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Optimization of Forming Process Parameters in Sheet Metal Forming Of Reinf-Rr End Upr-Lh/Rh for Safe Thinning

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ABSTRACT
During the forming process of sheet metal component i.e., REINF-RR END UPR-LH/RH, defects such as wrinkle and thinning is observed. These defects can be reduced by varying the process parameters by trial and error method which loss in time and money. The final component is obtained in its desired quality by optimizing the various process parameters which affect more on the forming process. This requires thorough knowledge about the process and expertise in tool design. In this project, Finite element method (FEM) is used to analyze the strain and thickness variations during the REINF-RR END UPR-LH/RH forming process and optimization is carried out using Design of experiment (DOE) technique. In this case, HYPERFORM software is used for the simulation of the component which avoids manufacturing the tool for the tryout. The optimization of process parameters is done by using DOE by Taguchi's orthogonal arrays in Minitab software. The result of optimization is validated with actual formed component with same optimized parameters.
Keywords - Design of experiments, Finite element method, Sheet metal forming, Taguchi, Thinning.

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I. INTRODUCTION

The sheet metal forming is the important manufacturing industry as it manufactures chip less products from automobile components to home appliances with process flexibility at possible cost. In forming process, the defects like thinning and wrinkling are observed very first in tryout. The quality of sheet metal component depends on the rate of flow of blank into the die cavity. By controlling the material flow rate, we can prevent the defects such as wrinkling and thinning. To control the material flow and to avoid these defects, draw bead is added to die surface or binder surface having its corresponding recess to binder surface or die surface as shown in Fig. 1.

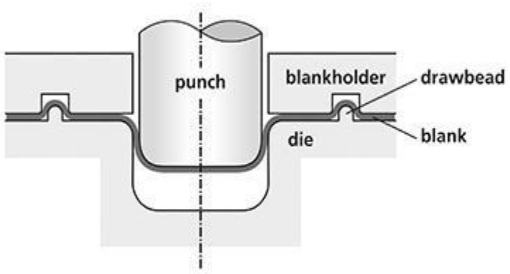


Figure 1: Position of draw bead

The restraining force is provided by the blank holder or draw bead to control the material flow rate and the force is created by friction between the blank & tooling.

The finite element method is very important in sheet metal forming operation. It is done in the computer by using simulation software such as HYPERFORM to detect errors and problem occurs in part at an initial phase of the process. It is not required to manufacture tool practically to run the test. As the forming process experiences complicated deformation, the result of process parameter on final formed component is difficult to determine. Before process design, these parameters should be found out for optimum forming condition. The tools design, process parameters, shape and material of the blank determines the quality of final product. Hence, it is important to consider these factors before manufacturing the final component otherwise it will result in defective component.

Design of experiment technique is used to determine accuracy and efficiency of process parameters. Optimization of forming process parameters is carried out using DOE by Taguchi orthogonal array. This paper uses FEM to analyze strain and thickness variations during the REINF-RR END UPR-LH/RH forming process and optimization is carried out using Design of experiment (DOE) technique.

II. LITERATURE REVIEW

P. Petkar et al. [1] used finite element method to replace the trial and error method for obtaining the desired component. Optimization was carried out by using the design of experiments to find out various parameters which affect the quality of sheet metal component.

Nimbalkar D. H. [2] discussed the mathematical modeling and theoretical investigation of sheet metal forming procedure. He carried out FEM simulation for an industrial part which is to be formed by deep drawing operation.

M. J. Worswick [3] given detail information regarding how sheet metal forming operation are carried out and what are effects of different parameters such as tool geometry, friction between sheet and tool and various loads on sheet metal. Also explained latest advances related to the numerical simulation of stampings which stated methodologies for foreseeing metal formability, containing damage-based models for both the large as well as small variety. The evolution of calculating competency improving implicit as well as explicit solver algorithms has delivered the required computational rapidity to support increasing levels of practicality in mathematical representation of material performance, lubrication and tooling geometry, along with increased levels of accuracy.

Tan C. J. et al. [4] explained various factors affecting the final thickness of the deep drawn sheet metal part. The small decrease in thickness is mainly because of reduction in blank thickness. Subsequently the fatigue strength of the disk abruptly reduces even for a small reduction in thickness at the inner corner; a tailored blank with local thickening at the area corresponding to the inner corner produced by stamping was used in the multistage stamping to increase the thickness at the inner corner.

Makinouchi [5] described different examples for simulation, in those examples defects such as, wrinkles, surface deflection are predicted and forming limit conditions are studied. So, if there is a need for obtaining valuable data within moderate time as well as cost, one has to bind the tenacity of simulation.

Sandeep Patil et al. [6] used Altair's HyperForm to simulate the process of sheet metal forming and presented few case studies related to deep drawing simulation of cylindrical shells to understand sheet metal behavior. The concepts such as metal flow during drawing, severity in drawing and die requirement for deep drawing of cylindrical shells explained for education purpose with education software. He also provided methodology for simulation of metal forming process using Altair's HyperWorks package.

III. METHODOGOLY

The thinning and wrinkling of REINF-RR END UPR-LH/RH is reduced by the use of FEM simulations. CAD model and specification of REINF-RR END UPR-LH/RH is required for FEM simulation. The CAD modeling of REINF-RR END UPR-LH/RH is done, then from the theoretical calculations the required number of draws and press tonnages are calculated. Further the forming tools are modeled in CATIA V5R25 and this collection of data is used for virtual simulation experimentation. The optimization of forming process parameters is carried out by using Design of experiment technique by Taguchi orthogonal array in Minitab software. Final simulation is carried out with the optimum parameters and tool is designed for tryout. The complete methodology of project is shown in Fig. 2.

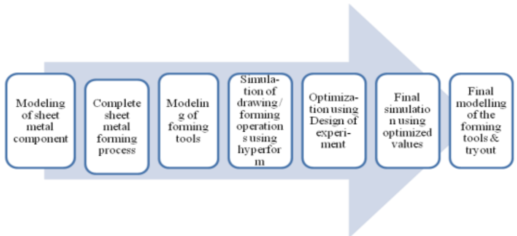


Figure 2: Methodology of project

3.1 Modeling of component

Modeling of REINF-RR END UPR-LH/RH was done in CATIA V5R25 as shown in Fig. 3 as per component specification and IGS provided by R&D department of the industry. Fig.3 shows the isometric view of REINF-RR END UPR-LH/RH.

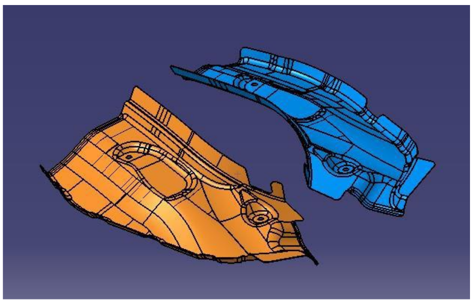


Figure 3: CAD model of REINF-RR END UPR-LH/RH

3.2 Specification of component

1) Material – IFHS350
2) Yield strength (YS) – 220 Mpa
3) Ultimate tensile strength (UTS) – 340 Mpa
4) Thickness – 0.65 mm

5) Develop blank – 740 mm × 715 mm

3.3 Complete process to manufacture the part
The complete process to manufacture the REINF-RR END UPR-LH/RH is shown in Fig. 4.
1) Blanking operation - First operation in single stage forming of REINF-RR END UPR-LH/RH.
2) Forming operation – The blank is deformed to required shape by plastic deformation.
3) Trim operation – It consists of cutting unwanted excess material from the periphery of previously formed component.
4) Restrike operation – The radii and form shape of previously formed component is sharpening in detail. Also eliminates spring back effect. Final component is obtained after this process.

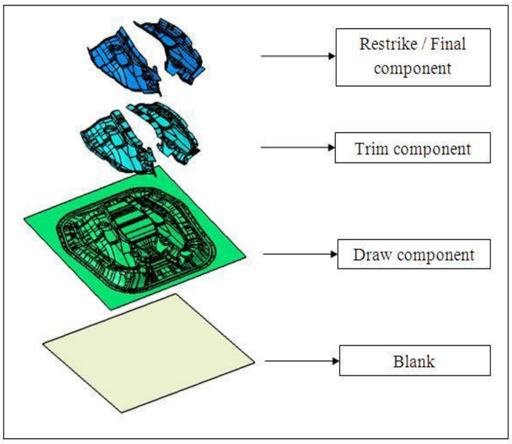


Figure 4: The complete process to manufacture REINF-RR END UPR-LH/RH

3.4 Mathematical Draw calculations
Given data:-
1) Draw perimeter = 1995 mm
2) Draw height (h) = 71 mm
3) Draw constant (K) = 0.6-0.7

3.4.1 Calculation of punch diameter (d) in mm
Punch diameter (d) = Punch perimeter/π
= 1995/π
= 635 mm

3.4.2 Calculation of h/d ratio to find number of draw required
Here, h/d = 0.111
0 < h/d < 0.75- Simple draw
0.75 < h/d < 1.5 - Deep draw
Hence simple draw is required for complete forming of REINF-RR END UPR-LH/RH.

3.4.3 Calculation of blank diameter (D)

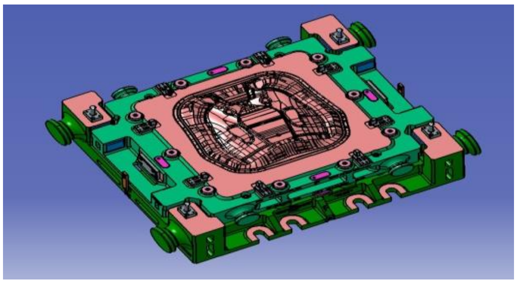
$$D = \sqrt{d^2 + 4dh}$$
$$= \sqrt{635^2 + 4 \times 635 \times 71}$$
$$= 764 \text{ mm}$$

3.4.4 Calculation of draw force (F)
F = πdtσy [D / d – K]
= 3.14 × 635 × 0.65 × 220 × [764 / 635 – 0.65]
= 157798 N
= 16 Ton

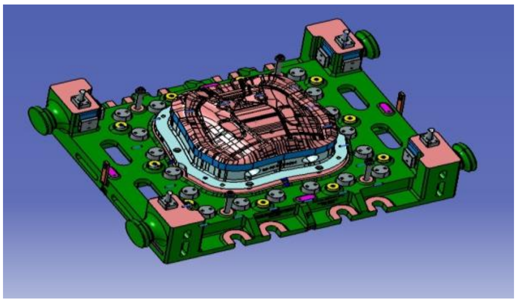
3.4.5 Blank holder load (BHL)
BHL = 20% of draw force (F)
= 3.2 Ton

3.4.6 Draw Tonnage (P) = F + BHL
= 16+ 3.2
= 19.2 Ton
Considering Factor of safety 25% then,
Draw Tonnage = 1.25 X 19.2
= 24 Ton

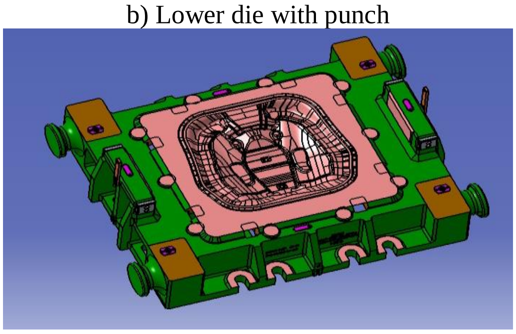
3.5 Modeling of forming tool
The modeling of forming tool of REINF-RR END UPR-LH/RH is designed as per above process in CATIA-V5 software. The single stage forming tool is as shown in Fig.5.



a) Lower die with punch and blank holder



b) Lower die with punch



c) Upper die
Figure 5: CAD model of forming tool

3.6 Simulation of drawing process

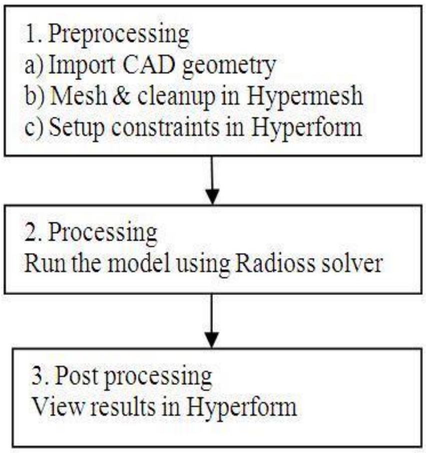


Figure 6: Steps in the simulation process

The steps in the simulation are as shown in Fig.6. Simulation of drawing operation is carried out in HyperForm software using the incremental Radioss platform. The values of press tonnage, blank holder force, and coefficient of friction were calculated which are used to simulate the process.

The component to be formed is transferred to IGES format for the simulation in HyperForm. The mesh was created for upper steel (Die) and blank which gives mesh of blank holder and lower steel (punch) using automatic tool build option. The setup of forming tool is as shown in Fig.7. Several iterations are carried out to achieve the final component with less than 20% thinning with variable draw bead dimensions and variable blank holding force.

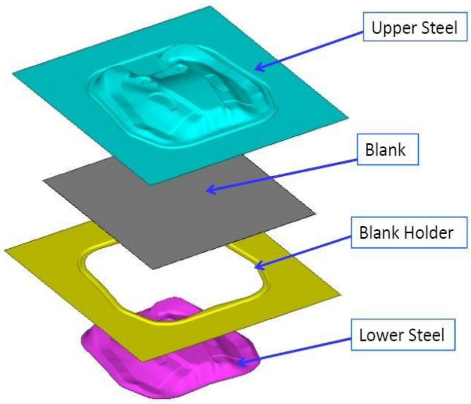


Figure 7: Forming tool set up

3.7 Design of Experiment using Taguchi's orthogonal array

For the optimization of forming process parameters, design of experiment is used with Taguchi's orthogonal array.

The basic steps associated with Design of experiments (DOE) using Taguchi are;
1) Experiments for selected influential factors
2) The statistical analysis of the data
3) Evaluate most influential factors
4) Find the optimized value from Taguchi analysis.
5) Carry out experiments
6) The conclusions reached and recommendations made as a result of the experiment.

3.7.1 Collection of Different Factors for Screening Experiments

The factors influencing the thinning error has been analyzed and it is observed that blank holding force, draw bead height and binder stroke affects most on the forming process of REINF-RR END UPR-LH/RH. Table 1 shows the factors influencing the % thinning.

Table 1: Factors influencing % thinning & their values

Factors influencing % thinning	Levels		
	Level 1	Level 2	Level 3
Blank holding force	20	28	60
Draw bead height	0	5	6
Binder stroke	85	90	95

L9-OA was constructed based on Taguchi method to evaluate the significance of interaction term as shown in Table 2. Virtual simulation experimentation is carried out using Altair's HyperForm software.

Table 2: L9- orthogonal array

Sr. No.	BHF	DBH	BS
1	20	0	85
2	20	5	90
3	20	6	95
4	28	0	90
5	28	5	95
6	28	6	85
7	60	0	95
8	60	5	85
9	60	6	90

3.8 Result of experimentation using simulation

3.8.1 Die design without bead

Initially, the die was designed without bead. The blank holding force was set as 28 Ton.

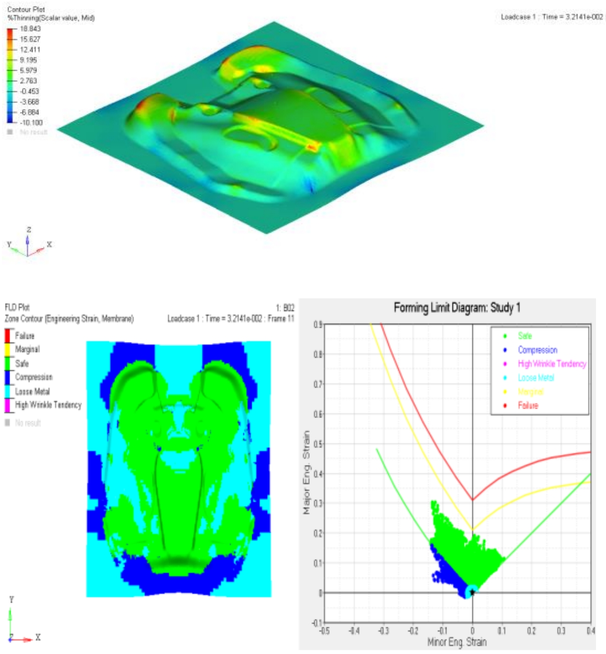


Figure 8: Simulation result of 1st iteration

Fig. 8 shows the result of 1st simulation without a draw bead. It shows safe thinning of 18.843% but forming limit diagram (FLD) shows wrinkle on the part. As the result shows wrinkle in part, we have to go for next iteration.

3.8.2 Die design with step bead

In this iteration, step bead was added to the die profile with a corresponding recess in the blank holder. The height of bead was considered as 5mm with entry and exit radius as 5mm. The blank holding force was considered as 28 Ton.

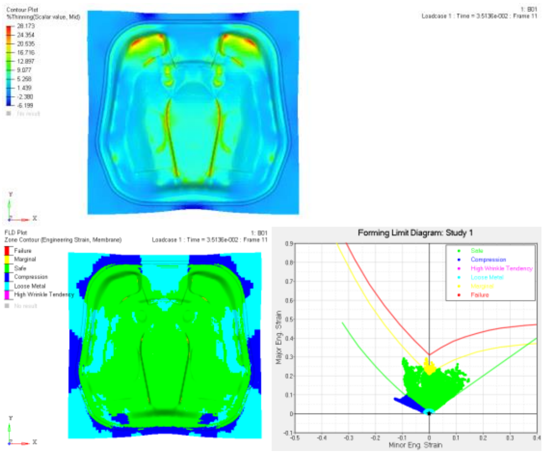


Figure 9: Simulation result of 4th iteration

Fig. 9 shows the result of simulation with step bead. In this case, maximum thinning occurred is 28.173% which is more than desired value i.e. more than 20%. Forming limit diagram (FLD) shows wrinkle on the component. To reduce thinning up to 20%, more iteration is required. So we have to take more iteration until the safe thinning will occur and there should be no tendency of wrinkle and any failure of part. But here we consider only 2 iterations based on L9 orthogonal array.

The result of simulation of these 9 experiments in terms of % thinning is used as a response for Taguchi method as shown in Table 3. The experiments were performed twice and the average is taken as response to calculate S/N ratio and mean.

Table 3: Experimental Results

BHF	DBH	BS	% Thinning 1	% Thinning 2	Average
20	0	85	14.28	14.78	14.53
20	5	90	25.16	25.45	25.305
20	6	95	19.33	18.78	19.055
28	0	90	18.84	19.25	19.045
28	5	95	28.17	26.45	27.31
28	6	85	17.606	17.95	17.778
60	0	95	14.19	14.56	14.375
60	5	85	15.45	15.58	15.515
60	6	90	17.59	17.86	17.725

3.9 Analysis of data

After conducting the experiments, results were converted in S/N ratio values. The final L9-OA displaying response values and their corresponding S/N ratio values for % thinning error are shown in Table 4. For these experimentation and analysis using Taguchi results are-

Table 4: S/N ratios and mean values

BHF	DBH	BS	Average	SNRA1	MEAN1
20	0	85	14.53	-23.2453	14.53
20	5	90	25.305	-28.0641	25.305
20	6	95	19.055	-25.6002	19.055
28	0	90	19.045	-25.5956	19.045
28	5	95	27.31	-28.7264	27.31
28	6	85	17.778	-24.9977	17.778
60	0	95	14.375	-23.1522	14.375
60	5	85	15.515	-23.815	15.515
60	6	90	17.725	-24.9717	17.725

Main effect plot

The main effects plot for means of blank holding force, draw bead height and binder stroke are shown in Fig. 10. From main plot effect, it has been observed that % thinning is maximum at level

2 of blank holding force, at level 2 of draw bead height and at level 2 of binder stroke.

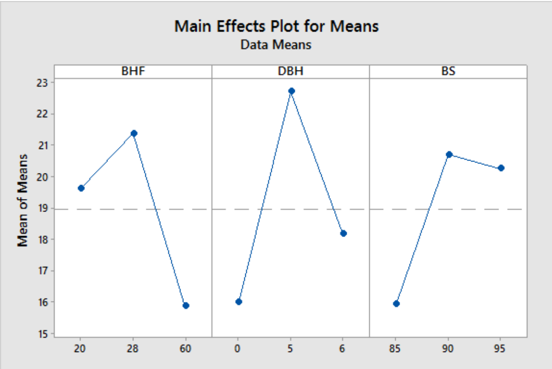


Figure 10: Main effect plot for means

Response Table for Means

Level	BHF	DBH	BS
1	19.63	15.98	15.94
2	21.38	22.71	20.69
3	15.87	18.19	20.25
Delta	5.51	6.73	4.75
Rank	2	1	3

Figure 11: Response table for Means

Response table for means is shown in Fig.11. The delta value given in the table gives the variations in mean within the levels, more the variation more is the delta value and hence more is the contribution of that factor in the response. The rank for each control factor given in a table gives the order in which every factor is contributing in a particular response and it is decided on the value of delta. From higher to lower value of delta ranks of all factors are decided. It can be seen from the table that the delta value for draw bead height is maximum followed by blank holding force and binder stroke. Hence in the same order rank is given to the control factors.

Taguchi's predictions for optimum %thinning results are collected as shown in Fig. 12.

Taguchi Analysis: Average versus BHF, DBH, BS
Predicted values
Prediction

S/N Ratio	Mean
28.8149	17.857

Settings

BHF	DBH	BS
28	5	90

Figure 12: Taguchi analysis predictions

For minimum % thinning, predicted optimum values are collected as shown in Fig. 12 which means for this predicted values of optimum setting if we carry out simulation experiment the % thinning will be 17.85%.

IV. RESULT AND DISCUSSION

The optimum values for influential factors for thinning % less than 20% i.e. 17.857% are obtained from Taguchi's prediction.

A. Blank holding force = 28 Ton
B. Draw bead height = 5 mm
C. Binder stroke = 90 mm

Now the simulation of whole process with these predicted optimized values is carried out, and the results of this simulation for %thinning at the forming stage are shown in Fig. 13.

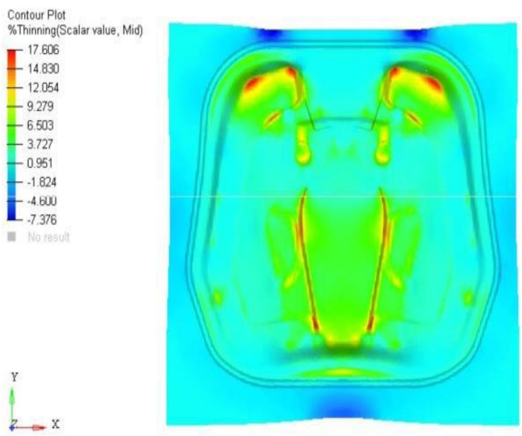


Figure 13: Simulation results for optimized parameters

The maximum %thinning observed in this process is 17.606%, which proves the optimization was successful till the simulation is concerned. Now, this virtual simulation experiments and the optimization results are to be validated with actual experimental run at industry. Hence, we manufactured the tooling and one experiment is carried out over actual metal sheet in industry and the part is analyzed for thinning error and the % thinning observed on the final part is 16.1 %.

V. CONCLUSION

In the forming process of REINF-RR END UPR-LH/RH, blank holding force, draw bead height and binder stoke are observed to have most influence on the % thinning error and thus contributed to improving the process's reliability. This study has shown the application of Simulation and Taguchi method on the optimization of forming process parameters to eliminate the thinning error. The simulation experiment was successful in terms of achieving the objective of experiment. Hence by using the simulation tool (Altair's HyperForm) and optimization of forming process parameters the optimum values for influential factors for thinning % less than 20% i.e. 17.857% are obtained from Taguchi's prediction. Using Taguchi, the error of thinning in REINF-RR END UPR-LH/RH is eliminated.

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