International Journal of Mechanical Engineering (IJME)
ISSN (P): 2319-2240; ISSN (E): 2319-2259
Vol. 10, Issue 1, Jan–Jun 2021; 11–20

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

OPTIMIZATION OF PROCESS PARAMETERS IN DEEP DRAWING OF MONEL-400 CONICAL CUP

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ABSTRACT

In this present work, a statistical approach was adopted based on taguchi techniques and finite element analysis to determine the influence of process parameters on the formability of conical cups of Monel-400 alloy using the cold deep drawing process. The process parameters considered for the present work were punch velocity, coefficient of friction, blank thickness and displacement per step. It was found that the sheet thickness and coefficient of friction were influencing the quality of the cup. With increase in blank thickness damage was decreasing. Higher the coefficient of friction higher was the surface expansion ratio.

KEYWORDS: *Deep Drawing, Monel-400 Conical Cup*

Article History

Received: 06 Nov 2020 | Revised: 09 Nov 2020 | Accepted: 18 Nov 2020

INTRODUCTION

The deep drawing process is an effective method of manufacturing of cups, cans and other similar deep drawing products. Deep drawing is a type of forming process. It takes place under a combination of tensile and compressive conditions. To obtain an optimal blank shape that can be deformed into the near net shape, many investigations have been carried out. A.C. Reddy et al. [1] in their work have simulated that the cup drawing process with an implicit finite element analysis. The effect of local thinning on the cup drawing has been investigated. The thinning is observed on the vertical walls of the cup. Ayari et al. [2] suggested that the coefficient of friction between different contact (blank – die, punch blank contact etc.) is the very important parameter. Chung et al. [3] have proposed a direct design method based on an ideal forming theory to get an initial blank shape. The real forming conditions such as friction force, blank holder force and tool geometry are not considered. A. C. Reddy[4] investigated on Formability Analysis of 6063 Al Alloy for deep drawn cylindrical cups with constant and progressive blank holding force and results indicated that the von Mises stress was least at operating temperature of 300ºC, strain rate of 1.0 s^{-1}, friction coefficient of 0.1 and blank holder velocity of 0.13 mm/s. Finch et al. [5] investigated how drawability of both rectangular and circular cups from annealed and hardened aluminium sheet alloys was effected by warm forming. The results indicated a significant enhancement in the drawability (in terms of cup height) around the temperature of 150^{0}C, also for the precipitation hardened alloys like 2024-T4 and 7075-T6.Cwiekala et al. [6] proposed a method that combines various analytical approaches into a single accurate and fast deep drawing simulation. This developed simulation method is applicable to prismatic and axisymmetric deep drawing processes. Consideration of deformation paths, process parameters and material behaviour is possible in the proposed method. Time dependent effects can also be considered because this is a multistep simulation. The developed simulation method gives a better accuracy in calculating strain distributions compared to numerical one step solvers.

Optimizing the deep drawing process of Monel-400 alloy using Taguchi techniques was the objective of the present work. To determine the degree of importance of each of the process parameter on the formability of deep drawn cups an ANOVA technique was adopted. In the present work the simulation of deep drawing process was carried out using DEFORM software.

MATERIALS AND METHOD

Monel 400 is a nickel-copper alloy (about 67% Ni – 23% Cu). Monel-400 is resistant to sea water and steam at high temperatures.It is also resistant to salt and caustic solutions. The Monel 400 alloy is also known as super alloy Monel. The tensile and yield strength of this alloy are 520MPa and 270MPa respectively. The modulus of elasticity of this alloy is 179GPa. The Poisson's ratio is 0.32

The levels of the control parameters were chosen in such a way that there are in the operational range of Monel 400 alloy for deep drawing process. All the considered control parameters were studied at three different levels. The control parameters and their levels are given in table 1. For the present work the orthogonal array (OA), L9 was selected. The parameters were assigned to the various columns of the O.A L9. The assignment of parameters at different levels in the OA matrix is given in table 2.

Table 1: Process Parameters and Levels

Factor	Symbol	Level – 1	Level – 2	Level – 3
Punch velocity, m/s	A	2	3.5	5
Coefficient of friction	B	0.1	0.15	0.2
Thickness, mm	C	0.8	1	1.2
No. of steps	D	50	75	100

Table 2: Orthogonal Array (L9) and Process Parameters

Trial No	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Design of Deep Drawn Conical Cups

To calculate the blank size, the surface area of the finished drawn cup was equated with the area of the blank. The blank diameter, D is given by:

$$D = \sqrt{d_2 + (d_1 + d_2)\sqrt{(d_1 - d_2)^2 + 4h^2}} \quad (1)$$

Where d_1 *and* d_2 are the top and bottom diameters of the cup and h is the height of the cup.

The top and bottom diameters of the punch are those of the cup. The height of the punch is equal to that of the cup. The corner radius of drawing punch must be more than three times the blank thickness (t). At the same time, the punch radius should be less than one-fourth the cup diameter (d).

3t< punch radius < d/4.

The punch radius r_p mm is expressed as:

$$r_p=\frac{12t+d}{8} \quad (2)$$

Where *t* is thickness of sheet and *d* is mean diameter i.e. $(\frac{d_1+d_2}{2})$

For smooth material flow the die edge should have generous radius preferably four to six times the blank thickness but never less than three times the sheet thickness because lesser radius would hinder material flow while excess radius would reduce the pressure area between the blank and the blank holder. The corner radius r_d, mm of the die can be calculated from the following equation:

$$r_d=0.8\sqrt{(D-d)t}$$

Where *D* is blank diameter (mm), *d* is mean diameter (mm) and *t* is thickness (mm). (3)

The material flow in drawing may undergo some flange thickening and wall thinning of the cup. For this purpose, the space for drawing is kept slightly bigger than the sheet thickness. This space is known as die clearance.

$$\text{Clearance, } \boldsymbol{c_d}=t \pm \mu\sqrt{10t} \quad (4)$$

Where μ is the coefficient of friction.

The top diameter of the die d_{d1} is obtained from the following equation:

$$d_{d1}=d_1+2c_d \quad (5)$$

The bottom diameter of the die d_{d2} is obtained from the following equation:

$$d_{d2}=d_2+2c_d \quad (6)$$

The height of the die is the height of the cup. The die corner radius is calculated by adding the clearance to the punch corner radius. The edge radius of the die is eight times the thickness of the blank.

Finite Element Analysis

The circular sheet blank was created according to desired sheet thickness and diameter. The conical die and bottom hollow punch were modelled with appropriate inner radius, corner radius and outer radius as shown in figure 1. The die and punch were modelled using UNIGRAPHICS software. The blank sheet was meshed into tetrahedral elements. The modelling parameters of deep drawing process for trail were as follows:

- Number of elements for the blank: 9432
- Number of nodes for the blank: 3235
- Top die polygons: 842
- Bottom die polygons: 1858

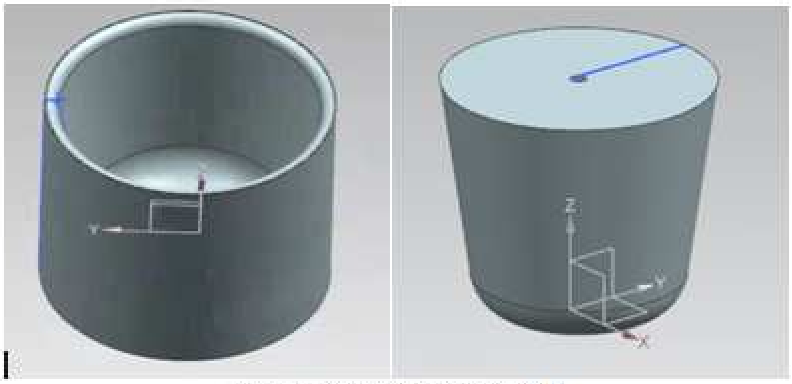

Fig 1: Conical die and punch

The contact between blank and punch, die and blank holder were coupled as contact pair. Mechanical interaction between the contact surfaces was considered to be frictional contact. Effective stress, height of the cup and damage of the cup were found using finite element analysis. Finite element analysis and modelling was done using DEFORM 3D software.

RESULTS AND DISCUSSION

Influence of Control Factors on the Damage of Conical Cups

Table 3 gives the ANOVA summary of raw data. The Fisher's test column establishes all the parameters accepted at 90% confidence level. Factor A, punch velocity, contributes 2% of the total variation. Coefficient of friction, factor B, contributes almost quarter (24.64%) of the total variation. Factor C, thickness, assists 49.94% of the variation and factor D, no of steps, contributes 23.34 % variation on the cup damage.

Table 3: ANOVA Summary of Conical Cups Damages

Factor	S1	S2	S3	SS	v	V	F	P
A	0.7654	0.7936	0.7919	0.0015	1	0.0008	0.06	2.08%
B	0.724	0.8311	0.7957	0.01785	1	0.00893	0.98	24.64%
C	0.83	0.8269	0.694	0.03618	1	0.01809	2.99	49.94%
D	0.7748	0.8405	0.7355	0.01691	1	0.00845	0.91	23.34%
e				0	4	0	0	0
T	3.0942	3.2921	3.0171	0.07245	8			100%

Note: SS is the sum of square, v is the degrees of freedom, V is the variance, F is the Fisher's ratio, P is the percentage of contribution and T is the sum squares due to total variation

The effect of process parameters on the damage of cups is given in figure 2. As the punch velocity increases, damage decreases as shown in figure 2(a). Damage factor increases along with increase in coefficient of friction as shown in figure 2(b). With increase in thickness there is a damage factor as shown in figure 2(c). The damage of the cup is highest at 75 steps as shown in figure 2(d). The damage of the conical cups at different trials is shown in figure 3.

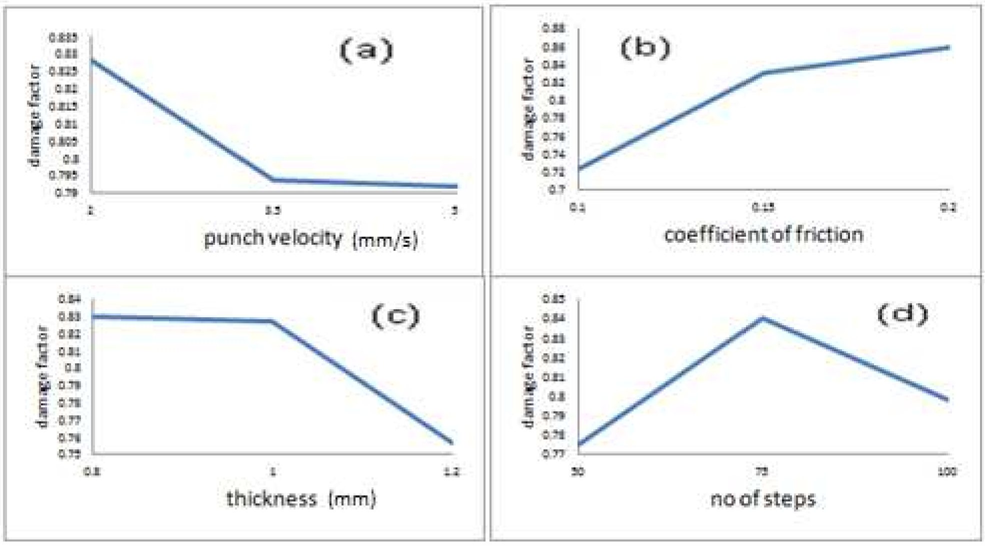

Figure 2: Effect of Process Parameters on the Damage of Cups.

The damage in the conical cups drawn with trial conditions of 2 and 6 were 0.913% and 0.909% respectively. The reason for relatively higher damage in these trials was because of greater coefficient of friction values. The damage in cups drawn with trial conditions of 4, 5 and 7 were 0.729%, 0.742% and 0.699% respectively. The reason for relatively less damage in these trials was due to higher values of thickness.

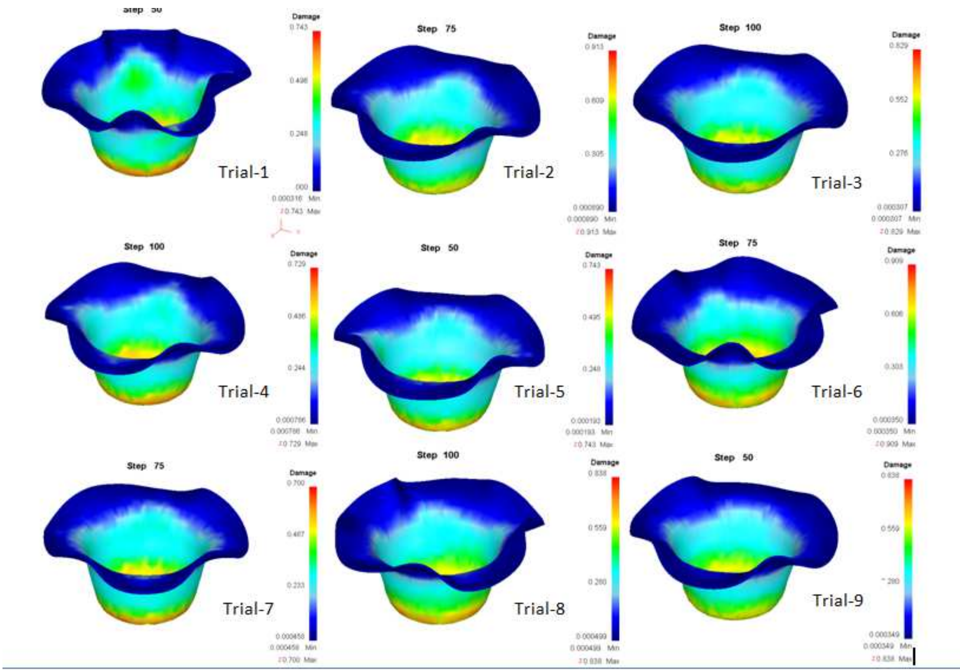

Figure 3: Damage in Conical Cups Under Different Operating Conditions.

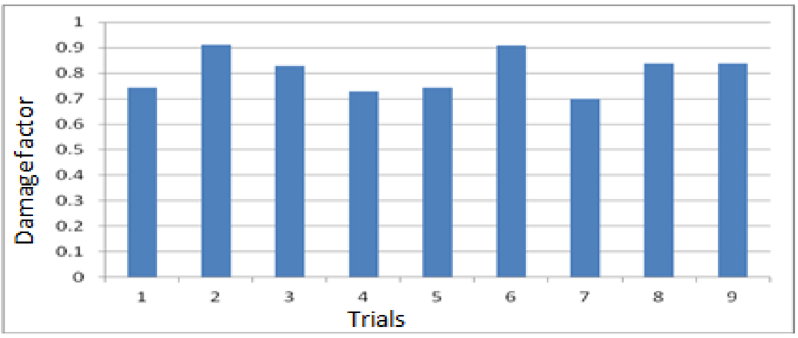

Figure 4: Cup Damages Under Different Trials.

Figure 5 depicts the forming limit diagram with damages in the conical cups drawn from Monel 400 sheets of different thickness. The conical cups drawn under trials 1, 6 and 8 with sheet thickness 0.8mm were most damaged on account of biaxial tension and compression induced in the blank material as shown in figure 5(a). Less damage was observed in the trials 3, 5 and 7 except wrinkles due to comparatively more sheet thickness of 1.2mm as shown in figure 5(c). The conical cups drawn under trials 2, 4 & 9 with sheet thickness 1mm were damaged due to uniaxial tension and stretching as shown in figure 5(b). Least damage occurred in the trial 7 because of low coefficient of friction. Conversely highest damage occurred in trial 6 due to high coefficient of friction and least sheet thickness.

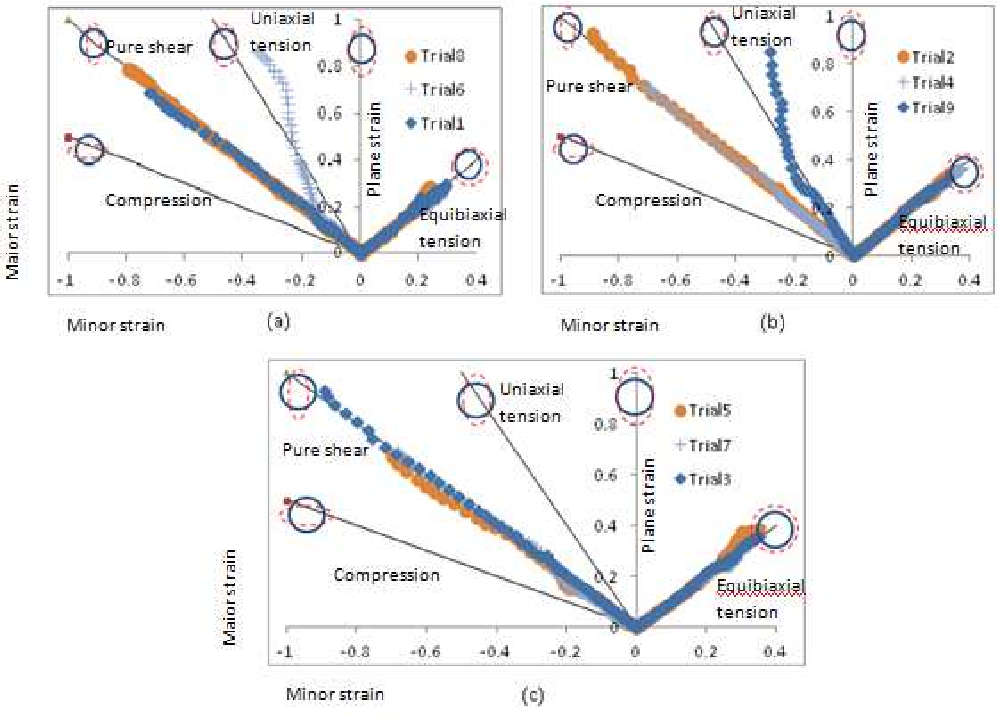

Figure 5: Forming Limit Diagrams with Damages for Different Blank Thickness.

Influence of Control Factors on Surface Expansion Ratio (SER)

Table 4 gives the ANOVA summary of raw data. The Fisher's test column establishes all the parameters accepted at 90% confidence level. Factor A, punch velocity, contributes 12.30% of the total variation. Coefficient of friction, factor B, assists 14% of the total variation. Factor C, thickness, contribute 13.66% of total variation and factor D, number of steps contributes 60.05% to the total variation.

Table 4: ANOVA Summary of Surface Expansion Ratio

Factor	S1	S2	S3	SS	v	V	F	P
A	1.87	1.853	1.83	0.002422	1	0.001211	0.42	12.30%
B	1.827	1.86	1.867	0.002756	1	0.001378	0.49	14.00%
C	1.863	1.863	1.827	0.002689	1	0.001344	0.47	13.66%
D	1.813	1.9	1.9	0.011822	1	0.005911	4.51	60.05%
e				0	4	0	0.00	-0.01%
T	7.373	7.476	7.424	0.019689	8			100%

The effect of process parameters on the surface expansion of cups is shown in figure 6. As the punch velocity increases, surface expansion ration decreases. With increase in coefficient of friction, surface expansion also increases. Initially there is no effect of thickness on the surface expansion ration, but later surface expansion ratio decreased with increase in thickness. The surface expansion ratio of cup is maximum at 75 steps. The surface expansion ratio of the cups at different trials is shown in figure 7.

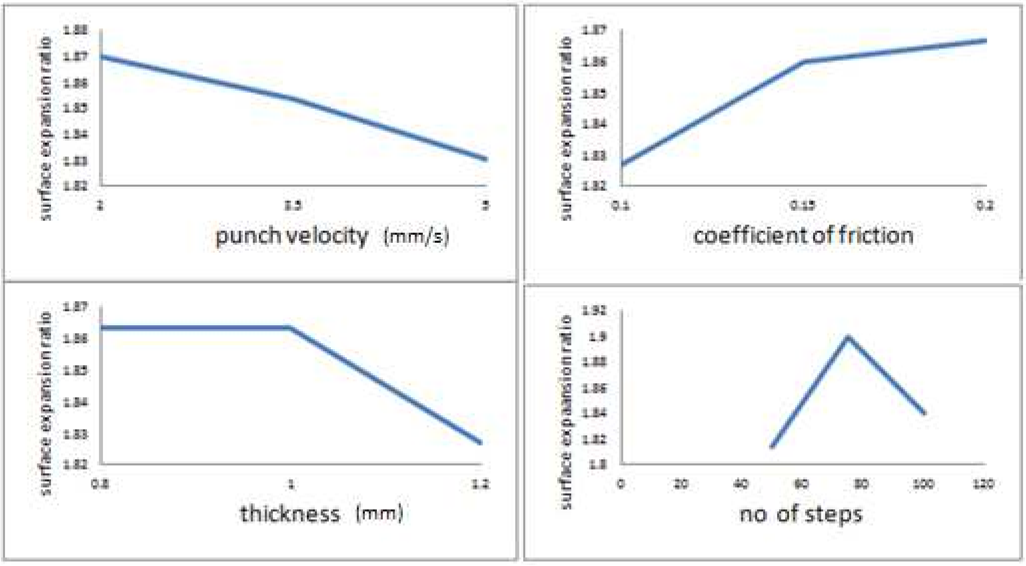

Figure 6: Effect of Process Parameters on Surface Expansion Ratio.

The surface expansion ratio when drawn with trial conditions 2 and 6 was observed to be 1.94 and 1.93 respectively. The SER values when drawn with conditions of 1, 5 and 9 were 1.82, 1.8 and 1.82 respectively. For trial conditions 3 and 8 the SER values were 1.85 and 1.84 respectively. The relatively higher values of surface expansion ratio in trial conditions of 2 and 6 were because of greater coefficient of friction.

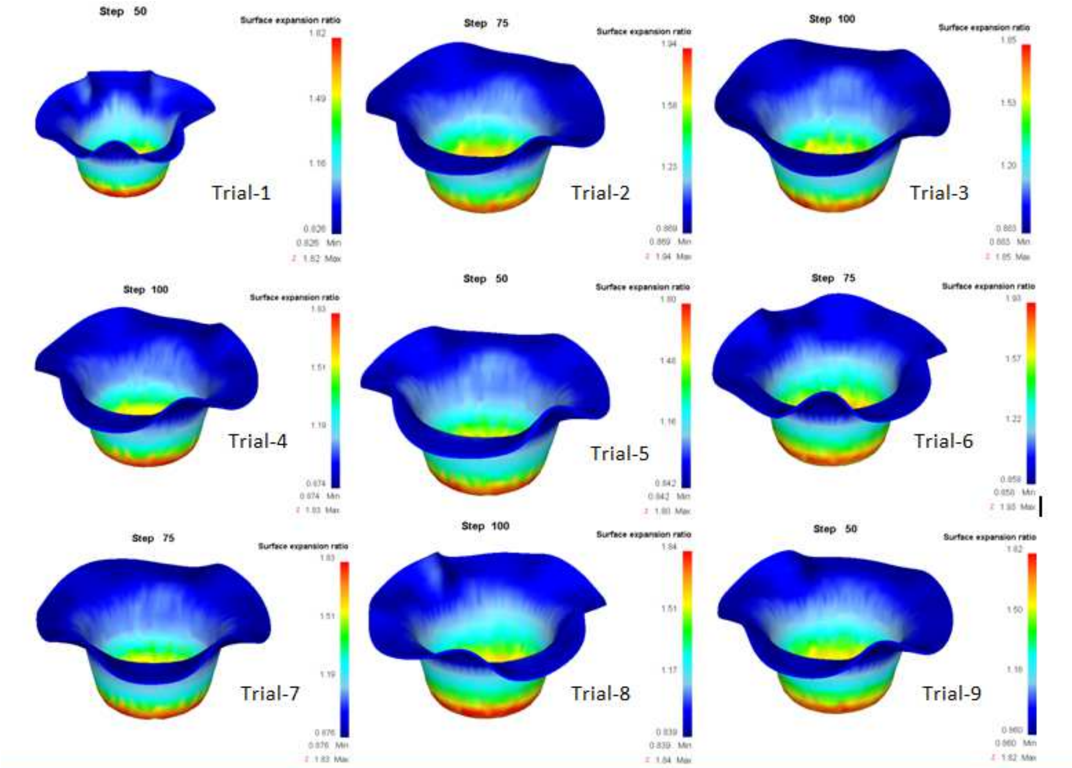

Figure 7: Surface Expansion Ratio in Conical Cups Under Different Operating Conditions.

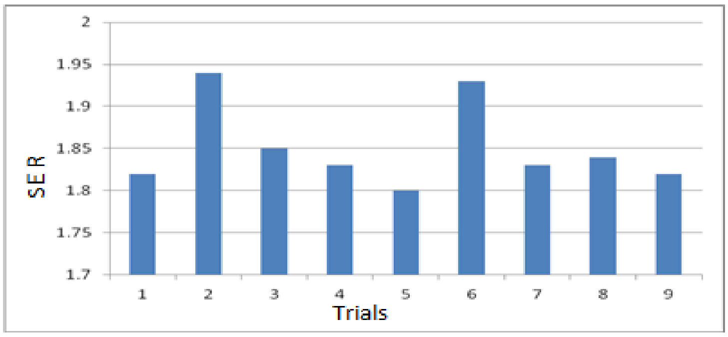

Figure 8: Surface Expansion Ratio Under Different Trials.

Influence of Control Factors on Cup Height

Table 5 gives the ANOVA summary of raw data. The Fisher's test column establishes all the parameters accepted at 90% confidence level. Factor A, punch velocity, contributes 1.32% of the total variation. Coefficient of friction, factor B, assists 2% of the total variation. Factor C, thickness of the blank contributes 4% and factor D or number of steps contributes 92%.

Table 5: ANOVA Summary of Height of Cup

Factor	S1	S2	S3	SS	v	V	F	P
A	25.22	25.26	25.27	0.005173	1	0.002586	0.04	1.32%
B	25.29	25.22	25.25	0.007856	1	0.003928	0.06	2%
C	25.22	25.31	25.22	0.01588	1	0.007938	0.13	4.04%
D	25.1	25.53	25.12	0.36405	1	0.182027	37.78	92.64%
e				0	4	0	0	0.00%
T	100.83	101.32	100.86	0.392958	8			100%

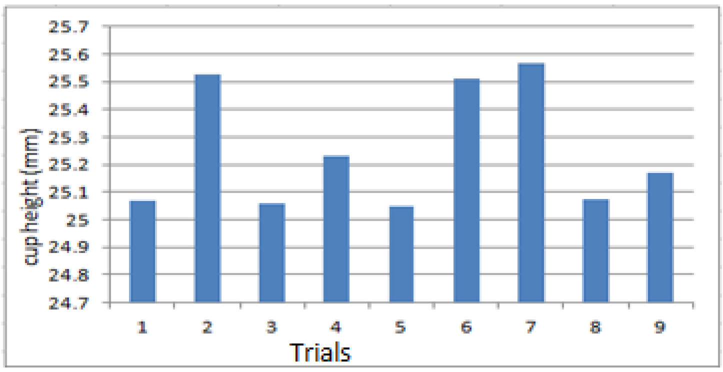

Figure 9: Cup Height Under Different Trials.

The effect of process parameters on the height of cups is given in figure 10. As the punch velocity increases, cup height increased. With increase in coefficient of friction, cup height first decreased then increased. With increase in thickness the cup height first increased and then decreased. The cup height is maximum at 75 steps.

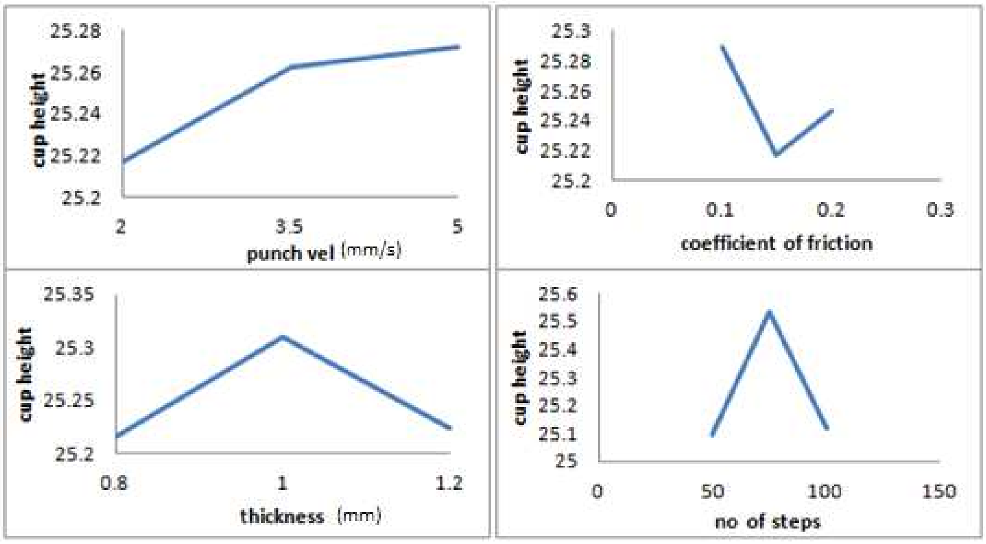

Figure 10: Effect of Process Parameters on Cup Height.

CONCLUSIONS

It was observed from the present work that the process parameters, which had greater influence on the formability of deep drawing of conical cups of Monel 400, were the coefficient of friction and the blank thickness. The damage of cups was lower in trial 7 when the coefficient of friction was low. Damage of the cup decreased with increase in thickness. Surface expansion ratio was higher for trial 2, where punch velocity was 2m/s and coefficient of friction was 0.15. Higher the coefficient of friction higher the surface expansion ratio. The cup height was higher when the coefficient of friction was 0.1 and blank thickness was 1mm.

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