FEA based Optimization of Die Design parameter on Thinning in deep drawing using DOE

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***Abstract*— Stamping problems are complex in nature since they involve shape, sizes, and boundary and material properties. Drawings part involves many parameters like draw force, draw radius, punch velocity and its trajectories etc. So designing the tools for part drawing involves a trial and error procedure. To reduce number of costly trial error steps, process can be simulated with the help of finite element methods. The dissertation work is relevant in the context of developing a cost effective component with a lower lead time through the phase of Design, Development, Trials and Testing, lot of production & Regular supply. In this dissertation work, the significance of three important deep drawing process parameters namely blank Holding force, die arc radius and punch nose radius on the deep drawing characteristics was determined. Existence of thickness variation in the formed component may cause stress concentration and may lead to acceleration of damage. The finite element analysis is a powerful tool to predict material thinning deformations before prototypes are made. In this dissertation work, the combination of finite element method and Taguchi design of experiments and ANOVA has been applied to analyze the influencing process parameters on Thinning in automotive Deep draw cup component.**

***Index Terms*— Deep drawing; FEM; Taguchi technique; ANOVA**

I. INTRODUCTION

Deep drawing is a process of forming sheet metal through a forming die and a punch. Metal in the area of the die corner undergoes stress, and will result in fractures, wrinkles if a blank holder is not used to control the flow of material into the die. Material is thickest in the area where the metal loses contact with the punch - the punch radius - and thinnest in the areas where stresses are greatest. [6].

A. Blank Holder Force (BHF)

Control of the blank holding force enables control of friction on the flange during deep drawing process. It is used to contain the formation of wrinkles that can appear in the component flange. When higher the BHF, stress normal to the thickness more which restrains any formation of wrinkles. in order to have less thinning in the component, the maximum punch force must be reduced. This can be getting by controlling the BHF throughout the process. BHF is small at beginning, which is good for the flow of material towards die cavity. Increase in blank holder force reduces sliding of the sheet between the die and the binder and reduces spring back by increasing the tension

B. Radius on Die (R_D)

Theoretically, the radius on the die should be as large as possible to permit complete metal flow as it passes over the radius. The die radius causes the metal to begin flowing plastically and side in compressing and thick the outer portion of the blank. If the draw radius is too large, the metal will be release by the blank holder too soon and causes wrinkling.

C. Radius on Punch (R_P)

There is no rule for the size of the radius on the punch.

A sharper radius can require greater forces when the metal is folded in the region of the punch nose and may result in uncontrollable thinning or fracture, tearing at the bottom of the cup component. A common rule to reduce the thinning is to design the punch radius of from 4-8 times the thickness of metal. It has been seen that the die and punch radii have the more effect on the thickness of the deformed mild steel cups compared to blank -holder force or friction.

D. Coefficient of Friction (μ)

In metal forming processes friction influences the strain distribution at blank -tool interface and draw ability of metal sheet. The force of friction between the work piece blank and surfaces of die must be overcome in a deep drawing operation. The force of the blank holder adds significantly to the force of static friction.

II. LITERATURE REVIEW-

R.Padmanabhan et al.[1] investigated that the use of FEM with Taguchi technique to determine the proportion of contribution of three important process parameters in the deep-drawing process namely die radius, blank holder force and friction coefficient. FEM and Taguchi technique forms an effective tools combination to predict the influence of process parameters. The analysis of variance (ANOVA) was carried out to examine the influence of process parameters on the quality characteristics (thickness variation) of the circular cup and their percentage contribution were calculated. Further optimization of these process parameters value can be facilitated based on the degree of influence of the factors on the deep-drawing behavior of the circular cup in order to improve the quality of the part.

J. Pradeep Kumar et al. [2] suggested that the response table for signal to noise ratio and standard deviations indicates the order of importance of the three parameters and they are in the order of Punch Nose Radius, Blank Holding Force and then the Punch Force. The S/N ratio graph shows that the S/N ratio first decreases and then increases suggesting that the point for higher S/N ratio gives the best results. Also the standard deviation decreases with the increase in punch force. Both these graphs indicate that a higher punch force is required to produce optimum results during drawing. The plots for Blank holding force versus S/N ratios and standard deviation show almost a linear relationship for both the variables. This indicates that for a higher S/N ratio and a lower standard deviation plot, a lower blank holding force gives the optimum results. Thus a lower blank holding force ensures uniform thickness by not applying excessive pressure on the flange..

G. Venkateswarlu et al. [3] investigated the use of FE simulations with Taguchi design of experiments technique to determine the proportion of contribution of the important process parameters in the deep-drawing process deformation response namely blank temperature, die arc radius and punch velocity. FEM simulation in combination with Taguchi DOE technique forms an effective method to predict the influence of process parameters. The analysis of variance (Pareto Anova) was carried out to examine the influence of process parameters on the deformation of the drawing cup and their percentage contribution.

S.Raju et al. [4], suggested Deep drawing experiments were carried out according to the central composite design. The optimum parameter setting for most even wall thickness was found out using TAGUCHI's signal-to-noise ratio. The parameter settings are punch nose radius ,die shoulder radius and blank holder force The degrees of influence of the selected parameters on the deep drawing behavior of circular cup in order to improve the quality of the formed part were determined

H. Zein et al. [5] said that Prediction of the forming results, determination of the thickness distribution and the thinning of the sheet metal blank will decrease the production cost through saving material and production time. The die shoulder radius and punch nose radius is depend upon of times sheet thickness so it is required to optimize the radius of die and punch.

III. METHODOLOGY

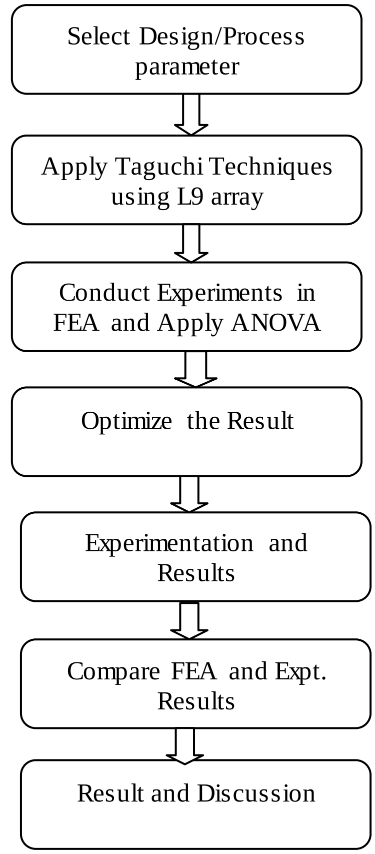


Fig. 1: Work Flowchart

IV. DESIGN CALCULATION

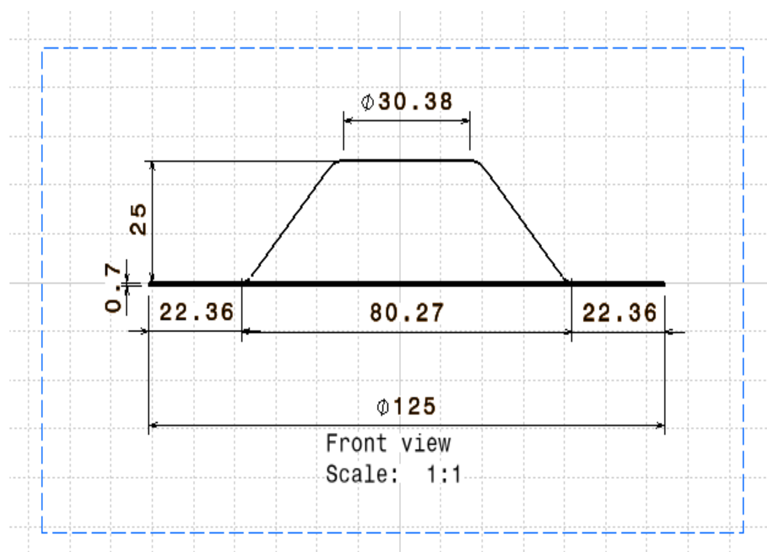


Fig. 2: Component Drawing

Developed Blank Diameter -

$D=\sqrt{(d_2)^2+2(d_1+d_2)h+(d^2_3-d^2_2)}=133mm$.

Draw Force –

Draw Force can be calculated by empirical relation [7],

$P = \pi.d.\ t.\ s.\ ((D/d) - C)$

Where, P = Draw Force in N

D = Blank Diameter in mm = 133 mm

d = Punch Diameter in mm = 30.38 mm

t = Thickness of Metal in mm = 0.7 mm

S = Yield strength =208.2

C = Constant (Take 0.6 to 0.7) =0.6

Therefore, Draw Force (P) = 52.5KN

Die & Punch radius –

The Die radius usually ranges from 4 to 8 times the Blank thickness,

The Punch Nose radius usually ranges from 4 to 12 times the Blank thickness,

Blank Holding Force –

Blank Holding Force (B.H.F.) is one Fourth to one third of Draw Force [7],

Blank Holding Force (B.H.F.) =17 KN

V. TAGUCHI TECHNIQUE

Taguchi proposed several approaches to experimental designs called Taguchi method. Using Taguchi method, a objective comparison of levels of the process parameters and reduction in the total number of required simulations will both be achieved. Taguchi L9 orthogonal array was used to investigate the effect of process parameters in nine experiments .The process parameters studied were, the die radius, the punch radius, the blank holder force, the lubricant type, the punch velocity .blank temperature the draw depth. Three levels were used for each parameter. The results indicate that die or punch radii have the more effect on the thickness of the deformed mild steel cups compared to other process parameters [1]. In the present study, Taguchi method of experimental design was used to plan the numerical simulations. In Taguchi techniques, using two levels of each factors form screening experiments to determine a model of the system to a linear approximation. By this, the less influential parameters are identified and eliminated before the most influential process parameters can be further studied. Hence, three levels of the process parameters were used in this study to detain the non-linear effects in the experimental design. There are many factors, both process and design parameters, which influence deep-drawing process.

After the experiments are designed with various combinations of process parameter and levels, simulations were carried out to predict the deformation behavior of the sheet of blank. The results obtained from the simulations were treated using statistical approach namely, ANOVA method. The purpose of using ANOVA is to illuminate the parameters that govern the deep-drawing process that markedly influence the thickness distribution. This will gives information about the impact of each parameter on the results predicted by the finite element method. As a result, the degree of importance of each process parameter in the deformation behavior of the blank sheet can be determined [1].

Table 1: Process Parameter and Their Level

Process Parameter	**level**		
	1	2	3
Punch nose radius (mm)	3	4	5
BHF(KN)	13	15	17
Die Shoulder radius(mm)	3	4	5

Table 2: Orthogonal array (L9) of Taguchi method

Expt.No.	**Parameter**		
	Punch Nose Radius	**BHF(KN)**	**Die shoulder Radius**
1	3	13	3
2	3	15	4
3	3	17	5
4	4	13	4
5	4	15	5
6	4	17	3
7	5	13	5
8	5	15	3
9	5	17	4

VI. FINITE ELEMENT ANALYSIS

As we selected the L9 orthogonal array, we did 9 experiments in Fast form software & took the thickness of the various region of the component showing in figures. Some of the experiment showing below

Table 3: Mechanical Properties of material

Material	CRCA mild steel
Yield strength	208.2MPa
Plastic strain ratio 'r' value	1.8
Strain Hardening exponent, 'n' value	0.2
Modulus of elasticity(E)	210000MPa
Poisson ratio(μ)	0.3
thickness	0.7mm

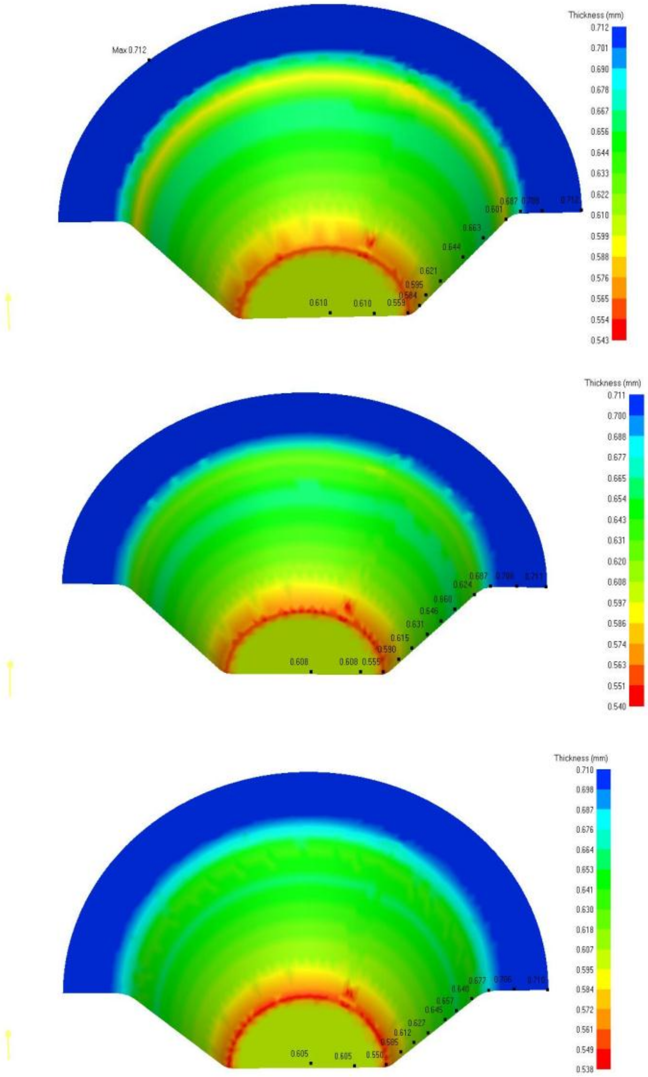


Fig.3: Thickness distribution of experiments no.1, 2, 3

a) ANOVA-

TAGUCHI's main idea was to control the noise factors indirectly by investigative how they are affected by different settings of the control factors. He suggested analyzing the combined effects of control and noise factors, and for this purpose, proposed a performance criterion called signal-to-noise ratio(S/N).Defects such as wrinkles, fractures and excessive thinning change the product geometry from the designed one, causing difficulties in joining and assembly of sheet products, and limiting the product serviceability. Therefore, thickness of the deep drawn cup section should be as uniform as possible, i.e. the nominal values are favored throughout the section. If the nominal value for a characteristic is the best, then the designer should take highest the S/N ratio, accordingly the S/N ratio chosen is given [1]

$$(S/N) = 10ln10\frac{1}{n}\sum_{i=1}^{n}\frac{\mu^2}{\sigma^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where

n = Total number of trials at the i^{th} setting,

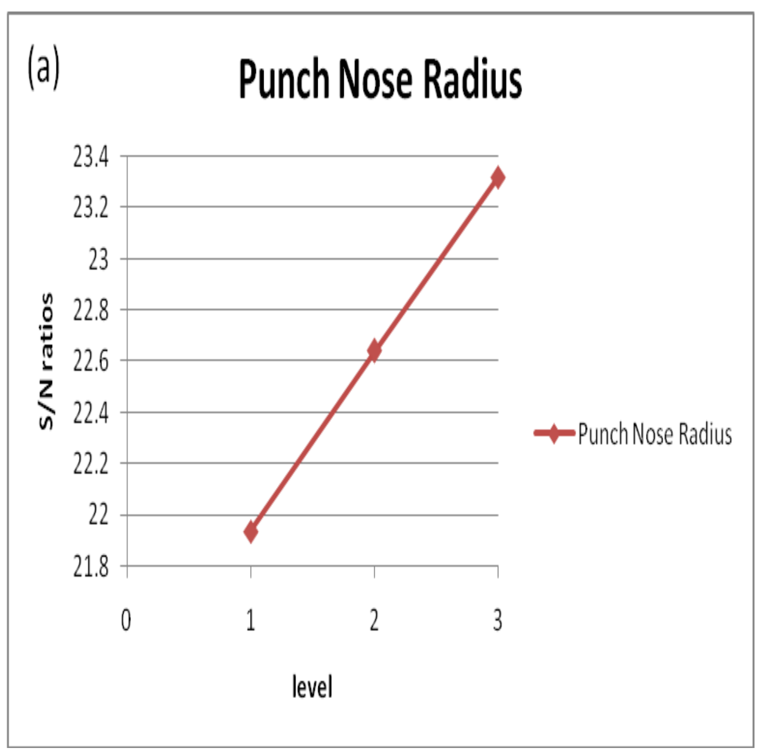
μ= Mean and

σ = standard deviation.

Table 4: Contribution of Parameter

Parameter	%Contribution
Punch Nose Radius	83.84
Blank Holding Force	15.67
Die shoulder Radius	0.475

b) ANOVA Result-



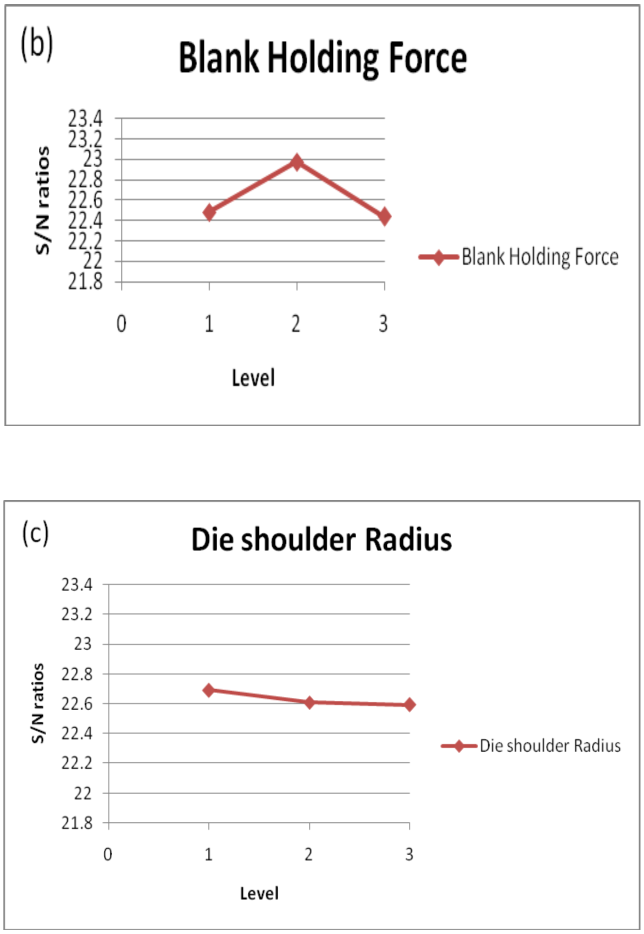


Fig.4: Plots of level Vs average S/N Ratios values of three parameters:
(a) Punch nose radius; (b) Blank holder force ;(c) Die shoulder radius;

For optimum values of the selected parameters, the level that gives the highest *S/N* ratio was chosen [4].Therefore, it can be assured that the optimum levels for the three significant factors, for the most even wall thickness distribution are punch nose radius of 5 mm, blank holder force of 13 KN, die shoulder radius of 3 mm, and which are the parameter level settings for the experimental No.8.

VII. EXPERIMENTATION AND VALIDATION

We carried out experimentation over a suitable press machine based On the 70 tonnage for the component. A per Work we took the Inputs from FEA of expt. No. 8 is given for experimentation i.e. Rp=5mm, BHF=13KN, Rd=3mm

Fig.5: Mechanical press and Tools.

Fig. 6: Defect free components

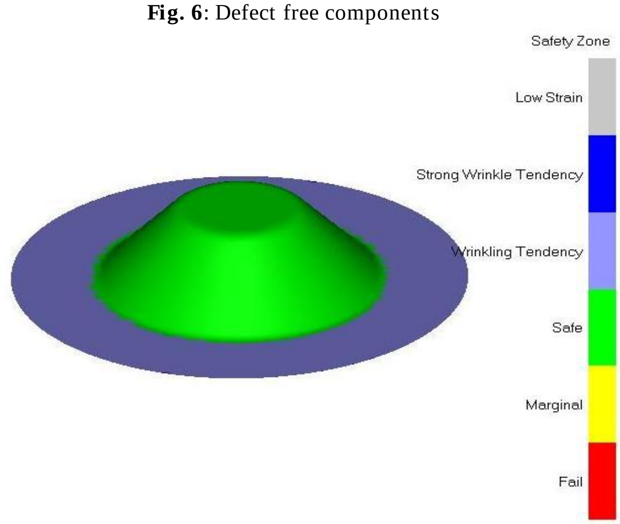


Fig. 7: Safety zone of Component

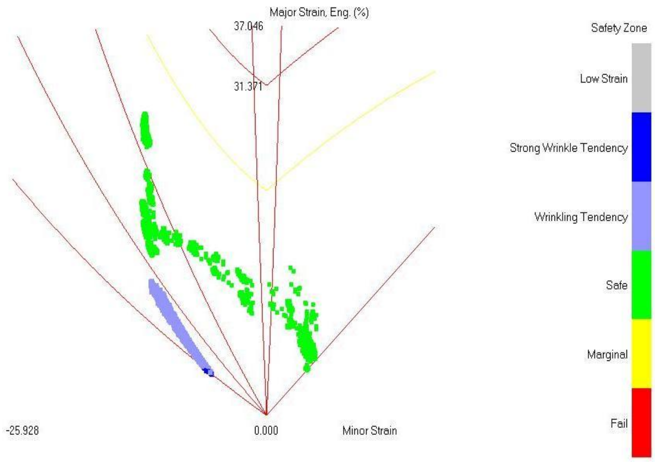


Fig. 8: Forming limit diagram-FEA result

VIII.CONCLUSION

Large thinning & fractures in areas of the sheet metal is an unwanted defect. Excessive thinning will most likely occur on the side wall, near the base of the part. So minimization of Thinning is important in deep drawing process. The parameters affecting on thinning in deep drawing are nose radius, blank holder force and Die shoulder radius. By controlling all these parameters minimization of thinning occurs. Here, in this paper Taguchi method with ANOVA is used to optimize the thinning in deep drawing. Simulation technique used effectively to optimize the die design and process parameters. So it is concluded that the proposed optimization approach is successful and it is validated with experiments which reduce the cycle time and material cost.

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