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FINITE ELEMENT SIMULATION OF DEEP DRAWING PROCESS

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ABSTRACT

Sheet metal forming is most widely used in manufacturing industries for the fabrication of a wide range of products. In this paper an attempt has been made to investigate the effect of process parameters viz., die radii, punch radii, blank holder force, lubricant type, lubricant position, punch velocity and draw depth and also to obtain the percentage contribution of each parameter on the outcome of process. Simulation is done using Altair® Hyperworks® 9 Software. Taguchi's orthogonal array is used for determining number of experiments and ANOVA is used as statistical tool to achieve the stated objective.

Keywords: *Deep Drawing, Taguchi's Orthogonal Array* and *ANOVA*

1. Introduction

Deep drawing is sheet metal forming process in which a sheet metal blank is radially drawn into forming die by the mechanical movement of the punch. It is thus a shape transformation process with material retention. There are two important regions: the flange, where most of the deformation occurs, and the wall which must support the force necessary to cause the deformation in the flange. The flange area experiences a radial drawing stress and a tangential compressive stress due to material retention property. These compressive stresses result in flange wrinkles.

1.1 Elastic and plastic deformation

Deformation of the work material takes place by the application of an external load known as work load. This type of deformation depends on the mechanical properties of work material. A material generally deforms elastically if it is under the influence of small forces, allowing the material to readily return to its original shape when the deforming force is removed. This phenomenon is called elastic deformation. It is dealt in detail in Hook's law. Materials behave elastically until the deforming force is within certain limits. This elastic limit is known as yield stress. At this point, the material is rendered permanently deformed and fails to return to its original shape when the force is removed. This phenomenon is called plastic deformation.

1.2 Mechanics of deep drawing

In a deep drawing process the blank is acted upon by a number of stresses. Radial stresses, hoop or circumferential stresses, compressive stresses are the most important among them. As shown in Fig. 1 the wall of cup experiences a longitudinal tensile stress due to transmission of drawing force by punch through the walls of cup and flange. The tensile hoop stress is developed due to the cup being tightly held in the punch.

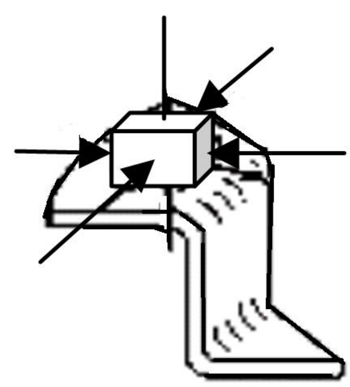

Fig. 1 Stress Distribution

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1.3 Design of experiments

Design of Experiments (DOE) refers to experimental methods used to quantify indeterminate measurements of factors and interaction between factors statistically through observance of forced. In each design, each row represents a run of the experiment. Each column represents the levels of factors the parameters under study. After the experiments are conducted the signal to noise ratio determined by using analysis of variation (ANOVA) techniques. For a full factorial design, the number of possible designs N is,

$$N=Lm \tag{1}$$

where, L= number of levels
m= number of factors

1.4 Analysis of variance (ANOVA)

It stands for Analysis of Variance. For each performance requirement, signal-to-noise (S/N) ratio is used to express how sensitive each design parameter is to uncontrollable noise i.e., it defines the robustness of the design.

The S/N ratio is calculated using following equation:

$$SN_i = -10 \log (MSD) \tag{2}$$

Mean – square deviation (MSD) = $1/n \sum 1/ y_i^2$

where y1, y2, …..yn are the responses of the minimum thickness after completion the process for trial conditions & n_i= no. of times each experiment is repeated; which is 1 in the present case.

In this paper L8 array is used to perform experimental runs. This array deals with only two levels of factors. The main drawback with this type of array is that curvature effect is not taken into account. To decrease this effect it has been decided to use 3 levels for 5 parameters (die radius, punch radius, blank holder force, punch velocity and draw depth) and 2 levels for remaining 2 parameters (lubricant type and lubricant position).

It is decided to select L36 orthogonal array since it best suits purpose required in this present study. In the present study only 7 parameters are considered so it is required to reduce the L36 orthogonal array to present requirements. To perform this task L36 orthogonal array was reduced to L36' orthogonal array. The factors and their level for L8 array is show in table 1. It has two levels for each parameter. The lower one will be called as low level and higher one will be called as high level throughout the paper.

In L36' array a third level is introduced which has value in mid of high and low levels of L8 array. Only two parameters (lubricant type and lubricant position) are continued with two levels since third value is not possible for them. The factors and their levels for L36' array is shown in table 2.

2. Numerical Simulation

Simulation is the imitation of some real thing, state of affairs, or process. After observing the punch and die geometries of Colgan[1], it was decided to perform simulations on similar geometry. The punch has a diameter of 39.4mm and the die has a diameter of 41.7mm. This gives a clearance of 1.15mm or 15%. The diameter of circular blank is 78mm.

The initial blank thickness is 1mm and material used is mild steel EN10130FeP01. Fig 2 shows the geometry of forming tools.

To start with, modeling is done using CATIA® V5 R16 of Dassault Systems. Simulations are carried out using Altair® HYPERWORKS® 9 software and Incremental Radioss is used as solver.

Table 1: Factors and their levels for L8 array

		Punch radii (mm)	Die radii (mm)	BHF (N)	Lubricant type	Lubricant position	Punch velocity (mm/sec)	Draw depth (mm)
2	High	8	8	18000	PE	Die	750	20
1	Low	2	2	11000	None	Punch	150	15

Table 2: Factors and their levels for L36' array

Level	Lubricant type	Lubricant position	Punch radius (mm)	Die radius (mm)	BHF (N)	Punch velocity (mm/sec)	Draw depth (mm)
3			8	8	18,000	750	20
2	PE	Die	5	5	15,000	420	17
1	None	Punch	2	2	11,000	150	15

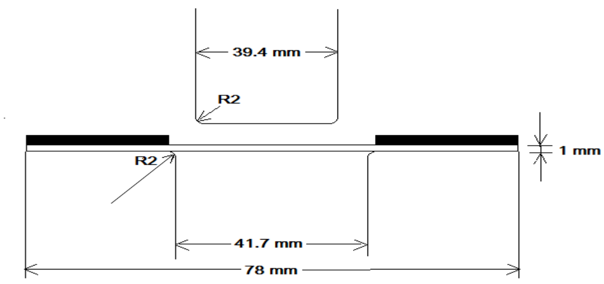

Fig. 2 Geometry of Forming Tools

3. Numerical Results

In this paper initially orthogonal array L8 is used to conduct experimental runs and various results are obtained.

4. Results and Discussion

The results of ANOVA shown in table 3 clearly indicate the foremost contribution of die radius towards the thickness distribution in a deep drawing process. It can also be seen that this parameter is followed by punch radius, draw depth and so on. The most critical case is found out to be experiment run 2 where maximum thinning takes place.

Fig. 3 shows FLD for most critical experiment run 2 at a draw depth of 17.21mm.

As it is clear from the study conducted in this paper till now that die radius has paramount effect on deep drawing process in comparison to other factors dealt in this present work. In this paper L36' is also used to see the effect of process parameters since it includes 3 levels and hence curvature effect is not left out as is in the case of L8 array. The minimum thickness shown in Table 4 for L36' orthogonal array and finally the most critical combination obtained is experiment run 7 of L36' orthogonal array. In experiment run 7(2-1-1-1-1-2-3) the levels of factors are low punch radii, low die radii, low blank holder force and maximum draw depth. It is clear from table 2 that whenever value of die radius is large percentage thinning is less as is evident from the thinning values of experiment run 1, 2, 3 where the value of die radius increases from 2 mm to 8mm. The percentage thinning is very high in experiment run 7, 19 and 25 can be attributed to the fact that the value of die radius in all the three cases is at minimum and also draw depth has maximum value of 20mm.

Table 3: Results of ANOVA for Wall Thickness

Factor	S	Df	Variance	F-Ratio	Contribution (%)
Punch radii	41.014122	1	41.014122	1.430489	15.01806
Die radii	56.3068851	1	56.3068851	1.963869	20.61778
BHF	28.671402	1	28.671402	1	10.49855
Lubricant type	32.109901	1	32.109901	1.119928	11.75760
Lubricant position	34.23753	1	34.23753	1.194135	12.53669
Punch velocity	40.134575	1	40.134575	1.399812	14.69600
Draw depth	40.624286	1	40.624286	1.416892	14.87531
ERROR	264.2276136				
TOTAL	273.0987011		273.0987011		
POOLED ERROR	28.671402		28.671402		

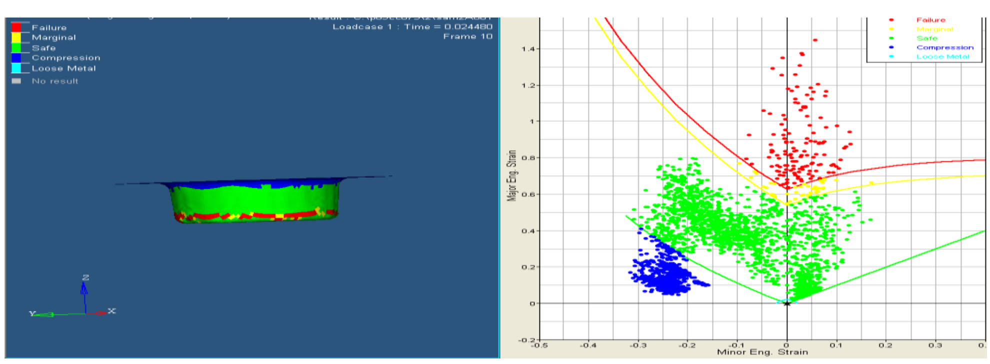

Fig. 3 FLD for Experiment Run 2 at 17.21 mm

Table 4: Minimum Thickness for L36' Orthogonal Array

Exp run	Thickness (mm)	Thinning (%)	Remarks	Exp run	Thickness (mm)	Thinning (%)	Remarks
1	0.6671	33.29	Fail	19	0.3307	66.96	Fail
2	0.7756	22.44	Safe	20	0.7414	25.86	Safe
3	0.8216	17.84	Safe	21	0.8358	16.42	Safe
4	0.7261	27.39	Safe	22	0.3815	61.85	Fail
5	0.7294	27.06	Safe	23	0.7527	24.73	Safe
6	0.7736	22.64	Safe	24	0.8362	16.38	Safe
7	0.2286	77.14	Fail	25	0.7830	21.7	Safe
8	0.7792	22.08	Safe	26	0.7813	21.87	Safe
9	0.8218	17.82	Safe	27	0.8229	17.01	Safe
10	0.7788	22.12	Safe	28	0.6954	30.46	Fail
11	0.7888	21.12	Safe	29	0.7806	21.94	Safe
12	0.7788	22.12	Safe	30	0.8632	13.68	Safe
13	0.6411	35.89	Fail	31	0.6578	34.22	Fail
14	0.7672	23.78	Safe	32	0.8543	14.57	Safe
15	0.7955	20.45	Safe	33	0.8668	13.12	Safe
16	0.6195	38.05	Fail	34	0.7783	22.17	Safe
17	0.7692	23.08	Safe	35	0.8065	19.35	Safe
18	0.7703	22.97	Safe	36	0.8557	14.43	Safe

4.1 Individual effects of process parameters

It is also clear from the results of L8 orthogonal array that the most critical case is observed in experiment run 2. Hence this experiment run will be used for studying the individual effects on deep drawing process.

4.1.1 Effect of die radii on minimum thickness

The die radius has paramount effect on the deep drawing process and also on the final component. Fig. 4 shows the variation of minimum thickness with die radius.

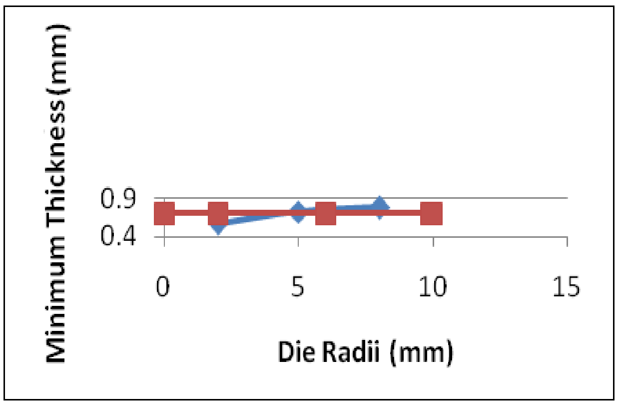

Fig. 4 Effect of Die Radius on Minimum Thickness

4.1.2 Effect of punch radius on minimum thickness

Fig. 5 shows the variation of minimum thickness with change in punch radius.

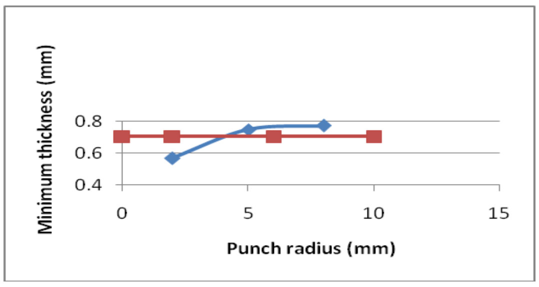

Fig. 5 Effect of Punch Radius on Minimum Thickness

4.1.3 Effect of punch and die radius graph

It is clear till now that of all the parameters considered in this paper punch and die radii have foremost effect on deep drawing process while rest parameters have satisfactory effect on deep drawing process. In other words it can be said that design parameters affect deep drawing process considerably. A 3 – D graph (fig. 6) is drawn to study the combined effect of these two process parameters. The optimum value of punch and die radius obtained is 4 mm for the value of n considered in this study.

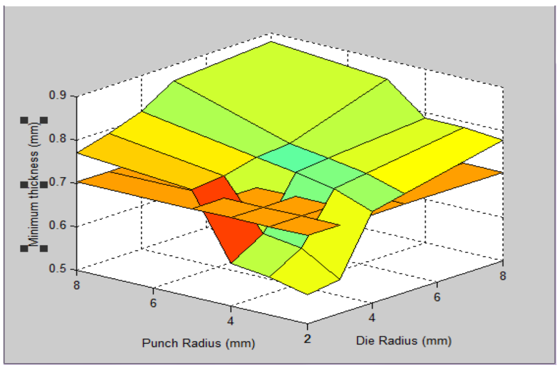

Fig. 6 A 3- D Graph

5. Conclusion

It can be concluded from the results of various simulation experiments performed in the paper that no parameter can be exactly pinpointed for the thickness distribution taking place in deep drawing process. The results mentioned in the paper highlight the importance of geometrical parameters in general and die radius in particular towards the thickness variation obtained in the deep drawing process.

The present work can be extended by considering other factors such as temperature, different blank diameter and different value of clearance between punch and die. The results obtained from ANOVA also indicate the dominating effect of geometry of tooling used in deep drawing process. It can be seen that die radius has predominant effect on the deep drawing process.

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