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Parametric Optimization of NI201 Deep Drawn Conical Cups

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Abstract

In this present work, the statistical approach based on Taguchi design of experiments and the finite element analysis were adopted to determine degree of each parameter i.e. Punch velocity, coefficient of friction, blank thickness and displacement per step on the formability of conical cups drawn from Nickel 201 alloy using the deep drawing process. The damage of cups was lower when coefficient of friction was low. The major parameters that would influence the surface expansion ratio were the thickness of sheet and the coefficient of friction. Greater the coefficient of friction higher would be the surface expansion ratio. The cup height was higher when the coefficient of friction was 0.15 and blank thickness was greater than 1mm.

Keywords: Deep drawing, Ni 201, Conical cups, Sheet thickness, Coefficient of Friction, punch velocity, damage.

1. INTRODUCTION

Deep drawing is a sheet metal forming process in which a combined tensile and compression loads are used to deform a sheet metal to form a hollow body without altering the sheet thickness. It is also defined as a process in which the height of the component is more than 0.75 times the mean diameter of the drawn cup. Reddy [1] has examined on the formability analysis of 6063 Al Alloy for deep drawn cylindrical cups with constant and progressive blank holding force and results shown von Mises stress was least at set off 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. [2] have studied the effect of warm forming on the drawability of both rectangular and circular cups from annealed and hardened aluminum sheet alloys. It is observed that at a temperature of 1500^0C, even for the precipitation hardened alloys there is a notable enhancement in the drawability in terms of cup height. Ouakdi et al. [3] have conducted experiments on evaluation of spring back under the effect of holding force and die radius in a stretch bending test and the results show that an increase in blank holder force reduces spring-back by increasing the tension. Ayari et al. [4] have recommended that coefficient of friction between die-punch contact, punch-blank contact is the very significant parameter. Reddy et al. [5] in another experimentation with an implicit finite element analysis on cup drawing process, the results explain that the thinning is observed mostly on the vertical walls of the cup. The values of strain are also discovered to be high at the diaphanous sections. Toros et al. [6] have developed a mathematical model to analyze the influencing formability factors on deep drawing process carried out at elevated temperatures and under various blank holding pressures (BHP). It is determined that working temperature, BHP, punch speed and friction are the parameters affecting the process. Reddy [7] has used Taguchi design of experiments to optimize the extrusion process of 6063 aluminum alloy to save the cost of experimentation. Chung et al. [8] have proposed a direct design method based on an ideal forming theory to get an initial blank shape.

Nickel 201 is a commercially pure wrought material, reinforced solid solution, with acceptable mechanical properties over a wide range of temperatures and has excellent corrosive resistance. Corrosion rates are very low in both the marine and rural atmospheres. Nickel 201 resistance to corrosion through distilled and natural waters is excellent. Nickel 201 is usually limited to operation under 600 °C. Nickel 201 products will suffer from graphitization at higher temperatures which can lead to seriously compromised properties.

Numerical investigation of cup drawing was carried out to study the stresses and strains induced during the deep drawing process. From the results of finite element simulations, a forming limit diagram (FLD) was constructed to analyze the fracture phenomena. Optimization of process parameters like thickness of blank, coefficient of friction and punch velocity were carried out based on their importance on the deep drawing characteristics.

The objective of the current work was to optimize the deep drawing process of Ni201 alloy using Taguchi design of experiments. In this present work, an ANOVA technique was adopted to decide the importance aspect of each of the process parameter on the formability of deep drawn conical cups. By using DEFORM software, simulation deep drawing of conical cups is carried out.

2. MATERIALS AND METHOD

Alloy Ni 201 is a pure Nickel with a maximum carbon level of 0.02%. Across a wide range of operating temperatures, this alloy provides remarkable ductile properties and provides corrosion resistance in adequate redox environments. Nickel 201 alloy is ferromagnetic, therefore layout eminent thermal and electric conductivity relatively to all nickel-base alloys. The tensile and yield strength of this alloy is 345MPa and 83MPa respectively.

The levels chosen for the process parameters were in the operational range of Ni 201 alloy using a deep drawing process. At three levels each of the four process parameters was studied. The outline of the chosen control parameters is shown in Table 1. For the present work Orthogonal Array (OA), L9 was selected. Various columns of OA were assigned with control parameters. OA matrix along with process parameters is given in Table 2.

Table 1: Process parameters and levels

Factor	*Symbol*	*Level – 1*	*Level – 2*	*Level – 3*
Punch velocity, mm/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

2.1 Design of deep drawn conical cups

The blank size was calculated by equating the surface area of the finished drawn cup with the area of the blank. The blank diameter, *D* is given by:

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

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

Corner radius of drawing punch must exceed 3 times the blank thickness (*t*). Although, the punch radius should not be greater than one-fourth the cup diameter (*d*).

$3t <$ punch radius $< d/4$. (2)

The punch radius r_p, mm is expressed as:

$$\boldsymbol{r_p = \frac{12t+d}{8}} \qquad (3)$$

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

For well-ordered material flow, the die radius should be ideally 4 to 6 times the blank thickness (*t*) but under any circumstances, it must be never less than 3 times the thickness of the sheet. Lesser is the radius, higher would be the obstruction to the material flow whereas surplus radius would lower the pressure area between blank and blank holder. The corner radius r_d , mm of the die can be calculated from the following equation:

$$\boldsymbol{r_d = 0.8\sqrt{(D-d\,)t}} \qquad (4)$$

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

In deep drawing, the material flow may exhibit thickening of the flange and thinning of walls of the cup. To this avoid this problem, some space must be created by modelling die diameter greater than punch diameter. This space is called die clearance.

Clearance, $\boldsymbol{c_d = t \pm \mu\sqrt{10t}}$ (5)

where μ is the coefficient of friction.

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

$$\boldsymbol{d_{d1} = d_1 + 2c_d} \qquad (6)$$

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

$$\boldsymbol{d_{d2} = d_2 + 2c_d} \qquad (7)$$

By adding clearance to the punch corner radius, corner radius of the die is obtained. The edge radius of the die is eight times the blank thickness.

2.2 Finite element analysis

The circular sheet blank was created according to desired sheet thickness and diameter. The conical hallow die and conical punch were modeled with suitable inner radius, outer radius and corner radius. The die and punch were modeled using UNIGRAPHICS software. The sheet blank was meshed into tetrahedral elements. The modeling 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

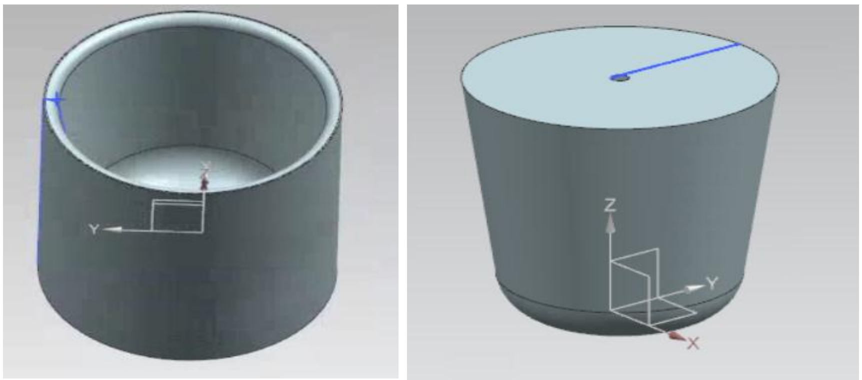

Fig1: Conical die and punch

The contact between blank and punch, die and blank holder were coupled as a contact pair. The mechanical interaction between contact surfaces was assumed to be frictional contact. Effective stress, height of the cup and damage of the cup were found using finite element analysis. According to the design of experiments for purpose of validating the results of experimenting, finite element modelling and analysis was done using DEFORM 3D software.

3. RESULTS AND DISCUSSION

3.1 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 (A, B, C and D) accepted at 90% confidence level. Factor A, punch velocity, contributes 16.96% of the total variation. factor B, Coefficient of friction, contributes 47.45%. Factor C, thickness, assists 33.58% of the variation and factor D, no of steps, contributes 13.03% variation on the cup damage.

Table 3: ANOVA summary of the conical cup damages.

Factor	*S1*	*S2*	*S3*	*SS*	*v*	*V*	*F*	*P*
A	11.45	22.41	12.51	24.32	1	24.32	-2.75	16.96
B	8.70	10.20	27.46	72.48	1	72.48	-8.18	47.75
C	25.49	10.43	10.45	50.32	1	50.32	-5.68	33.58
D	11.41	21.35	13.60	18.17	1	18.17	-2.05	13.03
e				-8.86	4	-2.21	0.25	-11.32
T	57.05	64.39	64.02	156.43	8			100.00

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 control parameters on the damage of cups is given in figure 2. Damage was highest when punch velocity is 3.5 mm/s as shown in figure 2(a). The damage of cups is lowest when coefficient of friction is lowest as shown in figure 2(b). The damage of cup is lowest when thickness of blank is 1mm as shown in figure 2(c) and damage of cups are highest when the number of steps are 75 as shown in figure 2(d).

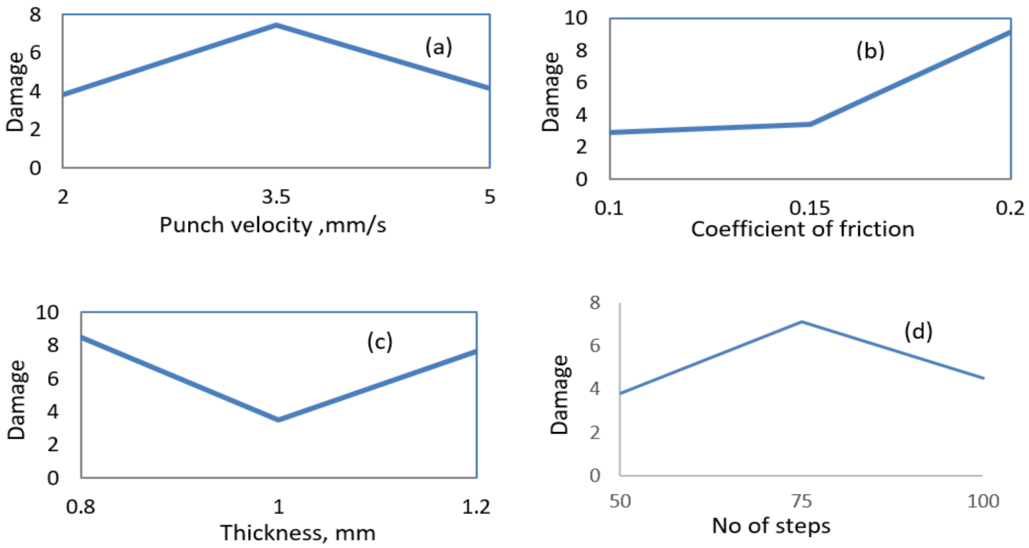

Fig 2: Effect of control factors on the damage of cup

Figure 3(a) depicts the formability limit diagram with damages in the conical cups drawn from Ni 201 sheets of first 3 trails. Trail 1 and trail 3 are fractured on account of compression induced in the blank material. No damage is observed in trail 2 except the wrinkle tendency at the flange.

Conical cup drawn under trail 6 is fractured under compression and uniaxial tension induced in blank material. No fracture is found in trails 5,7 as shown in figure 3(b). The conical cups drawn under trails 8 and 9 are torn in the area of punch corner radius owing to uniaxial stretching and equal axial tension, whereas cup drawn under trail 7 is observed with no fractures as shown in figure 3(c).

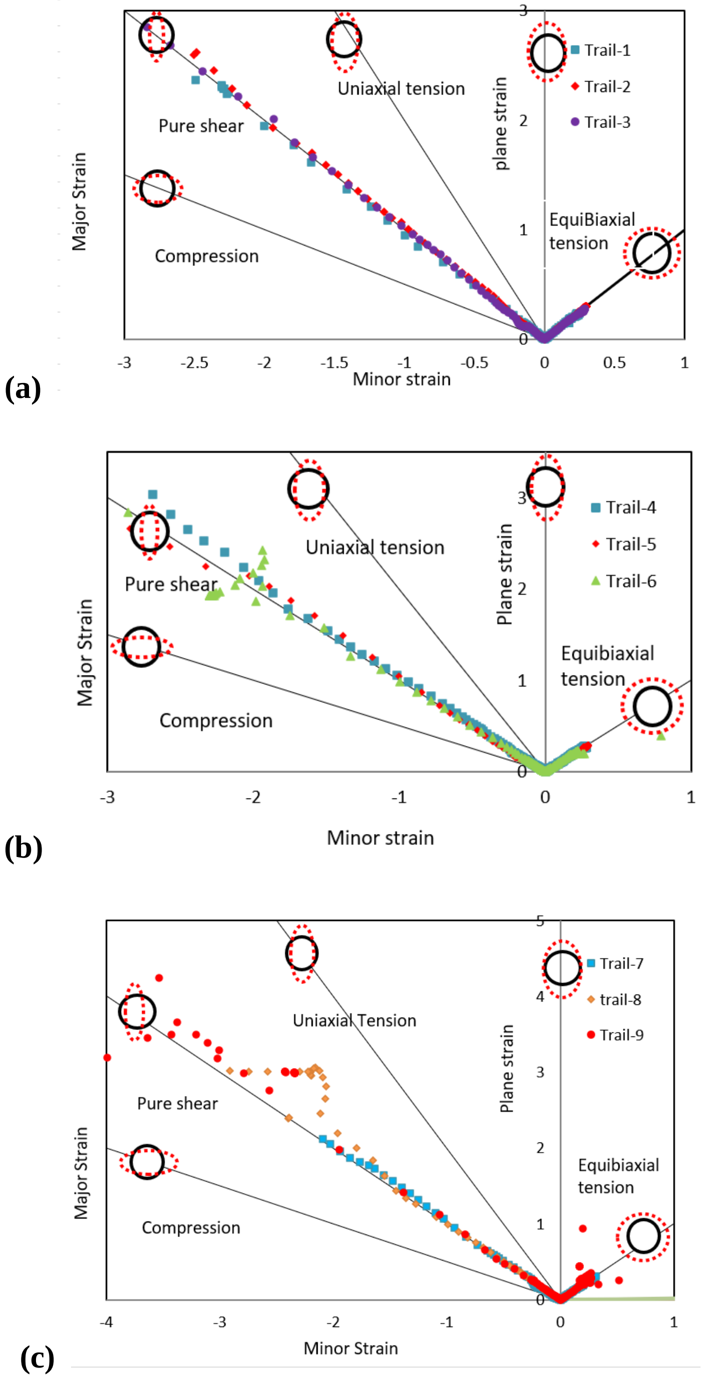

Fig 3: Formability limit diagrams with damage with cups under different trail conditions

The damages of the conical cups drawn for the trial conditions of 2, 4, 5 and 7 are respectively 2.356%, 2.924%, 2.700% and 2.213%. The reason for relatively lower damage in these trials might be due to lower coefficient of friction values. The damages of the cups drawn for the trial conditions of 1, 3, 8 and 9 are 3.562%, 5.534%, 5.144% and 5.150% respectively. The reason for higher damage in these trials is due to higher values of punch velocities and higher coefficient of friction values. The damage of cup drawn with trail condition of 6 is 16.780%. This might be due to higher value of thickness and relatively higher values of punch velocity and coefficient of friction as shown in figure 4 and figure 5.

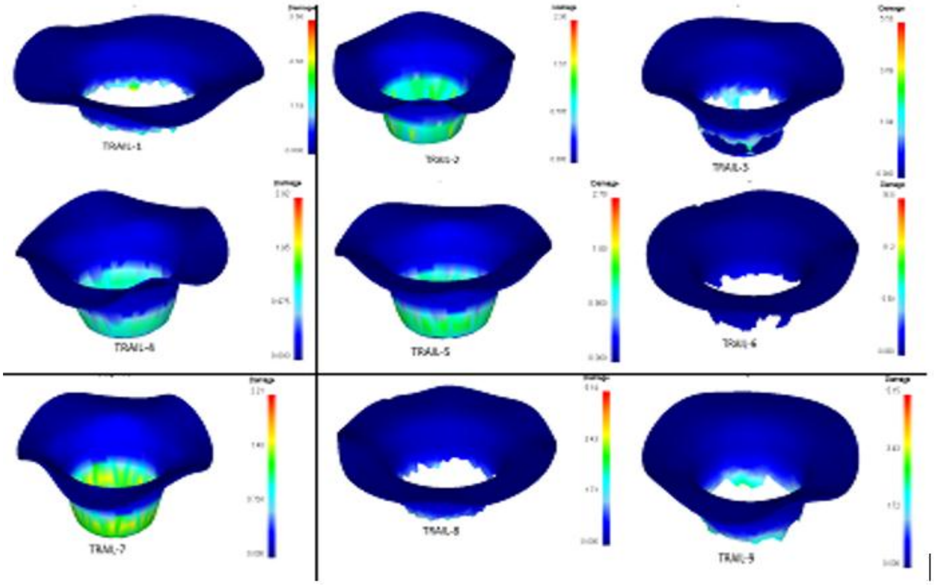

Fig 4: Damage in conical cups under different operating conditions

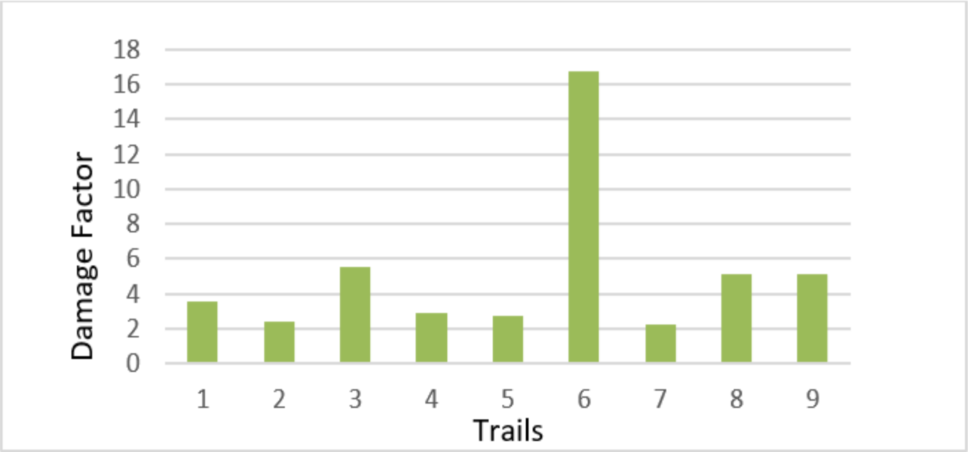

Fig 5: Damage under different trails

3.2 Influence of control factors on surface expansion ratio (SER)

Table 4 gives the ANOVA summary of raw data for surface expansion ratio. The Fisher's test of all the parameters was acceptable at 90% confidence level. Factor A, punch velocity contributes 27.37% of the total variation; factor B, Coefficient of friction contributes 47.4% of the total variation. Factor C, thickness contributes 2.2% of total variation. Factor D, number of steps, contributes 24.68% of total variation.

Table 4: ANOVA summary of SER

Factor	*S1*	*S2*	*S3*	*SS*	*v*	*V*	*F*	*P*
A	11.41	10.36	12.91	1.11	1	1.11	40.81	27.37
B	10.01	11.29	13.38	1.93	1	1.93	70.96	47.4
C	11.17	11.76	11.75	0.08	1	0.08	2.94	2.2
D	11.72	10.27	12.69	1	1	1	36.76	24.68
e				-0.0272	4	-0.01	0.37	-1.65
T	44.31	43.68	50.73	4.0928	8			100

The effect of control parameters on the surface expansion ratio of cups is given in figure 6. As the punch velocity increases, the surface expansion ratio also increases as shown in figure 6(a). With increase in coefficient of friction, surface expansion also increases as shown in figure 6(b). Initially there is no effect of thickness on the surface expansion ratio, but later on the surface expansion ratio increases with increase in thickness as shown in figure 6(c). The surface expansion ratio of the cup is minimum at 75 as shown in figure 6(d).

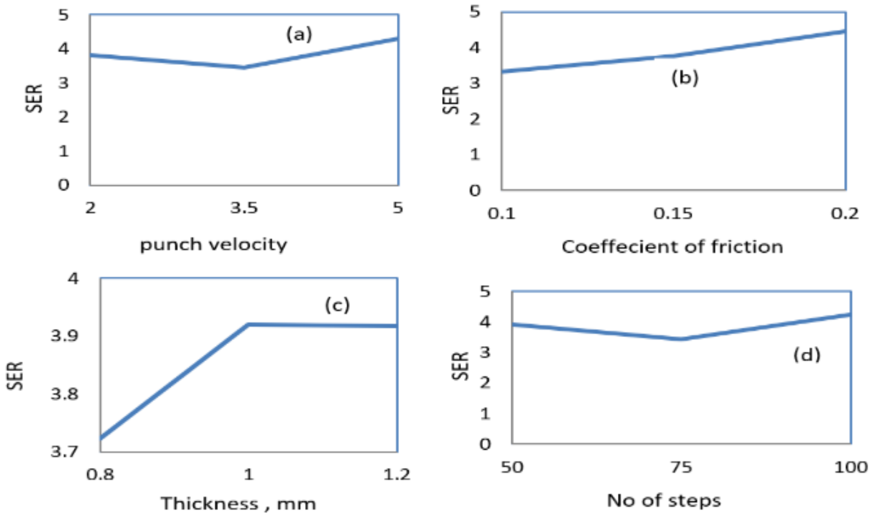

Fig 6: Effect of control parameters on Surface expansion ratio (SER)

The surface expansion ratio (SER) is a property of ductility. Higher the SER greater would be the ductility of the material. The SER values when drawn for the trial conditions 1, 2, 4, 5, 6 and 7 are observed to be 3.21, 3.35, 3.38, 3.48, 3.50 and 3.42 respectively. The SER values when drawn for the trail conditions of 3, 8 and 9 are 4.58 ,4.46 and 5.03 respectively. The relatively higher values of surface expansion ratio in trial conditions of 3, 8, 9 are because of greater coefficient of friction as shown in figures 7 and 8.

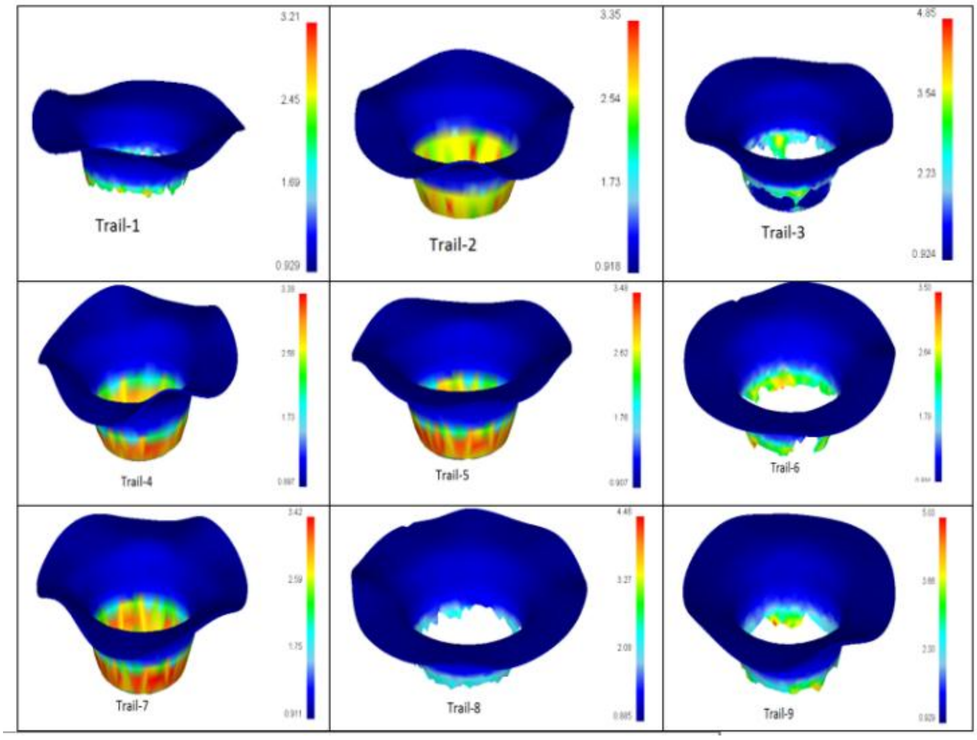

Fig 7: SER in conical cups under different operating conditions

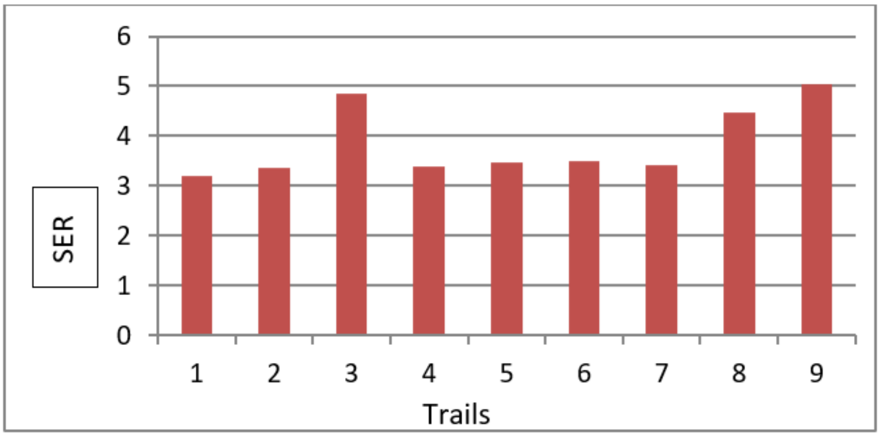

Fig 8: SER under different trails

3.3 Influence of control factors on the height of conical cups

Table 5 gives the ANOVA (analysis of variation) summary of raw data of the cup heights. The Fisher’s test was acceptable for all the parameters (A, B, C and D) at 90% confidence level. The percent contribution indicates that the factor C, thickness, contributed 73.97% towards the variation. The punch velocity (A), Coefficient of friction (B), number of steps (D) offer 10.91%, 8.3 %, 6.88% of variation on the cup height respectively.

Table 5: ANOVA summary of the conical cup height

Factor	*S1*	*S2*	*S3*	*SS*	*v*	*V*	*F*	*P*
A	73.39	72.50	75.31	1.38	1	1.38	-229.98	10.91
B	73.26	75.16	72.78	1.05	1	1.05	-174.99	8.3
C	69.41	75.91	75.89	9.36	1	9.36	-1559.88	73.97
D	72.90	73.27	75.04	0.87	1	0.87	-144.99	6.88
e				-0.01	4	0	0.00	-0.06
T	288.98	296.85	299.03	12.65	8			100

The effect of control parameters on height of cup is given in figure 8. The height of cup is maximum when punch velocity is 5mm/s and the least when punch velocity is 3.5mm/s as shown in figure 8(a). The height of cup is maximum when the coefficient of friction is 0.15 as shown in figure 8(b). The height of the cup rapidly increases from 0.8mm to 1mm sheet and then there is negligible change in height of the cup as shown in figure 8(c). The cup height increases as the number of steps increases as shown in figure 8(d).

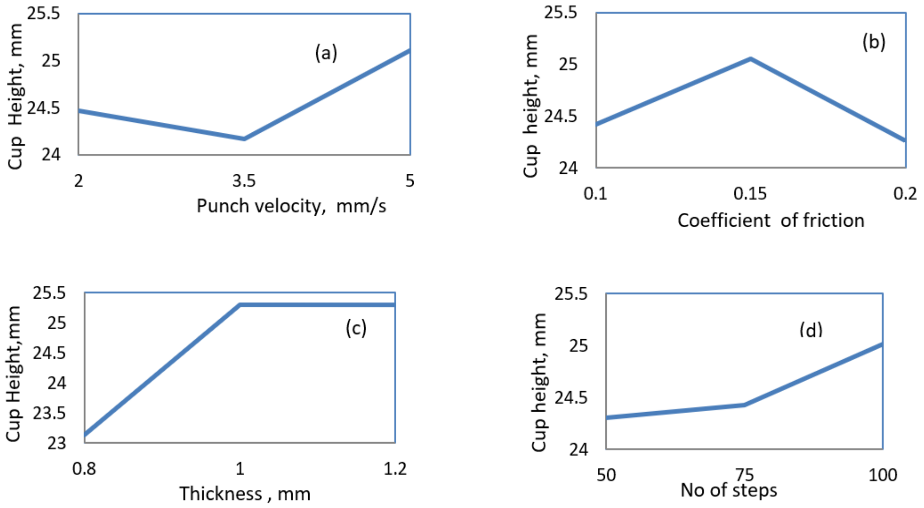

Fig 9: Effect of control parameters on Height of cup

The height of the conical cups under different trial conditions are shown in figures (9) and (10). For the cups drawn in trail conditions 1, 6, 8 the cup height values are 22.58, 22.25 and 24.57mm respectively. The height of cups drawn with trail conditions 1, 6, 8 is less because of low sheet thickness of 0.8mm. The heights of cups drawn with trail conditions 2, 3, 4, 5, 7, 9 are 25.50, 25.30, 25.20, 25.1mm, 25.50, 25.20 mm respectively and these trail conditions have relatively more cup height as the thickness of sheet is high.

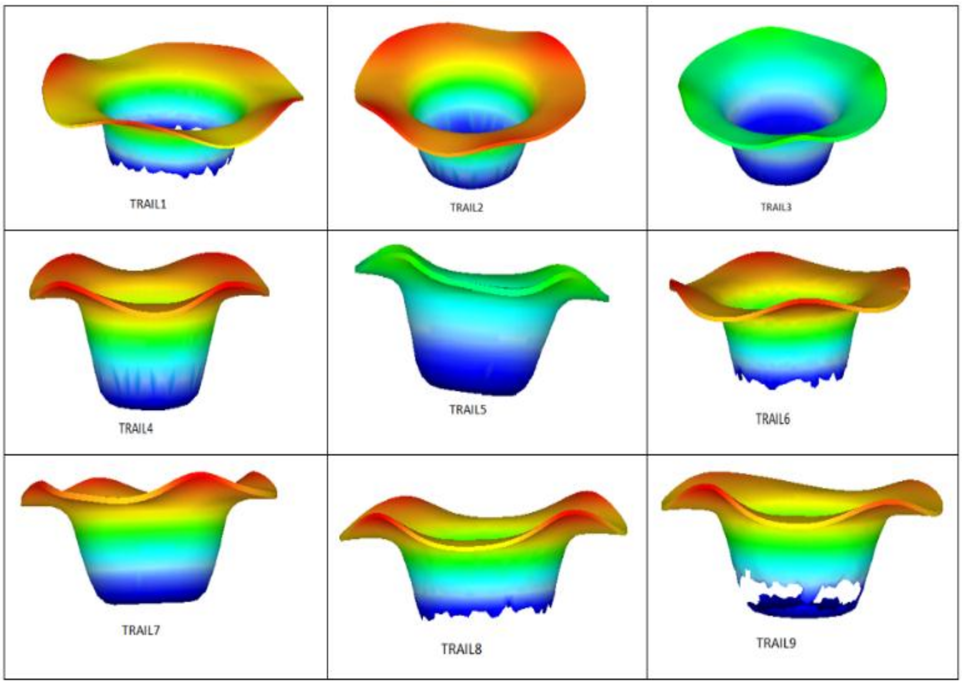

Fig 10: height of the conical cups under different trial conditions

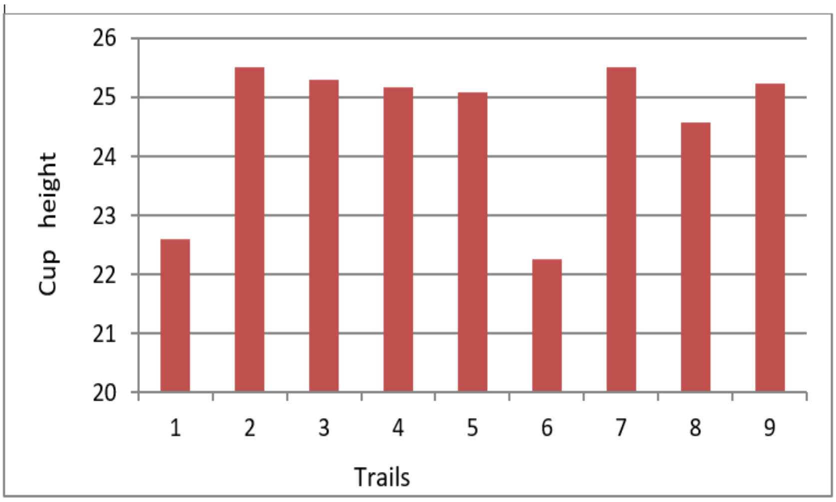

Fig 11: Height of cups under different trails

4. CONCLUSION

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 Nickel 201, were the coefficient of friction and the blank thickness. The damage of cups was lower when the coefficient of friction was low. The major parameter that influenced the surface expansion ratio was thickness and the coefficient of friction. Higher the coefficient of friction higher the surface expansion ratio. The cup height was higher when the coefficient of friction was 0.15 and blank thickness was greater than 1mm.

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