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Optimization of Process Parameters of Deep Drawing Process for Inconel-600 Conical Cups

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Abstract

In this present work, a statistical approach based on Taguchi Technique and finite element analysis adopted to determine the influence of process parameters on formability of conical cup from Inconel-600 using cold deep drawing process. The process parameters were punch velocity, Thickness, Coefficient of friction, Displacement per step. The thickness of the blank, punch velocity, and co efficient of friction have been found influencing the quality of the cup.

Keywords: Inconel 600, cold deep drawing, punch velocity, coefficient of friction, conical cups, formability.

1. INTRODUCTION

Cold deep drawing process is the sheet metal forming process which is used to produce cans, boxes, and bottles from flat circular blank. The cups are produced by forcing a punch against the blank into the die opening. In this process the flange undergoes radial tension as the blank drawn radially inward and compression is occurred in circumferential. Due to the clearance produced between the punch and die there are no wrinkles produced inside the wall of cup.

Many researchers investigated on cup drawing to find the effect of optimization parameters on formability of cups. Devender [1] used Nickel 201 to fabricate the cylindrical cups and found that major process parameters which affected the formability of cups were punch velocity and strain rate. Effective stress increased with increase in punch velocity. Venkateshwarlu [2] proposed an effective method of FEM simulation in combination with Taguchi technique to predict the influence of process parameters. The results show that the blank temperature (84.4%) has major influence on the deep-drawing process, followed by punch velocity (9%) and die arc radius (6.6%).Forming at a temperature above room temperature and below recrystallization temperature is known as warm forming, it changes the properties of material. It is one of methods used to improve formability. S.Toros [3] found that the formability and surface quality of these alloys is not good at room temperature whereas better formability of these alloys and surface quality has been achieved at the temperature range of 300^0C. Thinning also one of the factor that effects the part geometry. A.C.Reddy[4] conducted experimental characterization on the warm deep drawing process of EDD steel and results show that the extent of thinning at punch corner radius is less in the warm deep drawing process at a temperature of 200^0C. Liwen Tian [5] investigated the important factors which would influence the sheet thickness. The results show that blank holder force affects the most, second is the concave die entrance radius, the influence of punch velocity and radius is minimum. Chandra Pal Singh [6] result shows the limit thinning ratio will be decreased gradually and the deformation area tends to be scattered with the increase of blank holder load value and the coefficient of normal anisotropy. Also the occurring of wrinkles in the local deformation area reduces and the maximum height increases, which is favorable to formation of sheet metal. Tetsuo [7] investigated the effects of forming speed and temperature on the deep drawability for Al-Mg alloy. It was found that the Limit drawing ratio (LDR) increases with increasing die temperature, because as temperature rise the deformation resistance in flank shrinkage decreases. LDR decreases with increase in forming speed at all temperature. Halil Ibrahim Demicri [8] prepared a new experimental method which can be implemented by applying variable forces in computer controlled manner on sheet plate. It helps to reduce the manufacturing cost. The numerical results can be compared with experimental results. R.Padmanabham [9] used FEM with Taguchi technique to determine the proportion of contribution of process parameters in deep drawing process. The analysis of variance (ANOVA) results show that the die radius (89.2%) has major influence on the deep-drawing process, followed by friction coefficient (6.3%) and blank holder force (4.5%).

Inconel-600 is composition of nickel and chromium which provides good resistance. The high nickel content of the alloy enables it to retain the resistance under reducing conditions and makes it resistant to corrosion by a number of organic and inorganic compounds. In nuclear reactors Inconel-600 used for such components as control rod inlet stub tubes, reactor vessel components and seals, steam dryers and separators in boiling water reactors.

The objective of the present study is to optimize the process parameters of Incone-600 alloy at room temperature by using Taguchi technique for the conical cups. ANOVA technique was adopted to determine the influence of each process parameter on the formability of deep drawn conical cups and executed by using the finite element analysis software namely ***DEFORM-3D***.

2. MATERIALS AND METHODS

Inconel 600 was used to fabricate conical cups. The tensile and yield strengths of this alloy are 670MP and 245.5MPa respectively. The Poisson's ratio is 0.29. The percent of elongation is 41.The levels chosen for the control parameters were in the operational range of Inconel 600 using deep drawing process. The chosen control parameters are summarized in table 1. The orthogonal array (OA), L9 was selected for the present work. The assignment of parameters along with the OA matrix is given in table 2.

Table 1: Control 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
Displacement per step	D	0.5	0.75	1.00

Table 2: Orthogonal array (L9) and control parameters

Treat 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 and Fabrication 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_b is given by**:**

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

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 that of the cup. The drawing punch must have corner radius exceeding three times the blank thickness (t). However, the punch radius should not exceed one-fourth the cup diameter (d). The punch radius is expressed as:

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

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 of the die can be calculated from the following equation:

$$r_d = 0.8\sqrt{(D-d)t} \quad (3)$$

The material flow in drawing may render some flange thickening and thinning of walls of the cup inevitable. The space for drawing is kept bigger than the sheet thickness. This space is called die clearance.

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

Where μ is coefficient of friction

The top diameter of the die is obtained from the following equation:

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

The bottom diameter of the die is obtained from the following equation:

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

The height of the die is the height of the cup.

2.2 Finite element analysis

The finite element modeling and analysis was carried out by DEFORM 3D software. The circular sheet blank created with desired thickness and diameter. The Conical punch and Hollow die are designed by using UNIGRAPHICS software. The inner and outer radius, corner radius and clearance between punch and die is calculated by using the above equations. The modeling parameters of deep drawing per trail were as follows:

Number of elements for the blank: 7075

Number of nodes for the blank: 2443

Top die polygons: 1100

Bottom die polygons: 1688

Figure 1: Conical punch and die

3. RESULTS AND DISCUSSION

3.1 Influence of control factors on Surface expansion ratio

Table 3 gives the ANOVA (analysis of variation) summary of raw data. The Fisher's test column establishes all the parameters (A, B, C and D) accepted at 90% confidence level. Coefficient of friction (B) contributes half (52.9%) over the variation. Thickness of the cup (C) contributes one-fourth 23.2% variation .Punch velocity (A) and Displacement per step (D) contributes 14.88% and 23.2% respectively.

Table 3: ANOVA Summary of the Surface expansion ratio

Source	Sum 1	Sum 2	Sum 3	SS	V	V	F	P
A	12.73	10.49	11.48	0.84	1	0.84	280.00	14.88
B	10.12	10.59	13.99	2.97	1	2.97	990.00	52.59
C	10.05	11.84	12.81	1.31	1	1.31	436.67	23.2
D	11.52	10.7	12.48	0.53	1	0.53	176.67	9.39
E				-0.003	4	0	0.00	-0.06
T	44.42	43.62	50.76	5.647	8			100

Note: SS is the sum of square, v is the degrees of freedom 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 surface expansion ratio is given in figure 2. SER is high when the punch velocity is 2m/s and it decreases further as shown in figure 2(a). SER remains same at initial state and shows no effect, but as coefficient of friction increases SER also increases as shown in figure 2(b).SER increases as thickness of cup increases, it is high when thickness is 1.2mm as shown in figure 2(c).As number of steps increases SER is gradually decreased and then increases as number of steps increase as shown in figure 2(d).

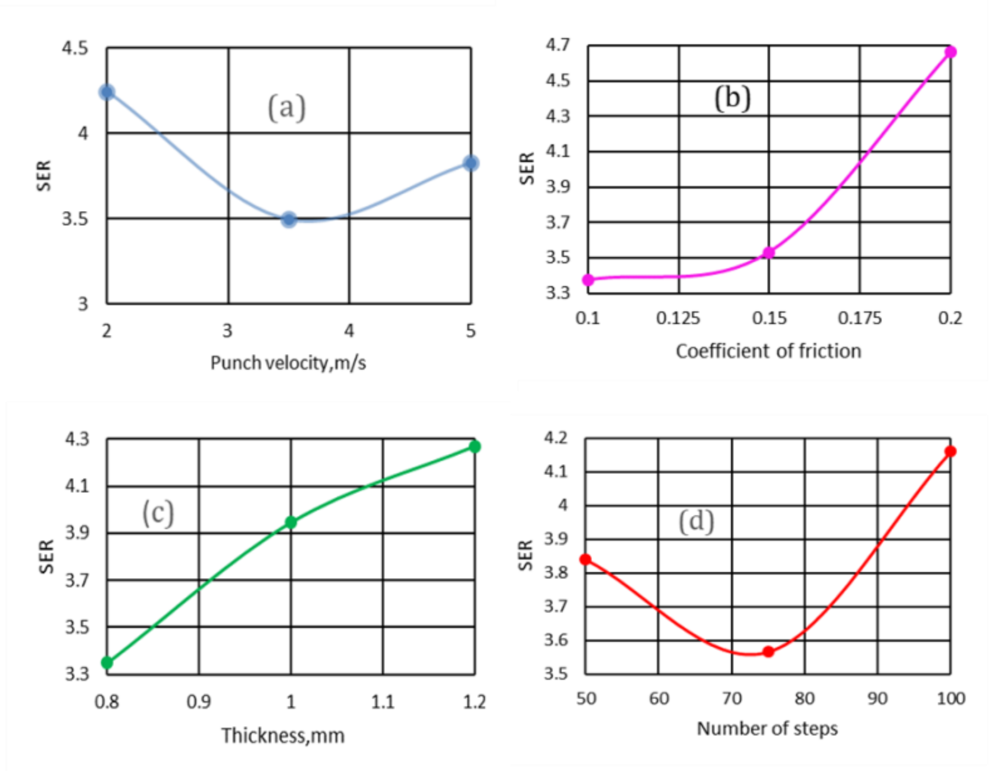

Figure 2: Effect of control parameters on Surface expansion ratio

The surface expansion ratio for different trials are shown in figure 3and figure 4. Surface expansion ratio is highest for the trial 3is 5.77. For the remaining trials 1, 2, 4,5,6,7, 9the surface expansion ratio is 3.24, 3.72, 3.41, 3.57, 3.51, 3.47 3.3and 4.71 respectively.

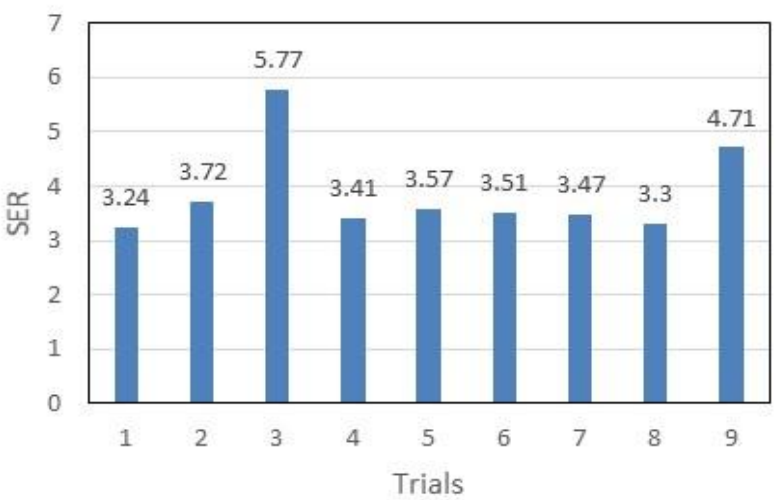

Figure 3: Surface expansion ratio for different trials

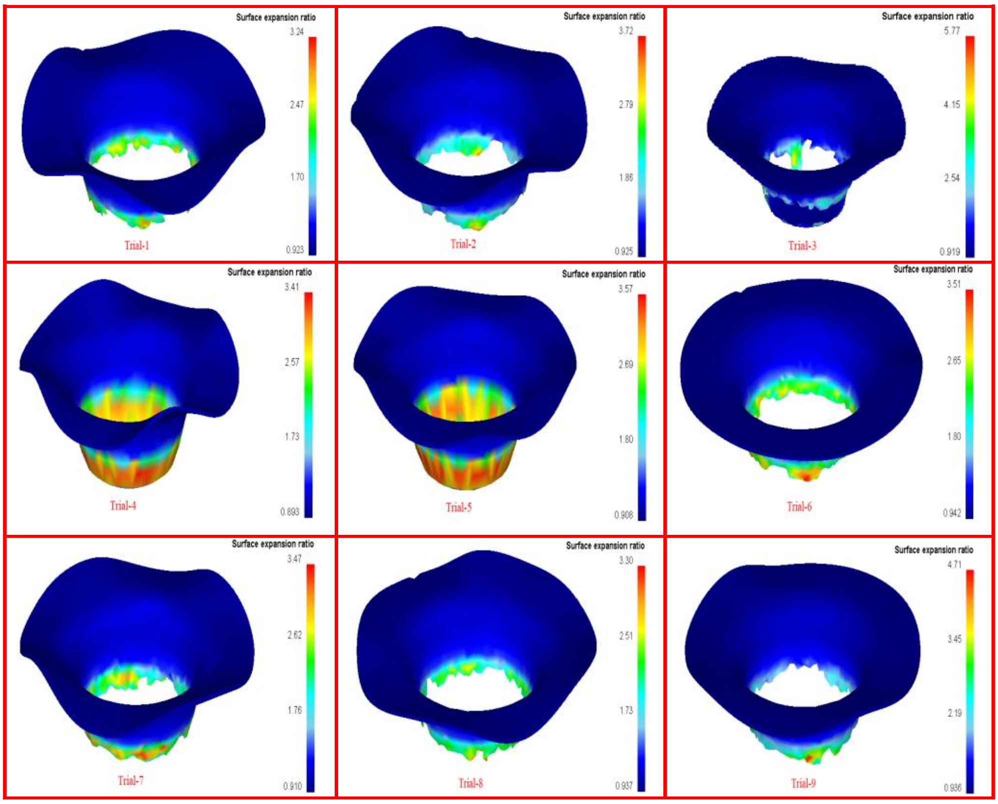

Figure 4: SER of conical cups under different operating condition

3.2 Influence of control factors on Cup Height

Table 4 gives the ANOVA (analysis of variation) summary of raw data. The Fisher's test column establishes all the parameters (A, B, C and D) accepted at 90% confidence level. Thickness (C) contributes 86.16% over the variation. Punch velocity (A), Coefficient of variation (B) and Number of steps (D) contribute 3.4%, 4.38% and 6.11% of the variation respectively.

Table 4: ANOVA summary of Cup height

Source	Sum1	Sum2	Sum3	SS	v	V	F	P
A	73.15504	72.59	70.78	1.04	1	1.04	-60.62	3.4
B	73.01936	70.54568	72.96	1.34	1	1.34	-78.11	4.38
C	64.92936	76.18568	75.41	26.35	1	26.35	-1535.89	86.16
D	73.21936	73.06568	70.24	1.87	1	1.87	-109.00	6.11
E				-0.02	4	0	0.00	-0.05
T	284.32312	292.38704	289.39	30.58	8			100

Note: SS is the sum of square, v is the degrees of freedom 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 height of cup is given in figure 5. The height of cup is maximum when punch velocity is 2mm/s and minimum when punch velocity is 5mm/s as shown in figure 5(a). Height of cup is decreases from 24.45mm to23.5 when coefficient of friction increases from 0.1 to 0.15.further increase of coefficient of friction to 0.2 height of the cup increases to 24.3mm as shown in figure5 (b). As thickness of blank increases the cup height up to 1mm rapidly increases and almost remains constant after 1mm to 1.5mm as shown in fig5(c). Cup height remains constant up to 75 steps and decreases gradually after 75 steps to 100 steps as shown in figure 5 (d).

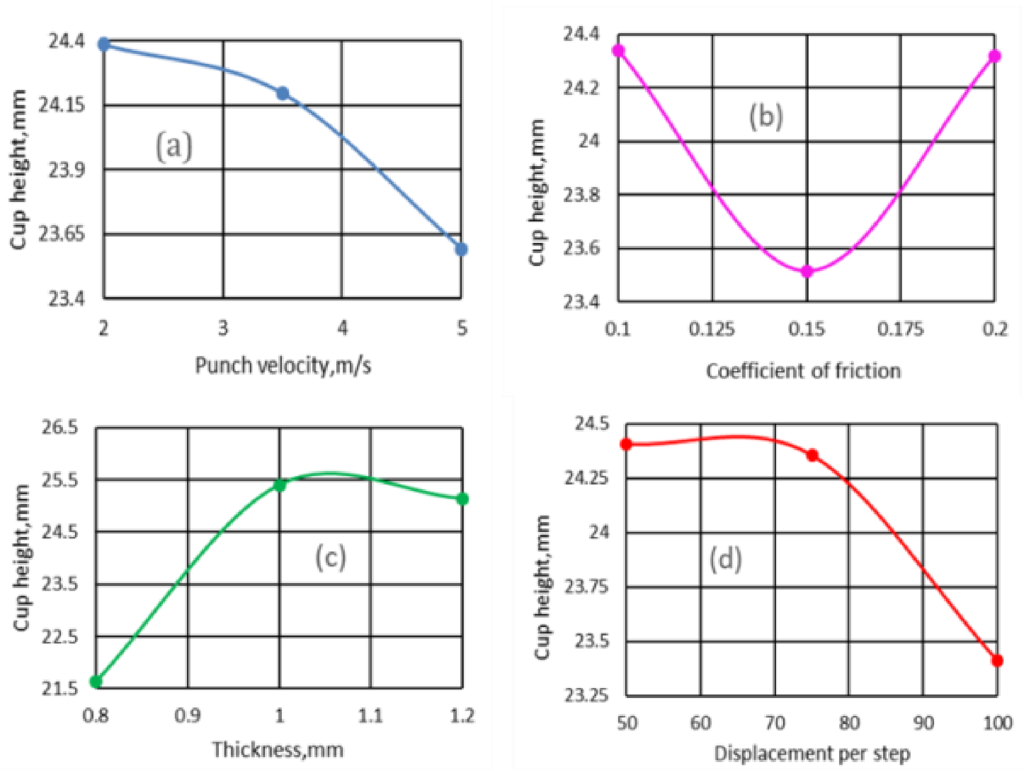

Figure 5: Effect of control factors on cup height

The FEA results of surface expansion ratio are is shown in figure 6and figure 7 for various test conditions as per the design of experiments. For the conical cups drawn with trials conditions 2,3,4,5,7,9 the height of the cup are 25.47, 25.08, 25.17, 25.07, 25.25, 25.54 respectively. Cups drawn with trial conditions 1, 6 and 8 the height of the cup is 22.6, 22.34 and 20 respectively.

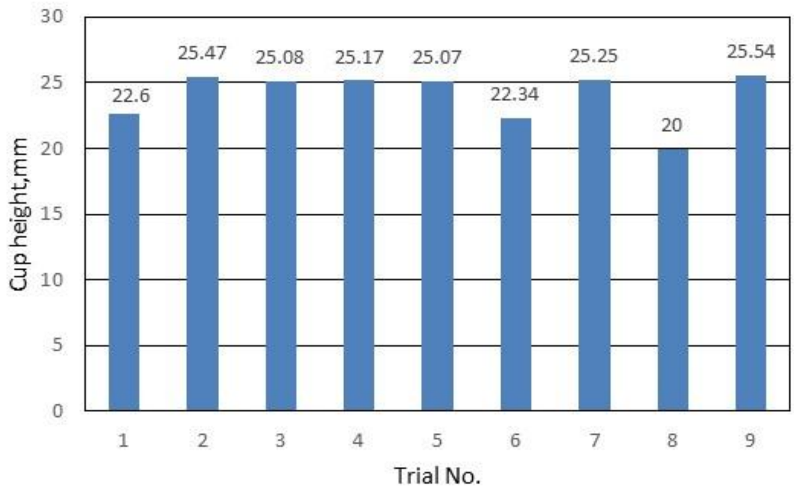

Figure 6: Cup height under different trials

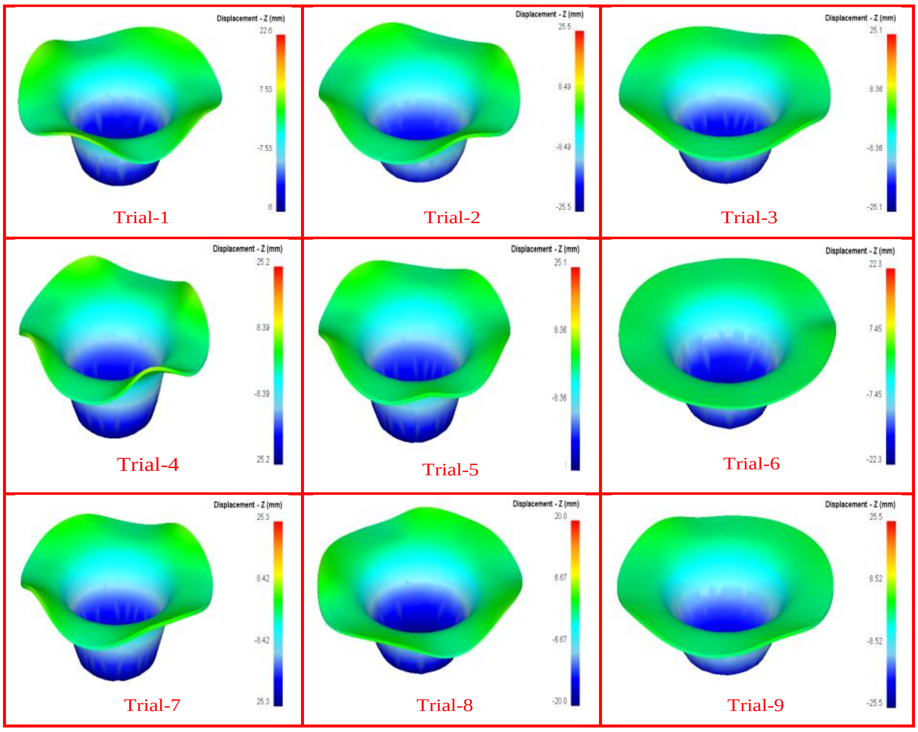

Figure 7: Height of the cup under different operating conditions

3.3 Influence of control factors on Cup damage

Table 5 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. Coefficient of friction (B) and Thickness(C) contribute 41% most over the variation. Displacement per step contribute over 17% of the variation. Whereas Punch velocity shows no effect on variation.

Table 5: ANOVA summary of damage of cups

Source	Sum1	Sum2	Sum3	SS	V	V	F	P
A	18.04	18.44	20.18	0.86	1	0.86	-56.33	0.66
B	8.61	23.03	25.01	53.45	1	53.45	-3500.96	41.19
C	27.10	20.16	9.40	53.03	1	53.03	-3473.45	40.86
D	13.89	25.25	17.52	22.45	1	22.45	-1470.47	17.30
e				-0.02	4	0.00	0.00	-0.01
T	67.64	86.88	72.12	129.77	8			100.00

Note: SS is the sum of square, v is the degrees of freedom 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 8. Damage is highest when punch velocity is 5 m/s as shown in fig 8(a). The damage of cups is lowest when coefficient of friction is lowest as shown in fig 8(b). The damage of cup is lowest when thickness of blank is 1mm as shown in fig 8(c) and damage of cups are highest when no of steps are 75 as shown in fig 8(d).

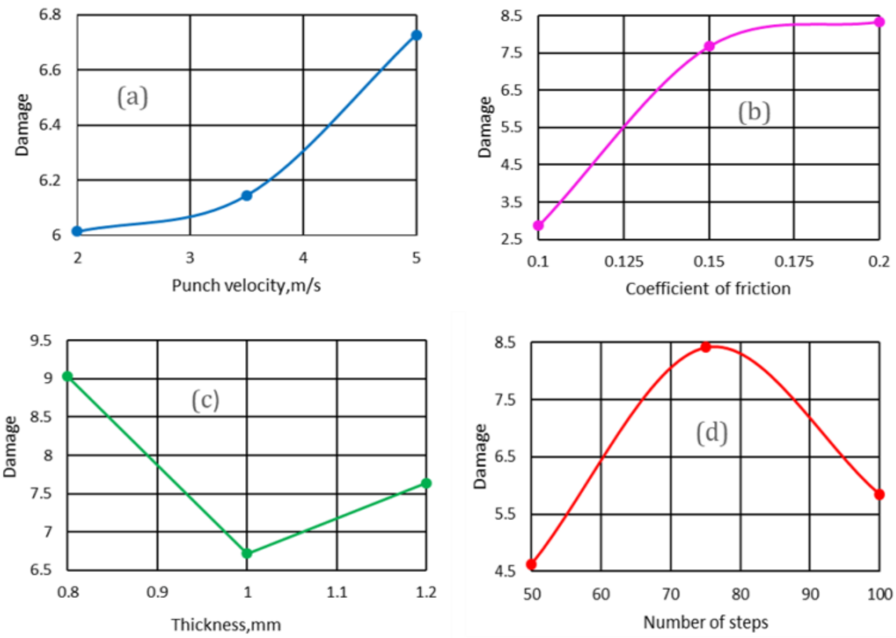

Figure 8: Effect of control factors on cup damage

The FEA results of Cup damage is shown in figure 9 and figure 10 for various test conditions as per the design of experiments. For the conical cups drawn with trials conditions of 6, 8 and 2, the damage factor of cups are 13.0, 10.39and 9.94 respectively. For the conical cups drawn with trials conditions of 9, 1, 3 and 7, the damage factor of cups are 7.52, 4.44, 3.65and 2.25 respectively. For the conical cups drawn with trials conditions of 4 and 5, the damage factor of cups are 2.7 and 2.7 respectively.

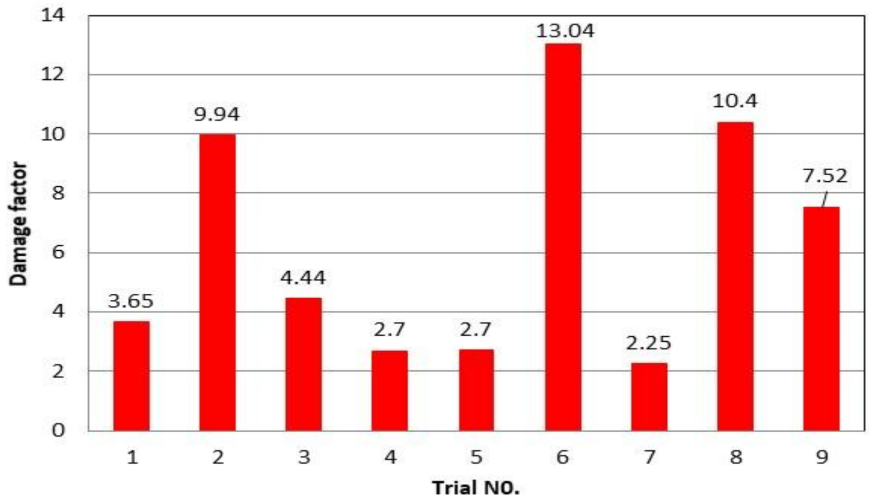

Figure 9: Cup damage under different trials

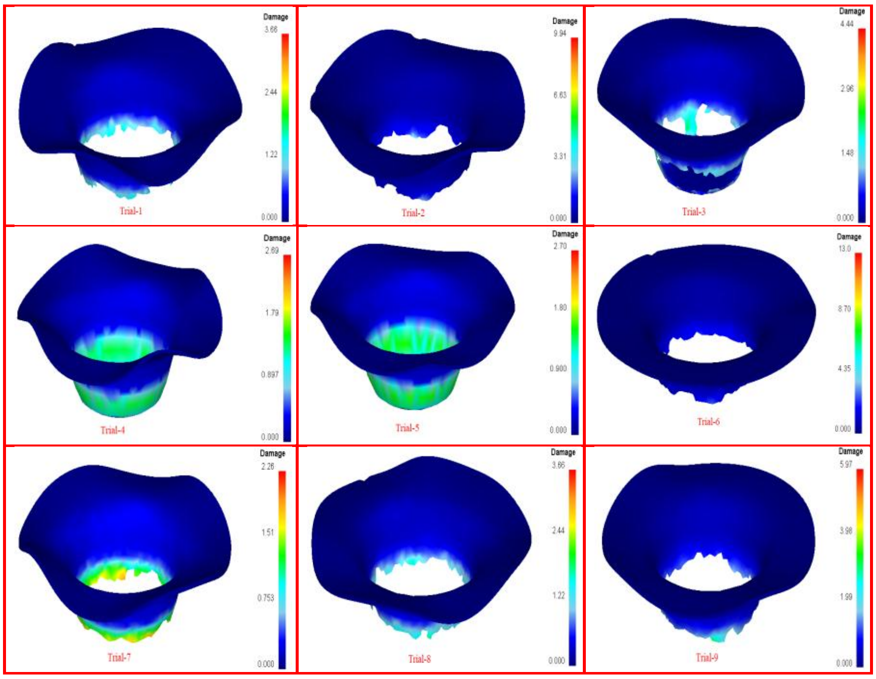

Figure 10: Damage of Conical cups under different operating conditions

The figure 11 shows the forming limit diagram of conical cups drawn from Inconel 600 of 0.8mm thickness. Trial 1 experiences both pure shear and Equibiaxial tension. Biggest damage can be seen in cups from trial 6 and trial 8, they are ruptured because of both uniaxial and biaxial tension. Figure 12 depicts the FLD and damage in the cups drawn from Inconel 600 of 1mm thickness. Cups drawn on trial 2 and trial 9 are damaged due to shear and biaxial tension. The least damaged cup can be seen in trial 2. Figure 13 demonstrates the FLD and damage in cups drawn from Inconel 600 of 1.2mm thickness. Cup drawn from trial 8 are fractured on account of both shear and biaxial tension .Cups drawn from trial 3, 4 were least damaged. Therefore, the successful process parameters are taken from trial 4 and 5 conditions.

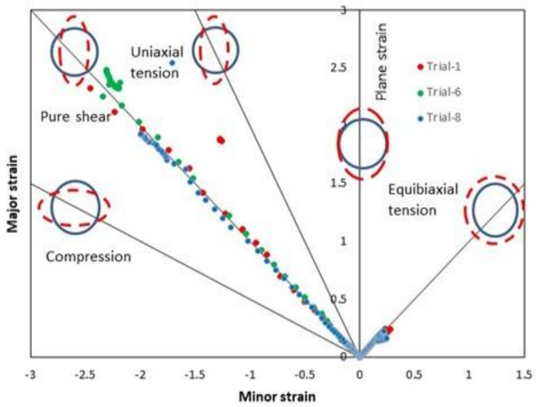

Figure 10: Forming limit diagram with damage in cups of 0.8mm thickness

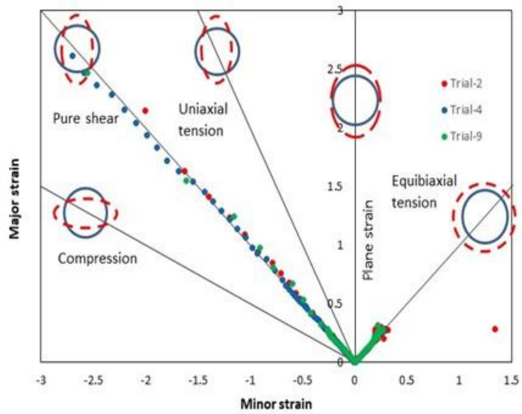

Figure 11: Forming limit diagram with damage in cups of 1mm thickness

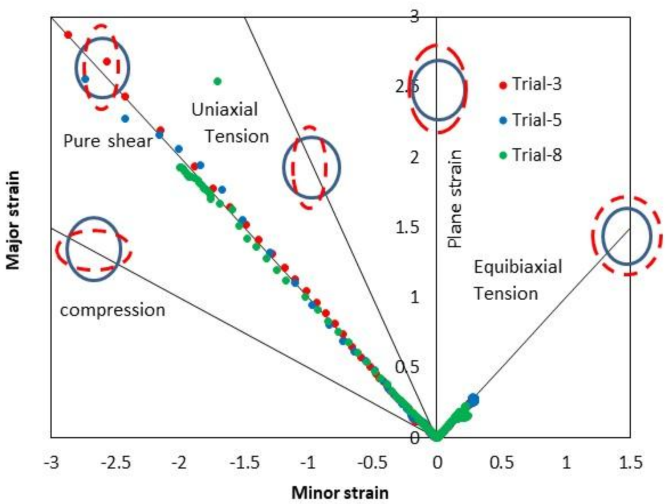

Figure 12: Forming limit diagram with damage in the cups of 1.2 mm thickness

4. CONCLUSION

The Present investigation was focused on the process parameters such as punch velocity, coefficient of friction, Thickness and displacement per step. The major process parameters which could influence the deep drawing formability of Inconel 600 conical cups, were Thickness and step length. The successful conical cups were obtained with optimal process parameters were Sheet thickness of 1mm, Punch velocity of 3.5m/s, coefficient of friction of 0.1, Step length of 1.00mm.

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