Analyze the Effect of Process Parameters in Deep Drawing of Stainless Steel 316

[1]Dhaval P. Shah,[2]S. J. Chaudhary
[1]Student,[2]Assistant Professor
[1]Mechanical Engineering Department,
[1]S. P. B. Patel Engineering College, Mehsana, India
dhaval_shah2009@yahoo.com,sandip.chaudhary@saffrony.ac.in

Abstract- One of the most common outcomes in deep drawing process is the defects that occur in the cup shell. These defects are caused by many parameters like blank holder force (BHF), Die Radius, Punch Radius, Blank diameter, friction between punch and blank and Die, normal anisotropy of material, blank thickness and many more. The main objectives of the present study are to determine the most critical process parameters that cause defects and thinning in the blanks. The effect of various process parameters will be determined by using Statistical as well as Experimental methods.

IndexTerms - SS 316, BHF, Punch radius, Die radius, Thinning of sheet, Wrinkling, Taguchi's orthogonal array, ANOVA

I. INTRODUCTION

Forming is a process in which force is applied to metal to modify its geometry instead of removing of material. The applied force stresses the metal beyond its yield strength, causing the material to plastically deform, but not to fail. The stresses induced during the process are greater than yield strength, but less than fracture strength, of the material. The type of loading may be tensile, compressive, bending or combination of these. This is very economical process as the desired shape, size and surface finish can be obtained without any significant loss of material.

Deep drawing is process to produce cups, shells, boxes and similar parts from metal blank. It is a 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.

A simple drawing operation is shown in fig 1. A round blank is first cut from flat stock. The blank is then placed in the draw die, where the punch pushes the blank through the die. On the return stock the cup is stick with punch, to avoid this blank holder is used. Generally, a drawing operation is referred to as shallow drawing when the depth of cup is less than the diameter of cup and drawing of cup is deeper than half its diameter then it is called deep drawing.

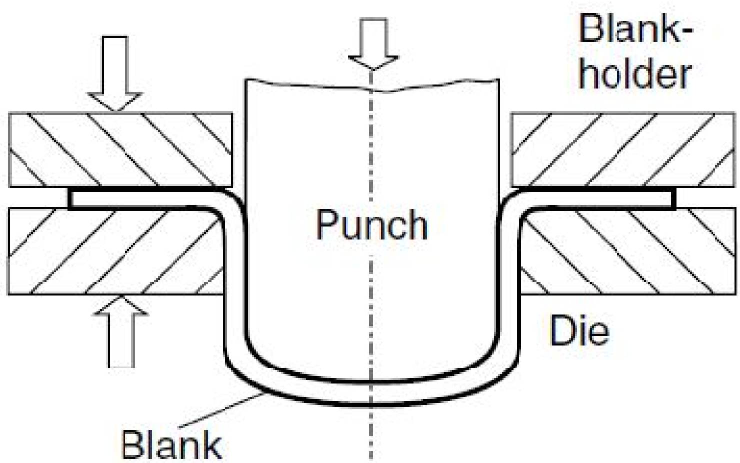

Fig 1: A typical Deep drawing operation

To understand what happened to the metal during operation, the process should be broken into progressive stapes of formation as shown in fig 2. Here the flat circular blank is drawn into a flat-bottomed cup by forcing a punch against the blank, which is rest on a die. During first stage the punch contacts the blank. As the punch penetrates, the metal is bent from die radius and also from the punch radius, half cup will be formed. After further penetration, the metal that was previously bent over the die and punch radius becomes straight. As the punch progress downward final cup will form.

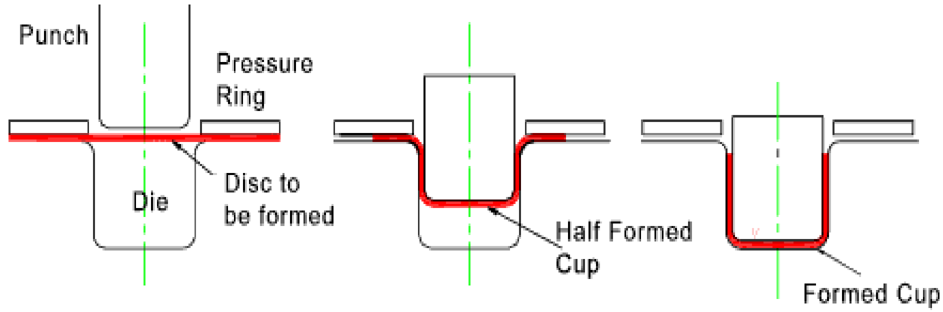

Fig 2: Steps during deep drawing process

To understand the forming process, the circular Workpiece can be divided into the three zones as shown in fig 3. (i.e. x, y and z). The material in zone x will form the bottom of the drawn cup. This material must slide freely along the surface of the punch and undergoes some stretching, but typically the change in thickness during the drawing of the material in zone x is minimal. The material in zone y predominantly undergoes bending. Material in zone z is drawn radially inward.
The effect of this decrease in radius and circumference is to cause the sheet thickness to increase and induce compressive hoop stresses in the material of zone z. The role of the blank holder is to ensure that, as the material in zone z moves along radially inward the compressive hoop stresses do not cause wrinkling of the Work piece.

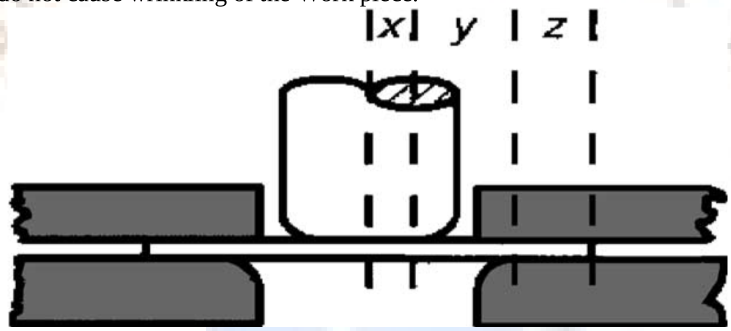

Fig 3.Deformation zones during deep drawing

Wire EDM Input Parameters:

- **Punch Radius:**

There is no set rule for the size of the radius on the punch. A sharper radius will require higher forces when the metal is folded around the punch nose and may result in excessive thinning or tearing at the bottom of the cup. A general rule to reduce the thinning is to design the punch with a radius of from 4-10 times the metal thickness.

- **Die Radius:**

Theoretically, the radius on the draw die (draw ring) should be as large as possible to permit full freedom of metal flow as it passes over the radius. The draw ring causes the metal to begin flowing plastically and side in compressing and thickening the outer portion of the blank. However, if the draw radius is too large, the metal will be release by the blank holder too soon and wrinkling will result. Too sharp a radius will hinder the normal flow of the metal and cause uneven thinning of the cup wall, with resultant ering.

- **Blank Holding Force (BHF):**

A deep drawn part's quality is affected significantly by the flow of metal into the die cavity .The force exerted by the blank holder on the sheet supplies a restraining force which controls the metal flow. This restraining action is largely applied through friction. Blank holding force is small at beginning, which is good for the flow of material towards die cavity. But if blank holding force is less than the chances of wrinkling is more and if blank holding force is higher than chances of tearing is higher.

Different Response Parameters:

- **Wrinkling In The Flange:**

This defect occurs due to compressive buckling in the circumferential direction. Due to less blank holding force this defect may occur. Because of the material flow is not restricted and more material is trying to flow inside the die cavity.

- **Wrinkling In The Wall:**

This defect takes place when wrinkled flange is drawn into cup or if the clearance is very large, which results in large unsupported region. Wrinkling is avoided by applying a blank holder force through a blank holder. This increases friction and hence the required punch load increases. The edges of punch and die are rounded for the easy and smooth flow of metal.

- **Tearing:**

This defect occurs because of high tensile stresses that cause thinning and failure of the metal in the cup wall. Tearing can also occur in a drawing process if the die has a sharp corner radius. If die radius is too small because of that more restriction to flow of material. If punch radius too small because of that more thinning of material is occur at that corner of formed part.

II. LITERATURE SURVEY

Mark Colgan et al [4], reports on the initial stages of a combined experimental and finite element analysis (FEA) of a deep drawing process. The objective of this research was to determine the most important factors influencing a drawing process, utilizing the help of a design of experiments and statistical analysis. The parameters varied include the punch and die radii, the punch velocity, clamping force, friction and draw depth. After observing the anisotropic effects of the rolling process on the sheet material through drawing it and seeing the extent of earing in the flange, some blanks were annealed for stress relief, then the draw depth was compared to that of the original mild steel blanks. The main aspect that the ANOVA highlighted is that the geometry of the tooling is generally most important, especially the die radius. The smaller is the die radius, the greater is the drawing force induced and the greater is the overall thinning of the cup sidewall. Through series of Experiments it was revealed the If the blank-holder force is not kept within the upper and lower limit of reasonable range it does have a significant effect on depth of draw, with the punch tearing through the bottom of the cup if the force is too high and if too low wrinkling of the flange area occurs.

G. Venkateswarlu et al [5], carried study on AA7075.It is one of the most important structural materials extensively used in automobile and aerospace industries. In this study, the significance of three important deep drawing process parameters namely blank temperature, die arc radius and punch velocity on the deep drawing characteristics of Aluminium 7075 sheet was determined. The combination of finite element method and Taguchi analysis was used to determine the influence of process parameters. Simulations were carried out as per orthogonal array using DEFORM 2D software. Based on the predicted deformation of deep drawn cup and analysis of variance test (ANOVA), it was observed that blank temperature has greatest influence on the formability of Aluminium material followed by punch velocity and die arc radius. ANOVA methods can provide optimal parameters, however, these parameters have to be validated by conducting experiments. They have not considered blank holding force as a variable parameter but it plays critical role in product quality.

S. RAJUet al [6],reported that Deep drawing is one of the most important processes for forming sheet metal parts. It is widely used for mass production of cup shapes in automobile, aerospace and packaging industries. Cup drawing, besides its importance as forming process, also serves as a basic test for the sheet metal formability. The effect of equipment and tooling parameters results in complex deformation mechanism. Existence of thickness variation in the formed part may cause stress concentration and may lead to acceleration of damage. Using TAGUCHI's signal-to-noise ratio, it is determined that the die shoulder radius has major influence followed by blank holder force and punch nose radius on the thickness distribution of the deep drawn cup of AA 6061 sheet. 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 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. The die shoulder radius has major influence followed by blank holder force and punch nose radius.

R. Padmanabhanet al [7], in his studies revealed that to determine the optimum values of the process parameters, it is essential to find their influence on the deformation behavior of the sheet metal. The significance of three important process parameters namely, die radius, blank holder force and friction coefficient on the deep-drawing characteristics of a stainless steel axi-symmetric cup was determined. Finite element method combined with Taguchi technique form a refined predictive tool to determine the influence of forming process parameters. The Taguchi method was employed to identify the relative influence of each process parameter considered in this study. A reduced set of finite element simulations were carried out as per the Taguchi orthogonal array. Based on the predicted thickness distribution of the deep drawn circular cup and analysis of variance test, it is evident that die radius has the greatest influence on the deep drawing of stainless steel blank sheet followed by the blank holder force and the friction coefficient. This paper illustrates 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. The die radius has major influence on the deep-drawing process, followed by friction coefficient and blank holder force.

Young Hoon Moonet al [8], studied the effects of internal air-pressing on deep draw ability to increase the deep drawability of aluminum sheet. The conventional deep drawing process is limited to a certain limit drawing ratio(LDR) beyond which failure will occur The intention of this work was to examine the possibilities of relaxing the above limitation through the deep drawing with internal air-pressing, aiming towards a process with an increased drawing ratio. The equipment and tooling parameters that affect the success or failure of a deep drawing operation are the punch and die radii, the punch and die clearance, the press speed and the lubrication. On the basis of the experimental investigation made herein, higher air pressing guarantees higher LDR. The increased LDR is mainly caused by the relaxation effect of local strain concentration at punch nose radius area.

Y. Marumoet al [9], The objective of the work was to study the influence of sheet thickness on blank holding force and limiting drawing ratio. The paper shows variation in the blank holding force required for the elimination of wrinkling and the limiting drawing ratio with sheet thickness. The blank holding force required for the elimination of wrinkling increased rapidly as the sheet thickness decreased. The blank holding force was strongly influenced by sheet thickness and the coefficient of friction. The limiting drawing ratio decreased as sheet thickness decreased.

A. Fallahiet al [10], stated that deep drawing process has some noticeable defects such as wrinkling, tearing, spring back, and thickness variation in different locations of produced cups. In the research the parameters of interest were punch/die shoulder radius, blank holder force, friction between sheet and die/punch/holder. Simulations were carried out using ABAQUS finite element software, and to study the effects of these parameters, Taguchi method was used. To verify the study's simulation results, experimental tests was carried out. Also By applying Analysis of Variance (ANOVA) method the significance and magnitude of each parameter in determining the thickness was used. Finally, to get the initial blank thickness in different locations the optimum level of parameters was calculated. He concluded that Die radius and Punch radius had the major influence in variation in thickness.

Kopanathigowthamet al [11], reports on the initial stages of finite element analysis(FEA) of a Deep drawing process. The objective of this study was to determine the factors influencing a drawing process and analyzing the process by varying the Die radius and keeping the Friction, Punch radius and Blank Thickness as constant. In this paper Punches, blank thickness of same geometry and dies of various geometries were drawn by using CATIA software. And an effort is made to study the simulation effect of main process variant namely die radius using finite element analysis. As the FEM code, the commercially available software DEFORM-3D is used here. Aluminium alloy 6061 is used for deep drawing with initial diameter as 56mm. It has been found that as the die radius is reduced, the amount of fore required to draw the material is increased. A decreased die radius created stretching marks and earring type problems.

R. Venkat Reddyet al [12], studied that the appearance of dimensional deviations of shape and position, of the defects in the metal sheets that have been subjected to a cold plastic deformation process (deep drawing), represents a critical problem for the mass production, like the machine manufacturing industry. The aim of this publication was to present the principal aspects that effect of various factors like BHF, punch radius, die edge radius, and coefficient of friction on the wrinkling of cylindrical parts in deep drawing process. The initiation and growth of wrinkles are influenced by many factors such as stress ratios, the mechanical properties of the sheet material, the geometry of the work piece, and contact condition. He concluded that the height of the wrinkles is reduced by increasing the BHF, decreasing friction, increasing the tools edge radius all together in one operation. It was also noticed that when Friction forces are low, the wrinkling is more pronounced, but if the friction forces are too high the material can break.

H.Zeinet al [13], reported that determination of the thickness distribution and the thinning of the sheet metal blank will decrease the production cost through saving material and production time. In the study, A Finite Element (FE) model was developed for the 3-D numerical simulation of deep drawing process (Parametric Analysis) by using ABAQUS/EXPLICIT FEA program with the proper material properties (anisotropic material) and simplified boundary conditions. The FE results were compared with experimental results for validation. The developed model predicted the thickness distribution and thinning of the blank with the die design parameters. He concluded that Die shoulder radius has major impact on thinning of sheet. Punch nose radius, thickness of sheet metal also influence the draw quality followed by BHF.

III. EXPERIMENTAL SETUP

In our project work, we choose three factors at range of two level in deep drawing process as below shown in table.1

Table.1 Values of Process parameters for L4 & L27 orthogonal array

			parameters	
Sr no.	Level	Die radius (mm)	Punch radius(mm)	BHF (N)
1	Level-1	2	2	300
2	Level-2	8	8	700

			parameters	
Sr no.	Level	Die radius (mm)	Punch radius(mm)	BHF (N)
1	Level-1	2	2	300
2	Level-2	5	5	500
3	Level-3	8	8	700

From the above table according to design of experiments with taguchi's orthogonal array by using Minitab_16 statical tool have produced total numbers of 27 experiments to be performed in deep drawing process as shown in below table.2.

Table.2 Experimental runs as perL27 orthogonal array

PARAMETERS				
Experiment no	**Die radius (mm)**	**Punch nose radius (mm)**	**Blank holding force (N)**	**Results**
1	2	2	300	F
2	2	2	300	F
3	2	2	300	F
4	2	5	500	F
5	2	5	500	F
6	2	5	500	F
7	2	8	700	S
8	2	8	700	S
9	2	8	700	S
10	5	2	500	S
11	5	2	500	S
12	5	2	500	S
13	5	5	700	F
14	5	5	700	F

15	5	5	700	F
16	5	8	300	S
17	5	8	300	S
18	5	8	300	S
19	8	2	700	F
20	8	2	700	F
21	8	2	700	F
22	8	5	300	F
23	8	5	300	F
24	8	5	300	F
25	8	8	500	S
26	8	8	500	S
27	8	8	500	S

Finally we take total 27 number of experimental run to perform SS 316 with the help of hydraulic press machine.
The experimental work performed at i.i.t.e.

Fig.4 Experiment perform on hydraulic press

MATERIAL SELECTION

Stainless steel 316 blank.Dimension for material is diameter of 82 mm and thickness is 1mm.

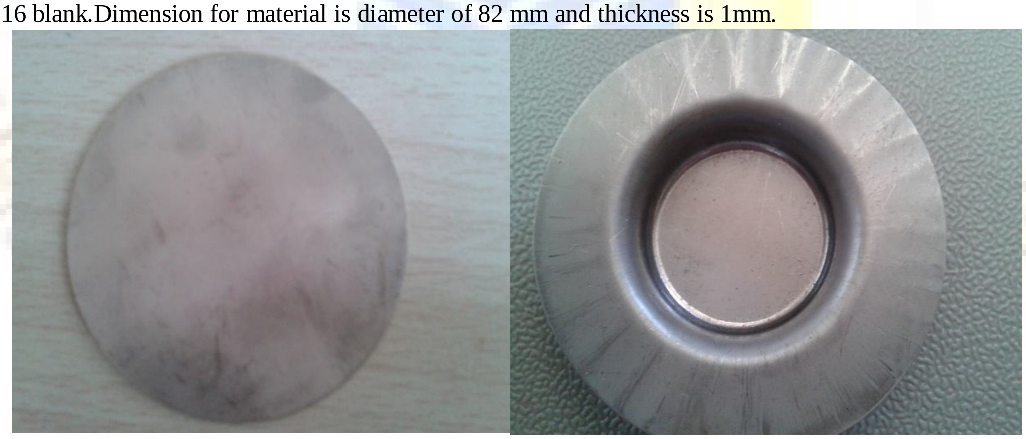

Fig.5Before/After Machining SS 316 blank

IV. DATA ANALYSIS – TAGUCHI'S ORTHOGONAL ARRAY

Experimental results are given in table.3 for thinning. Altogether 27 experiments were conducted using taguchi's L27 orthogonal array.

Table.3 Minimum thickness at a position just before failure for L27 Orthogonal array

Experimental run	Draw Depth (mm)	Thickness (mm)	% Thinning	Remarks
1	20	0.74	26	F
2	20	0.74	26	F
3	20	0.74	26	F
4	20	0.75	25	F
5	20	0.75	25	F
6	20	0.75	25	F
7	20	0.80	20	S
8	20	0.80	20	S
9	20	0.80	20	S
10	20	0.81	19	S
11	20	0.81	19	S
12	20	0.81	19	S
13	20	0.73	27	F
14	20	0.73	27	F

16	20	0.80	20	S
17	20	0.80	20	S
18	20	0.80	20	S
19	20	0.72	28	F
20	20	0.72	28	F
21	20	0.72	28	F
22	20	0.73	27	F
23	20	0.73	27	F
24	20	0.73	27	F
25	20	0.80	20	S
26	20	0.80	20	S
27	20	0.80	20	S

ANOVA Analysis

The analysis of a second-order model is usually done by Minitab software.The data for different factors and their levels along with their results are as shown in Table 4 and table 5 respectively.

Table 4: Factors and their levels with values

Factors	Level-1	Level-2	Level-3
Die Radius (mm)	2	5	8
Punch Nose radius (mm)	2	5	8
Blank Holding force (N)	300	500	700

Table: 5 Data obtained from experimental work for thinning of sheet

PARAMETERS				
Experiment no	**Die radius (mm)**	**Punch nose radius (mm)**	**Blank holding force (N)**	**Thinning (mm)**
1	2	2	300	0.74
2	2	2	300	0.74
3	2	2	300	0.74
4	2	5	500	0.75
5	2	5	500	0.75
6	2	5	500	0.75

7	2	8	700	0.80
8	2	8	700	0.80
9	2	8	700	0.80
10	5	2	500	0.81
11	5	2	500	0.81
12	5	2	500	0.81
13	5	5	700	0.73
14	5	5	700	0.73
15	5	5	700	0.73
16	5	8	300	0.80
17	5	8	300	0.80
18	5	8	300	0.80
19	8	2	700	0.72
20	8	2	700	0.72
21	8	2	700	0.72
22	8	5	300	0.73
23	8	5	300	0.73
24	8	5	300	0.73
25	8	8	500	0.80
26	8	8	500	0.80
27	8	8	500	0.80

Total no of runs = n = 27
Total degree of freedom = F_t= n-1 = 26

Three Factors And Their Levels
Die Radius A: A1, A2, A3
Punch nose radius B: B1, B2, B3
Blank holding force C: C1, C2, C3

Degree Of Freedom
Factor A - Number of level of factor, $F_a = A-1 = 2$

Factor B - Number of level of factor, $F_b = B-1 = 2$

Factor C - Number of level of factor, $F_c = C-1 = 2$

For Error, $F_e = F_t - F_a - F_b - F_c = 26-2-2-2 = 20$
T=Total of all results = 20.64
Correction factor, $C.F = (T^2/N) = (20.64)^2/27 = 15.778$
Total Sum OfSqaures
$S_T = \sum y^2 - C.F = 15.896 - 15.778 = 0.118$
Total Contribution Of Each Factor Level
A1 = 0.74+0.74+0.74+0.75+0.75+0.75+0.8+0.8+0.8
= 6.67
A2 = 0.81+0.81+0.81+0.73+0.73+0.73+0.8+0.8+0.8
= 7.22
A3 = 0.73+0.73+0.73+0.72+0.72+0.72+0.8+0.8+0.8
= 6.75
B1 = 0.74+0.74+0.74+0.81+0.81+0.81+0.72+0.72+0.72
= 6.71
B2 = 0.75+0.75+0.75+0.73+0.73+0.73+0.73+0.73+0.73
= 6.73
B3 = 0.8+0.8+0.8+0.8+0.8+0.8+0.8+0.8+0.8
= 7.2
C1 = 0.74+0.74+0.74+0.8+0.8+0.8+0.73+0.73+0.73
= 6.41
C2 = 0.75+0.75+0.75+0.81+0.81+0.81+0.8+0.8+0.8
= 7.38
C3 = 0.8+0.8+0.8+0.72+0.72+0.72+0.73+0.73+0.73
= 6.85

Factor Sum Of Squares
$S_A = (A_1^2/N_{A1} + A_2^2/N_{A2} + A_3^2/N_{A3})-C.F$
$=[(6.67)^2/9] + [(7.22)^2/9] + [(6.75)^2/9] - 15.778$
$= 0.029$
$S_B = B_1^2/N_{B1} + B_2^2/N_{B2} + B_3^2/N_{B3} - C.F$
$=[(6.71)^2/9] + [(6.73)^2/9] + [(7.2)^2/9] - 15.778$
$= 0.027$
$Sc = C_1^2/N_{C1} + C_2^2/N_{C2} + C_3^2/N_{B3} - C.F$
$= [(6.41)^2/9] + [(7.38)^2/9] + [(6.85)^2/9] - 15.778$
$= 0.062$
$S_E = S_T - (S_A+S_B+S_C)$
$= 0.118 - (0.029+0.027+0.052)$
$= 0.01$

Mean Square (Variance)
$V_A = S_A/f_a = 0.029/2 = 0.014$
$V_B = S_B/f_b = 0.027/2 = 0.0135$
$V_C = S_C/f_c = 0.052/2 = 0.026$
$V_E = S_E/f_e = 0.01/2 = 0.005$

Variance Ratio F
$F_A = V_A/V_E = 0.014/0.005 = 2.9$
$F_B = V_B/V_E = 0.0135/0.005 = 2.7$
$F_C = V_C/V_E = 0.026/0.015 = 1.73$
$F_E = 1$

Percentage Contribution
$P_A = S_A/S_T = 0.029/0.118 = 0.245$
$P_B = S_A/S_T = 0.027/0.118 = 0.228$
$P_B = S_C/S_T = 0.052/0.118 = 0.440$

$P_B = S_E/S_T = 0.010/0.118 = 0.08$

Above analysis shows the percentage contribution of individual parameters on material during the deep drawing process. The percentage contribution of Die radius is 24.5 %, Punch nose radius is 22.8 % and Blank holding force is 44 % and the error is of 8 %. This error is due to human ineffectiveness.

V. CONCLUSIONS

From theaboveexperimentsandtheparametricanalysiscarriedoutduringthisproject, followingthings areconcluded.Theblankholdingforcehas themajorinfluenceinthedeepdrawingprocess.Thedieradiusalsohasaninfluenceintheprocesswhichisfollowedbypunch noseradius.Thefailureinthecomponenti.e.tearinginthecupwasobservedduetoless punchnoseradius.Wrinklingin the formed part was also seen during the experiments which occurredduetolessblankholdingforce.TheFuturescopeofthis experimentis thatsameoperations canbeperformed byusingmore numbers ofparameterswhich are lubrication, clearancebetweendie and thepunch, punch velocity.Theabove experiment can alsobeusedfordifferentmaterialswith different thickness of the blank.

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