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Research Article

BLANK SHAPE OPTIMIZATION ON DEEP DRAWING OF A TWIN ELLIPTICAL CUP USING THE REDUCED BASIS TECHNIQUE METHOD

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ABSTRACT
In this project thesis, initial blank shape optimization of a twin elliptical cup to reduce earring phenomenon in anisotropic sheet deep drawing process was studied .The purpose of this study is optimization of initial blank for reduction of the ears height value. The optimization process carried out using finite element method approach, which is coupled with Taguchi design of experiments and reduced basis technique methods. The deep drawing process was simulated in FEM software ABAQUS 6.12. The results of optimization show earring height and, in addition, a number of design variables and time of process can be reduced by using this methods. After optimization process with the proposed method, the maximum reduction of the earring height would be from 21.08 mm to 0.07 mm and also it could be reduced to 0 in some of the directions. The proposed optimization design in this article allows the designers to select the practical basis shapes. This leads to obtain better results at the end of the optimization process, to reduce design variables, and also to prevent repeating the optimization steps for indirect shapes.

Keywords: deep drawing; twin elliptical cup; reduce basic technique; anisotropic sheet; earring.

INTRODUCTION

Deep drawing process is one of the metal forming processes. During deep drawing process, blank under the blank holder was drawn into the deformation by the punch. Deep drawing process of the twin elliptical cups used in the medical instrument, automotive, aerospace and packaging industries have increased recently in order to reduce manufacturing costs and times, and It is widely used for mass production. However, the earring defect caused by anisotropy behavior of sheet metal seriously affects the process results. In deep drawing of anisotropic sheets, the blank shape is an important factor. Since the earring defect is generated by the sheet metal anisotropy, it is greatly influenced by the initial blank shape. Earring height minimization can be performed using blank shape optimization to obtain better stress distribution and also to reduce the number of production stages [1–7]. A theoretical analysis was presented for minimizing earing behavior in cylindrical deep drawing, They used the different blank shape optimization for reducing earings. It was observed that optimized blank shape reduced the punch load using experimental work for aluminum and low carbon steel sheets [11].

Among all the process parameters in deep drawing its optimum shape is one of the important factors, because it minimizes the forming defects, improves the formability of the sheet metal, the quality and thickness distribution of the drawn cup and also reduces the material cost.

Several methods were developed for the optimum blank design [3, 7] the optimum blank shape was designed using the slip-line field theory The method is capable of predicting an optimal blank shape within few seconds but assumes the blank material as isotropic, rigid and perfectly plastic [12].

Recently deep drawing process has been widely used because of high deformation rate compared to other production methods, including casting and machining. All parameters of the forming process should be controlled for the desired shape. These parameters are the velocity of the punch, the friction factor, the blank holding force, the initial shape of the blank and others. Since the earring defect is generated by the sheet metal anisotropy, it is greatly influenced by the initial blank shape. Earring height minimization can be performed using blank shape optimization to obtain better stress distribution and also to reduce the number of production stages [3, 7].

The proposed optimization design in this paper is an integrated algorithm and it is conducted to blank shape optimization in a sheet metal deep drawing process of a twin elliptical cup. An innovative, comprehensive way of using an efficient design variables linking method, termed as reduced basis technique [9, 10], is demonstrated for blank shape optimization. In the reduced basis technique, many initial blank shapes, called basis shapes, are combined linearly by assigning weight factors. Different resultant shapes can be generated by changing their weight factors. Therefore, the number of design variables required to define the blank shape is reduced to the number of basic shapes. So, the weights assigned for each basis shapes are the design variables and the optimization goal is to find the best possible combination of these weights to minimize earring height. The algorithm presented in this paper focuses on the Taguchi design of experiments method. The effect of many different parameters on the performance characteristic in a condensed set of experiments can be examined by using the orthogonal array experimental design proposed by Taguchi.

MATERIALS AND METHODS

Although the reduced basis technique is widely used in shape optimization in permanent magnet motors [9, 10], but it is suggested for blank shape optimization in this work. However, it should be adopted for shape optimization of Twin Elliptical shape deep drawing process.

The optimization process was carried out using finite element method approach which is coupled with Taguchi design of experiments and Reduced Basis Technique methods.

Sheet metal anisotropy and earring phenomenon

A material is isotropic if its mechanical and elastic properties are the same in all directions, When this is not true, the material is anisotropic and it is due to cold roll forming of sheet metal. In the deep drawing of anisotropic sheet, material flow is variable in various directions, and cup height is high in direction that the sheet is drawn further. For anisotropic sheet metals, the ratio of true plastic strain is defined as follows:

$$r = \frac{\varepsilon_w}{\varepsilon_t} \tag{1}$$

A measure of the variation of r with direction is known as the planar anisotropy coefficient. Equation (2) shows planar anisotropy which predicts earrings directions. If r is positive, earrings are created in zero and 90 degrees respect to the direction of rolling. If r is negative, earring is created in 45 degree respect to the direction of rolling. In an ideal sheet metal with zero planar anisotropy, earring defect does not appear.

$$\Delta r = \frac{r_0 - 2r_{45} + r_{90}}{2} \tag{2}$$

The normal anisotropy coefficient is obtained from the equation (3). Higher normal anisotropy, sheet metal drawing will be improved.

$$\bar{r} = \frac{r_0 + 2r_{45} + r_{90}}{4} \tag{3}$$

Finite element analysis of deep drawing

Modeling of deep drawing process was developed using Abaqus/CAE and commercial explicit software of Abaqus was used in the 3D simulation.

All tools (i.e. punch, die and blank holder) were modeled using a discrete rigid type R3D4 and the material were modeled using S4R (a 4-node quadrilateral in-plane general purpose shell, reduced integration). Material properties are listed in Table 1 [14]. Die and punch dimension as shown in Figure 1 die and punch clearance is 1.22 mm. As well as, in order to obtain desired mesh size and calculate earring height, the blank was partitioned to the required form. A view of the twin elliptical cup deep drawing model is shown in Figure 2.

Assigning weighting factors and Design of Experiment (DOE)

The initial blank shape optimization was performed in this work. The finite element package

Table 1. Specification of the investigated sheet metals

Property/material	DC06
Initial blank diameter (mm)	86
Blank thickness (mm)	1
Density (kg/m^3)	7800
Poisson coefficient (υ)	0.3
Young module (Gpa)	210
Yield stress (Gpa)	123.6
Ultimate tensile stress (MPa)	385
R_{11}	1
R_{12}	1.0827
R_{22}	1.01
R_{33}	1.352
R_{13}	1
R_{23}	1

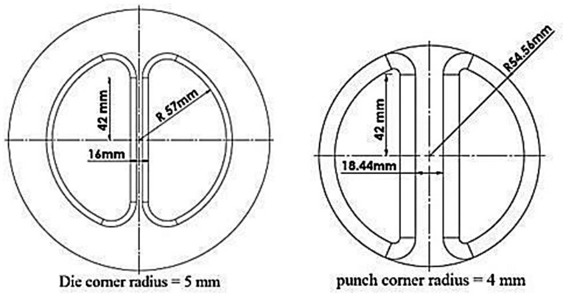

Fig. 1. .Die and punch dimensions

ABAQUS is used to simulate the process and to calculate the earring height. DOE performed with Taguchi method. A view of the twin elliptical cup deep drawing model is shown in Figure 2. 3-D FEA simulations of the basis shapes are performed in ABAQUS software to find the earring height for preliminary analysis as shown in Figure 2. These basis vectors is combined with the weighting factors, a_1, a_2 and a_3 that correspond to each basis vector based on the following equation:

$$R = \frac{A_1 R_{max} + A_2 R_{mid} + A_3 R_{min}}{A_1 + A_2 + A_3} \quad (4)$$

Where $0 \leq A_i \leq 1$ and n is the number of basis shapes. The reduced basis technique is applied to three basis vectors and the number of design variables is limited to three, which are the weights for each basis vector. By changing these weights, it is possible to obtain various resultant blank shapes for the optimizer to find the best combination of these weights. 9 DOE points are generated to conduct simulation. All of the resultant blank shapes are scaled to maintain in a limited area. Simulations are conducted at these DOE points to find the earring height and to build the Taguchi models for optimization. Optimization is performed in QualiTek-4 to minimize the earring height [13].

Procedure of ANOVA

A DOE/Taguchi approach is used to study the effects of multiple variables simultaneously. Three factors including Basis shapes weighting factors will be investigated and their optimum values will be specified through ANOVA. Based on known variation of earring height with respect to different factors, each factor is considered to have three levels. Therefore, an L-9 orthogonal array was selected to run the experiments. Table 2 shows the initial weighting factors and their levels for 0 and 90 directions. and the layout for the selected array is also presented in Table 3 [13].

RESULTS AND DISCUSSION

When the analysis of the experiment is complete, one must verify that the predictions are good, These are called confirmation runs. Having performed the analysis of results, the predicted optimum result must be verified through carrying out experiments at optimum combination of

a) b)

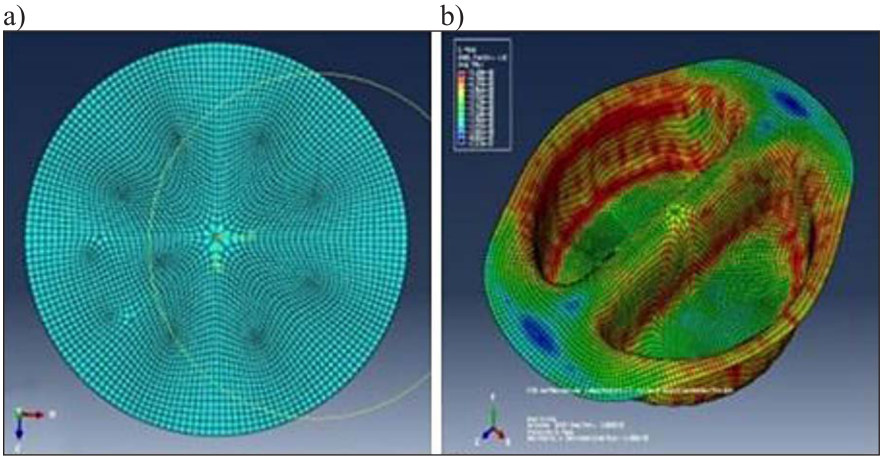

Fig. 2. A view of deep drawing process finite element modeling, (a) meshed blank, (b) final cup with earring defect

Table 2. Initial weighting factors and their selected values for 0 and 90 directions

0 degree	L1	L2	L3
R_{max} = 86 mm	0.02	0.03	0.04
R_{mid} = 85 mm	0.48	0.42	0.4
R_{min} = 84 mm	0.5	0.55	0.56
90 degree	L1	L2	L3
R_{max} = 86 mm	0.05	0.04	0.03
R_{mid} = 75 mm	0.5	0.6	0.62
R_{min} = 64 mm	0.45	0.36	0.35

Table 3. A standard L-9 (9 Experiments Runs) array for three levels factors

Trial no.	1	2	3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

factors. If the result of optimum experiment is within the permissible limit, the predicted result will be verified and otherwise, the DOE experiments must be redesigned and return considering interactions between factors.

Acceptable tolerance for earring height in all direction in this work is ±0.08 mm, this value is within the permissible limit and the predicted result is confirmed. Confirmation means that for 90% confidence level, there is no need to repeat the procedure of DOE with counting for interactions between factors.

Optimum curve designing

After two iterations in 0 degree the optimum values for weighting factor a_1, a_2 and a_3 are 0.02, 0.42, 0.56, respectively and optimum radius is 84.21 mm. After four iterations in 90 degree the optimum values for weighting factor a_1, a_2 and a_3 are 0.01, 0.65, 0.45, respectively, and optimum radius is 64.21 mm at the end of this stage, the initial blank shape was drawn by using optimal weighting factor in 0 and 90 direction (Fig. 3).

The finite element model after applying optimization in 0 and 90 directions as shown in Figure 4. Blank was partitioned once again (Fig. 5),

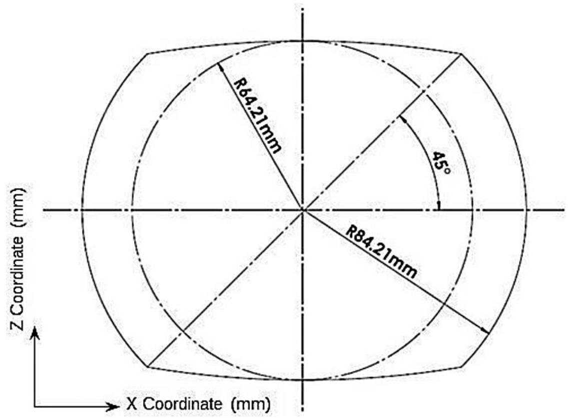

Fig. 3. After applying optimization on initial blank shape in 0 and 90 directions

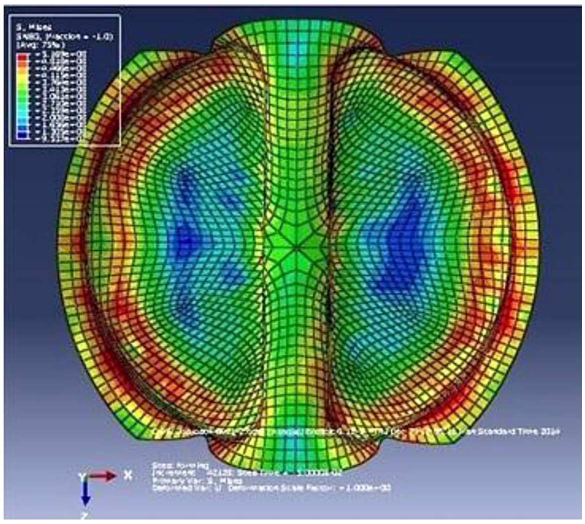

Fig. 4. After applying optimization on the finite element model in 0 and 90 directions

Table 4. Initial weighting factors and their selected values for significant directions

Base factors	30°	45°	50°	60°	70°	L1	L2	L3
	[mm]							
R_{max}	84.21	84.21	79.60	79.76	67.72	0.03	0.02	0.01
R_{mid}	83.42	81.16	79.45	75.96	67.65	0.5	0.55	0.6
R_{min}	82.63	79.01	79.30	72.16	67.58	0.47	0.43	0.39

and the coordinates of the edges were measured from important angles. Initial weighting factors and basic shapes were characterized for significant directions (Table 4).

Achieving this shape (Fig. 3) is an important step of the optimization because it reduces design variable and prevents repeating the optimization for other directions. After calculation, the optimum values for weighting factor a_1, a_2 and a_3 in 30 degree, are 0.03, 0.5, and 0.47, respectively,

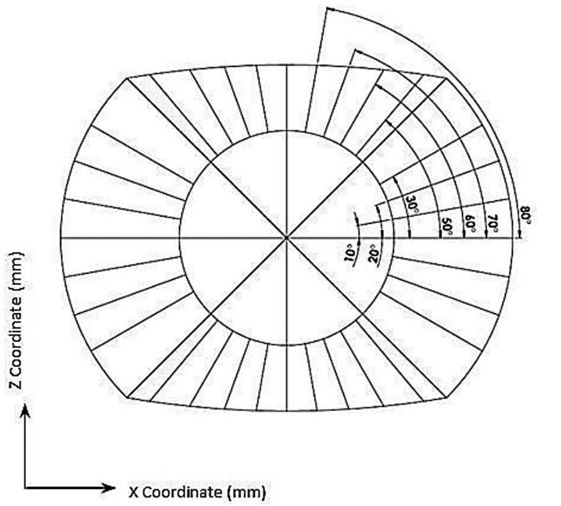

Fig. 5. A view of partitioned blank at the end of optimization step for 0 and 90 directions

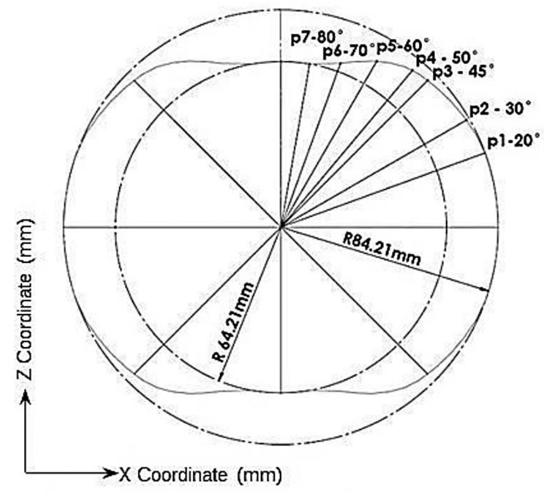

Fig. 6. Optimal blank shape at the end of optimization

and these values for significant directions in this step, as shown in Table 5.

The points coordination for optimal curve drawing is reported in Table 6, and optimum blank shape and final drawn cup as shown in Figures 6 and 7 respectively.

Optimal earring height in all directions as shown in Table 7. Earring height in all of directions is within the permissible limit and the predicted result is confirmed. Confirmation means that for 90% confidence level, there is no need

Table 5. Optimum values for weighting factors in significant directions

Directions	a_1	a_2	a_3
30°	0.03	0.5	0.47
45°	0.02	0.6	0.47
50°	0.01	0.5	0.47
60°	0.02	0.5	0.43
70°	0.02	0.6	0.47

Table 6. Point coordination for optimal curve drawing

Point	Optimal radius
P_1 = 20°	84.21 mm
P_2 = 30°	83.13 mm
P_3 = 45°	80.53 mm
P_4 = 50°	79.37 mm
P_5 = 60°	74.31 mm
P_6 = 70°	67.60 mm
P_7 = 80°	64.21 mm

Table 7. Optimal Earring height in significant directions

Direction	Earring height
0°	0.03 mm
30°	-0.08 mm
45°	0.00 mm
50°	-0.02 mm
60°	0.00 mm
70°	-0.02 mm
90°	0.07 mm

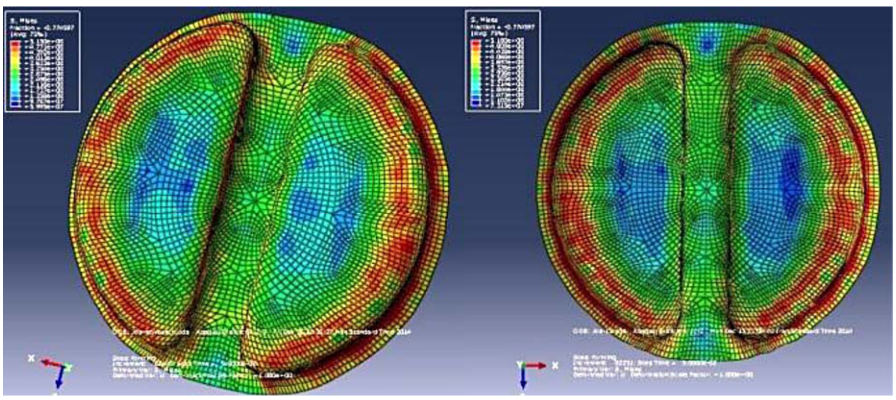

Fig. 7. After applying optimization on the finite element model in all directions (earring heights was optimized in all directions)

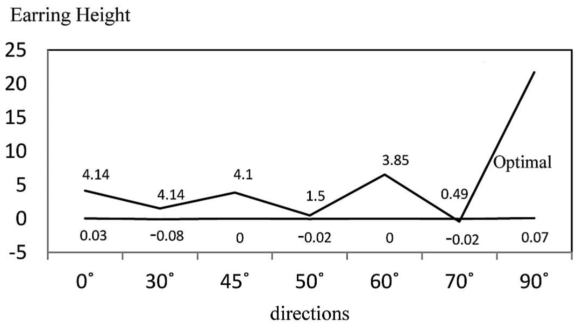

Fig. 8. Earring height diagram for initial and optimal blank

to repeat the procedure of DOE with counting for interactions between factors. Earring height diagram for initial and optimal blank as shown in Figure 8.

CONCLUSION

A method for determining optimum blank shapes for the production of twin elliptical cup with deep drawing process was proposed in this paper is the reduced basis technique. Reducing the earring height, design variable and selection of the applied basis shapes are a significant advantage of this method. The reduced basis method aids in the use of the Taguchi design of experiments models for optimization. The presented algorithm was applied on blank shape optimization of a twin elliptical cup as a case study. The proposed optimization design in this article allows the designers to select the practical basis shapes. This leads to obtain better results at the end of the optimization process, to reduce design variables, and also to prevent repeating the optimization steps for indirect shapes. An optimum blank shape was achieved by the implemented algorithms starting from tow circular arc and at the next level it completed with the point collection.

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