s
3	0.12	8m 53s	0.25	22m 21s
4	0.17	15m 13s	0.74	29m 36s
5	0.01	15m 33s	0.30	23m 10s
6	0.08	18m 40s	0.9	22m 38s
7	0.03	22m 8s		
8	0.07	20m 27s		
Total time	131m 51s		144m 00 s	

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It takes a total of five iterations and four modifications to reach to the optimal blank shape. The final shape error has been found to be 0.13mm.The progression of shape error history through all the iterations is shown in Fig.6.

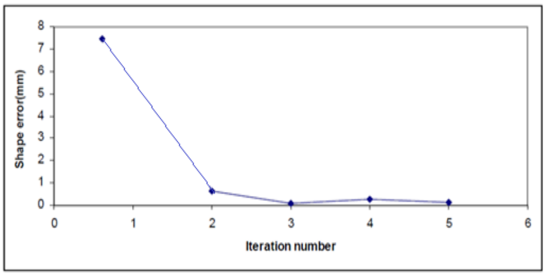

Fig.6. Shape the iterations for a cylindrical cup using single stage analysis

Table. 3: Shape error and CPU time history in progression of blank design for cylindrical cup undergone single stage and multiple stage analysis.

Iteration No.	For n = 3		For n =1	
	Shape error	CPU time	Shape error	CPU time
1	6.60	12m 14s	6.60	12m 14s
2	0.79	4m 32s	0.62	9m 47s
3	0.03	4m 34s	0.09	8m 32s
4	0.22	6m 37s	0.25	1 0m 26s
5	0.37	8m 15s	0.12	10m 50s
6	0.07	10m 57s		
Total time	47m 09 s		51m 49s	

III. RESULTS

3.1 Material Properties

Vital roles play in deciding the optimized blank size and shape to achieve the required shape of the cup of a depth. A change in the value of one of these parameters can result in different blank shape and size. the effect of material properties and process parameters, simulation of deep drawing process for square cup have been carried out considering different anisotropic values, coefficient of friction and blank holder force. Material properties, such as yield strength, anisotropic behavior, strain hardening exponent and process parameters such as friction, blank holder force, die profile radius, punch corner radius, etc.,

3.2 Coefficient of friction

All the surface pairs are specified to be of the same value. Simulations have been carried out taking different values of coefficient of friction of 0.09, 0.14 and 0.19 and optimized blank achieved as a result of each of them are compared. The contours of different blank shapes achieved are plotted in Fig. 7. It has been found that with the increase in friction there is very little effect on the shape and size of the blank.

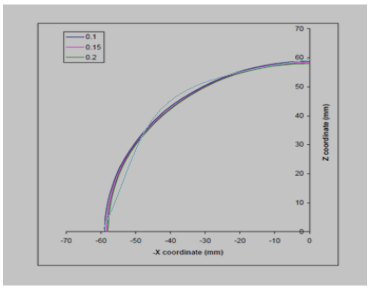

Fig. 7. Effect of friction

Friction can be considered useful to reduce the blank size to some extent but on the other hand it may result in punch out failure at the bottom radius of the cup, increase of friction will require more work to overcome friction.

3.3 Effect of blank holder force

Blank holder force helps in preventing wrinkling of the flange and to maintain the smooth flow of the material. Simulations have been carried out by taking different values of blank holder force of 12KN, 16 KN and 20KN. The different blank shapes achieved are plotted in Fig. 7. Results shows that change in blank holder force mainly affects the size of the blank and the shape of the blank is affected to a very less extent.

3.4 Effect of blank holder force

Flange friction increases with increase in blank holder force so the force should be just sufficient enough to prevent wrinkling. Optimum blank holder force required decreases with increase in thickness to diameter ratio. For very thin sheets the blank holder force necessary to prevent wrinkling is so large that the increased friction lowers the limiting drawing ratio.

3.5 Effect of anisotropy

Lower R value indicates easy thinning and larger R value indicates resistance to thinning. Material flow considerably depends on anisotropic values and thus it becomes a crucial parameter. Simulations have been carried out by taking different R-values, as listed in Table 4. The different blank shapes achieved are plotted in Fig. 7.

Table. 4. Anisotropic values

Case no.		R -values	
	R00	R45	R90
1	1.15	0.78	1.43
2	1.00	1.00	1.00
3	0.60	1.50	1.17

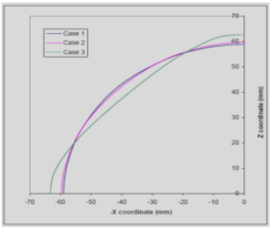

Fig. 8 Effect of anisotropy

It has been observed here that the change in anisotropy property changes both the size and the shape of the blank. This is clear from the plot of case 3 that larger R-value indicates restricted material flow in that direction as compare to the direction having lower R-value. Since the material in case 3 has got lower R-values in the 0^0 and 90^0 direction as compare to 45^0 direction, that is why optimum blank profile is shorter in the direction as compare to 0^0 and 90^0 direction.

3.6 Graphical Method to find the Initial Blank Geometry

To start the layout for the blank, a rectangle ABCD is drawn as shown in Fig.8 having side dimension (x-2r) is drawn where x, r are the side and bottom corner radius, respectively, of the required square cup. By continuing the sides beyond the points A, B, C, D, for a length equal to h+1 .57r, where h is the height of the flat portion of the sides of the finished shell, and connecting the points by lines parallel to the outline of the original rectangle, the outline of a shell blank is obtained where bending only is done during the drawing operation. The graphical method is considered more suitable for drawing of rectangular cups. To this outline adds the quadrants with a radius equal to Rc. The value of Rc is obtained by the equation (3):

$$R_c = (2Rh + R^2 + 1.41Rr)^{1/2} \qquad (3)$$

Where

R= corner radius

h = height of flat portion of sides

r = bottom radius

Blank outline contains enough metal to draw the shell. Due to the blank has sharp corners, slits, folds, and overlaps will occur at the points where the quadrants meet the side walls when the shell is drawn. The sharp corners must be blended by sloping curves by taking the metal from the side walls and adding it to the quadrants without any change in the amount of metal in the blank.

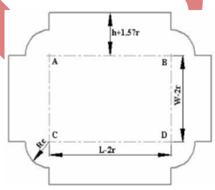

Fig. 9 Layout of a blank for a rectangular shell

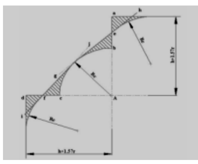

Fig. 10 Blanks for rectangular draws

The method for blending the corners of rectangular blanks by sloping curves is illustrated in Fig. 10. The development of the blank corners in this manner assures even distribution of the metal due to the areas of the shaded curvilinear triangles outside the sloping curves in the side wall are equal to the areas of similar triangles added to the quadrant arcs inside the sloping curve.

IV. CONCLUSIONS

The initial shape of the blank is found using line analysis technique. The iterative process is used to arrive at the optimum blank shape. A shape error is measured by comparing the deformed contour of the blank and target contour and is used to decide whether the deformed blank needs to be implemented or not. The deformed blank is repeatedly modified until the deformed contour of the blank becomes almost coincident with the target shape. The proposed method has been practiced in multiple stages.

Square cup and cylindrical cup have been investigated to examine the effectiveness of the proposed area. Both examples involve fairly significant levels of planar anisotropy in the blanks. The simulation results provide excellent prediction of blank shape for both the square cup and cylindrical cup in multiple stage analysis. Since it takes less computational time in multiple stage analysis as compared to single stage analysis for prediction of the blank shape, so the proposed method integrated with multiple stage analysis has been found as an effective tool for blank design. The present work is all about simulation so the experiments can be done to obtain the desired product from the blank obtained by the proposed method.

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