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OPTIMIZATION OF PROCESS PARAMETERS BY WARM DEEP DRAWING OF CYLINDRICAL CUP OF NICKEL 201

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ABSTRACT

In this present work, a statistical approach based on Taguchi techniques and finite element analysis were adopted to determine degree of each parameter that is punch velocity, coefficient of friction, temperature and blank thickness on the formability of cups from Nickel 201 using warm deep drawing process. The results obtained from finite element software namely DEFORM were validated experimentally. The blank thickness, temperature and coefficient of friction have been found influencing the quality of the cup drawn from Nickel201.

KEYWORDS: *Deep Drawing, Ni 201, Cylindrical Cups, Sheet Thickness, Coefficient of Friction, Punch Velocity, Damage.*

Article History

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INTRODUCTION

Deep drawing is a compression-tension metal forming process in which a sheet metal blank is radially drawn into a forming die by the mechanical action of a punch. Deep drawing process at room temperature, especially of high strength/low formability material has serious difficulties because of the large amount of deformations revealed and high flow stresses of the materials mentioned. Experimental [1] investigation of cup drawing was carried out and concluded that the extent of thinning at punch corner radius is lower in the warm deep-cup drawing process of EDD steel at 200°C. It was also found that the peak punch load is low in the warm deep drawing process. AC Reddy has done warm deep drawing process for different materials AA2618 alloy, AA3003 alloy, AA5052 alloy, 2017T4 Aluminium Alloy at elevated temperatures [2-9]. Optimization of the process parameters such as strain rate, temperature, friction coefficient, etc., was accomplished based on their degree of importance on the sheet metal forming characteristics. In fact, the metallic material is subjected to large irreversible deformation in sheet forming processes. This leads to high strain localization zones and then internal or superficial micro-defects (ductile damage). This damage causes quality problems such as necking and fracture, leading to process interruptions [10].Warm forming can be applied in these cases since it is useful in avoiding the martensitic transformation, thus eliminate the need for annealing process. This is because of the fact that the increase in temperature decreases the martensitic transformation.

Nickel 201 alloy is a nickel-manganese alloy. The manganese addition provides resistance to sulphur compounds at elevated temperatures and retains higher strength than Nickel 200 alloy at elevated temperatures. Nickel 201 alloy has been used as Caustic evaporators, Combustion boats and grids in vacuum tubes.

The objective of the present work is to optimize the warm deep drawing of Ni 201 alloy using Taguchi techniques for the cylindrical cups. In the present work, a statistical approach based on Taguchi and ANOVA techniques were adopted to determine the merit of each of the process parameter on the formability of deep drawn cylindrical cups. All the experiments results have been verified using DEFORM software.

MATERIALS AND METHODS

Nickel 201 was used to fabricate cylindrical cups. The levels chosen for the control parameters were within the operational range of Nickel 201 using deep drawing process. The chosen control parameters are summarized in table 2. The orthogonal array (OA), L9 was selected for the present work. The assignment of parameters alongside the OA matrix is given in table 3. Continental Steel may be a distributor of nickel-base alloy Ni-201 and Commercially Pure Nickel in rod, bar, pipe, tube, plate, sheet, strip, fittings, forgings, and wire. All of the above fall under one of the many strict industry standards, including those from ASTM, ASME, DIN, ISO, and B/SB. Nickel 201 can be hot formed to almost any shape. The temperature range 1200°F to 2250°F is suggested and will be carefully abided because the proper temperature is that the most vital think about achieving hot malleability.

Table 1: Chemical Composition of Nickel Alloy Ni-201 Commercially Pure Nickel

C	0.02%max
Cu	0.25 %max
Fe	0.4% max
Mn	0.35%max
Ni	99.0%max
S	0.01%max
Si	0.35%max

Table 2: Process Parameters and Levels

Factors	Symbol	Level-1	Level-2	Level-3
Punch Velocity, mm/sec	A	2	3.5	5
Coefficient of friction	B	0.2	0.3	0.4
Temperature, °C	C	600	700	800
Thickness, mm	D	0.80	1.00	1.20

Table 3: Orthogonal Array (L9) and Process Parameters

Trial	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

Fabrication of Deep Drawn Cups

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

$D = \sqrt{d^2 + 4dh}$ for d/r >20 (1)

$D = \sqrt{d^2 + 4dh}$ - 0.5r for 20>d/r>15 (2)

$D = \sqrt{d^2 + 4dh}$ - r for 15 (3)

$D = \sqrt{(d - 2r)2 + 4d(h - r) + 2\pi r(d - 0.7r)}$for d/r< 10 (4)

Where d is the mean diameter of the cup (mm), h is the cup height (mm) and r is the corner radius of the die (mm). The force required for drawing depends upon the yield strength of the material σ_y, diameter and thickness of the cup.

Drawing Force, $F_d = \pi dt\ D/d - 0.6\ \sigma_y$ (5)

Where D is the diameter of the blank before operation (mm), d is the diameter of the cup after drawing (mm), t is the thickness of the cup (mm) and σ_y is the yield strength of the cup material (N/mm^2). The drawing punches must have corner radius exceeding three times the blank thickness (t). However, the punch radius should not exceed one-fourth the cup diameter (d).

3t<Punch radius < d/4 (6)

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 the pressure area between the blank and the blank holder, and would cease to be under blank pressure. The corner radius of the die can be calculated from the following equation:

$r = 0.8\sqrt{(D - d)t}$ (7)

The drawing ratio is roughly calculated as

DR = D/d (8)

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.

Clearance, $c = t + \mu\sqrt{10t}$ (9)

The sheets of Nickel 201 were cut to the required blank size. The blank pressure was calculated, as in (5).

Finite Element Analysis

The cylindrical sheet blank was created according to desired sheet thickness and diameter. The cylindrical top punch and bottom hollow die were modelled with appropriate inner radius, outer radius and corner radius using CAD tools. The sheet blank was meshed into tetrahedral elements. The modelling parameters of deep drawing process for trail were as follows:

- Number of elements for the blank: 14475
- Number of nodes for the blank: 4991
- Top die polygons: 9120
- Bottom die polygons: 9600

RESULTS AND DISCUSSIONS

Influence of Control Factors on the Damage of Cylindrical Cups

Table 4 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 0.0% of the total variation. Factor B (Coefficient of friction) contributes 9.61%. Factor C (temperature) assists 67.27% of the variation and factor D (Thickness) contributes 38.44% variation on the cup damage.

Table 4: ANOVA Summary of Damage of Cups

	Factor	S1	S2	S3	SS	v	V	F	P
Punch Velocity	A	2.01	1.98	2.08	0.00	1	0.00	0.00	0.00
Coefficient of Friction	B	2.00	2.08	1.98	0.01	1	0.01	-0.63	9.61
Temperature	C	1.65	2.18	2.23	0.07	1	0.07	-4.39	67.27
Thickness	D	2.23	1.81	2.03	0.04	1	0.04	-2.51	38.44
	e				-0.02	4	0.00	0.00	-15.32
	T	7.89	8.04	8.32	0.10	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 1. Damage was highest when punch velocity was 5mm/s as shown in figure 1(a). The damage of cups at coefficient of friction 0.2, 0.665 was increased to 0.69 at 0.3 coefficient of friction. The damage was decreased from 0.69 to 0.6 at 0.4 coefficient of friction as shown in figure 1(b). The damage of cup at temperature 600°C to 700°C increased steadily and remained same at 800°Cas shown in figure 1(c) and the damage of cups was decreased to 0.6 at 1mm and increased to 0.7 at 1.2mm as shown in figure 1(d).

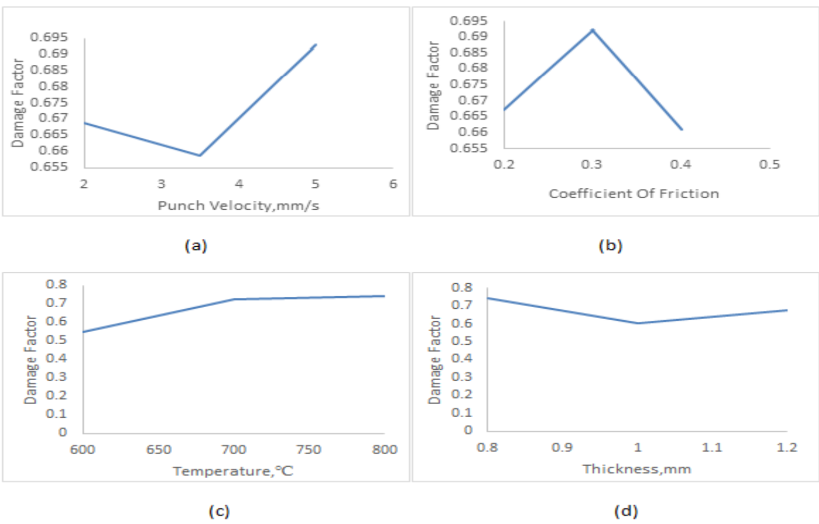

Figure 1: Effect of Control Factors on the Damage of Cup.

The damages of the cylindrical cups drawn for the trial conditions of 6, 8 were respectively 0.4%, 0.5%. The reason for relatively lower damage in these trials is due to lower coefficient of friction values. The damage of the cups drawn for the trial conditions of 1,2,3,4,5,7 and,9 were 0.6%,0.6%0.7%,0.7%,0.8%,0.6%,0.8% respectively as shown in figure 2. The reason for higher damage in these trials was due to higher values of punch velocities and higher coefficient of friction values.

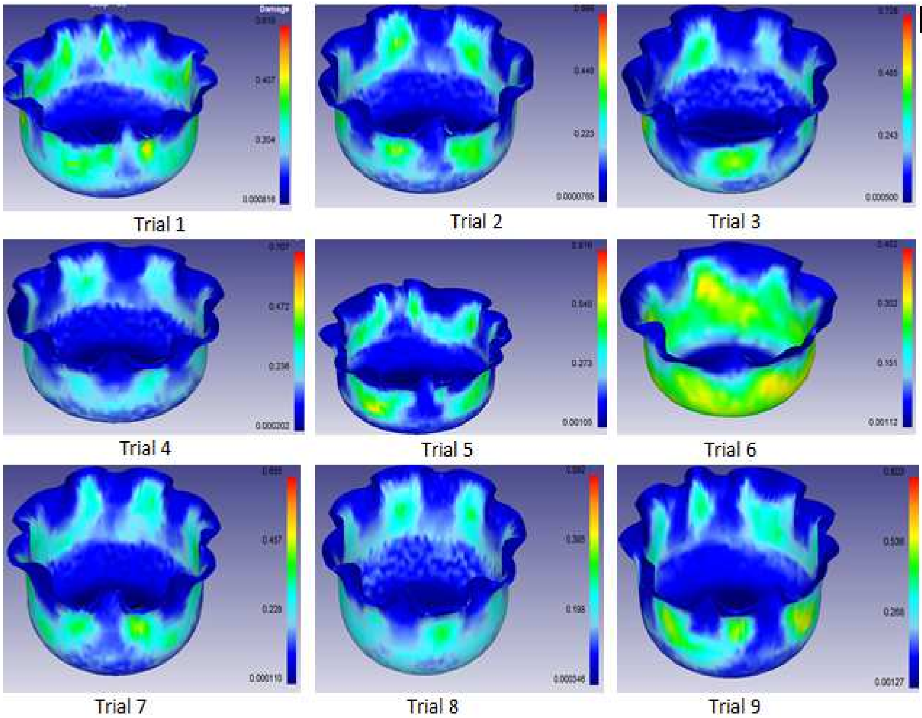

Figure 2: Damage in Cylindrical Cups Under Different Operating Conditions.

Figure 3 depicts the forming limit diagram with damages in the cylindrical cups drawn from Nickel 201 sheets of different thickness. The cylindrical cups drawn under Trial 1, 5, 9 with sheet thickness 0.8 were fully damages on account of biaxial tension and compression included in the blank material and also cup 9 observed wrinkles as shown in figure 3(a). Cylindrical cups drawn in trial 2,6,7 it was observed that cup 6 was less damaged due to lower coefficient of friction values and conversely cup 2, 7 observed most damage due to cup thickness of 1.2mm as shown in fig 3(b). The cups with thickness 1mm were damaged due to uniaxial tension and stretching as shown in fig 3(c). Least damage occurred in trial 8 because of low coefficient of friction. Conversely highest damage occurred in trial 5 and 9 due high coefficient of friction and least sheet thickness.

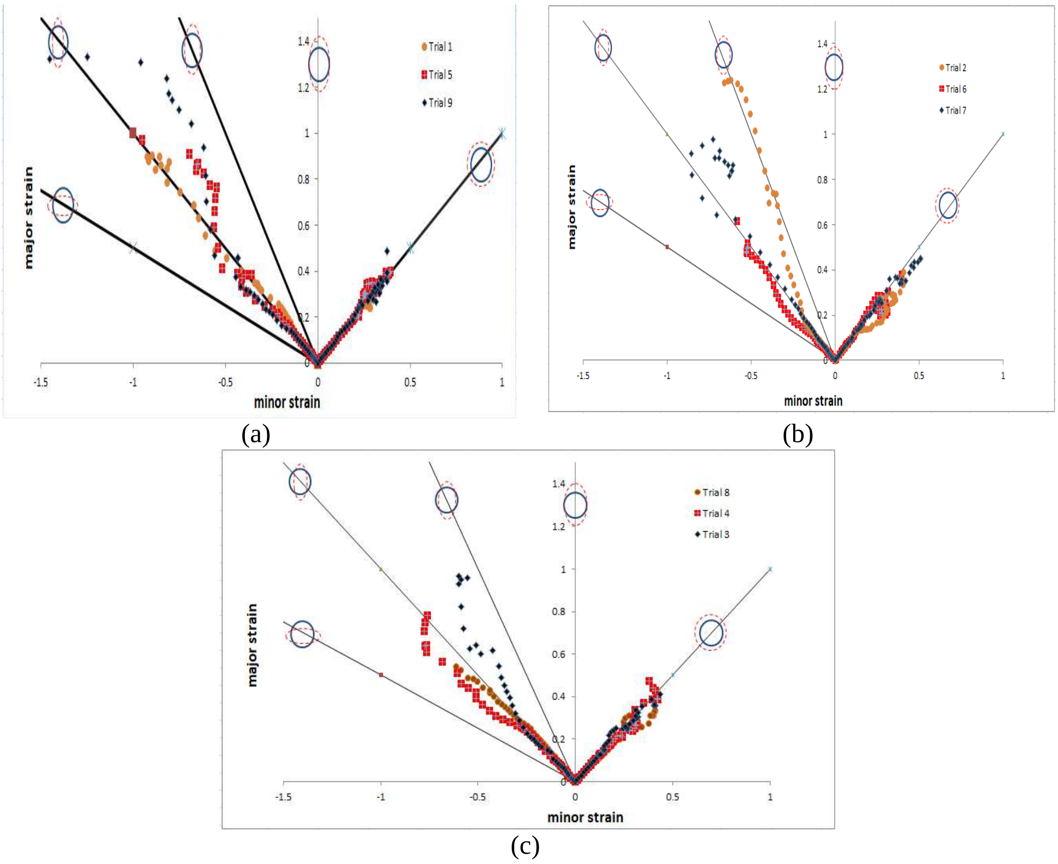

Figure 3: Forming Limit Diagram for Different Sheet Thickness.

Influence of Control Factors on Surface Expansion Ratio (SER)

Table 5 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 contributed 12.88% of the total variation; factor B, Coefficient of friction contributed 32.19% of the total variation. Factor C, temperature contributed 21.46% of total variation. Factor D, thickness, contributed 34.33% of total variation.

Table 5: ANOVA Summary of Surface Expansion Ratio (SER)

	Factor	S1	S2	S3	SS	v	V	F	P
Punch Velocity	A	4.39	4.04	3.79	0.06	1	0.06	15.00	12.88
Coefficient of Friction	B	3.58	4.54	4.1	0.15	1	0.15	37.50	32.19
Temperature	C	3.83	4.51	3.88	0.1	1	0.1	25.00	21.46
Thickness	D	3.96	4.6	3.66	0.16	1	0.16	40.00	34.33
	e				-0.004	4	0	0.00	-0.86
	T	15.76	17.69	15.43	0.466	8			100

The effect of control parameters on the surface expansion ratio of cups is given in figure 4. As the punch velocity decreased, the surface expansion ratio increased as shown in figure 4(a). With increase in coefficient of friction 0.2 to 0.3, surface expansion ratio also increases 1.2 to 1.5 and as the co efficient of friction further increases to 0.4 surface expansion ratio decreases to 1.3 as shown in figure 4(b). as the temperature increases 600°C to 700°C the surface expansion ratio increases to 1.2 to1.5 further increase in temperature to 800°C the surface expansion ratio decreases to 1.3 as shown in figure4(c). The surface expansion ratio of the cup was maximum at 1mm thickness as shown in fig 4(d).

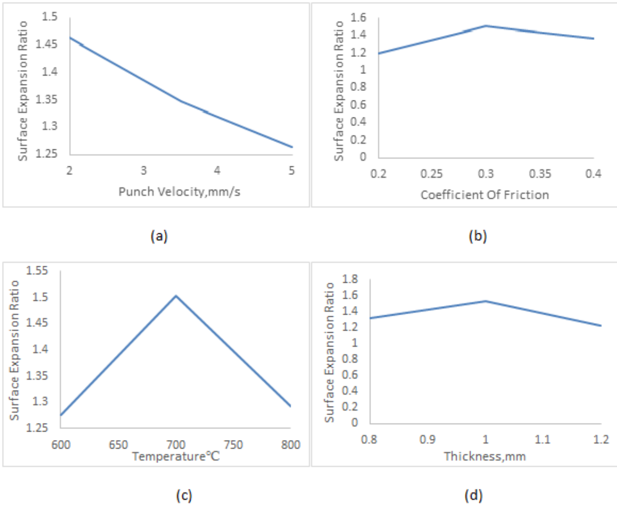

Figure 4: Effect of Control Parameters on Surface Expansion Ratio (SER).

The surface expansion ratio (SER) is a property of ductility. Higher the SER greater would be the ductility of the material. The SER when drawn for the trial conditions 2 is 1.9. The SER values when drawn for the trail conditions of 1,3,4,5,6,7 and 8 were 1.18,1.27,1.19,1.4,1.45,1.21 and 1.38 respectively. The relatively higher values of surface expansion ratio in trial conditions of 3, 8, and 9 were because of greater coefficient of friction as shown in figures 5.

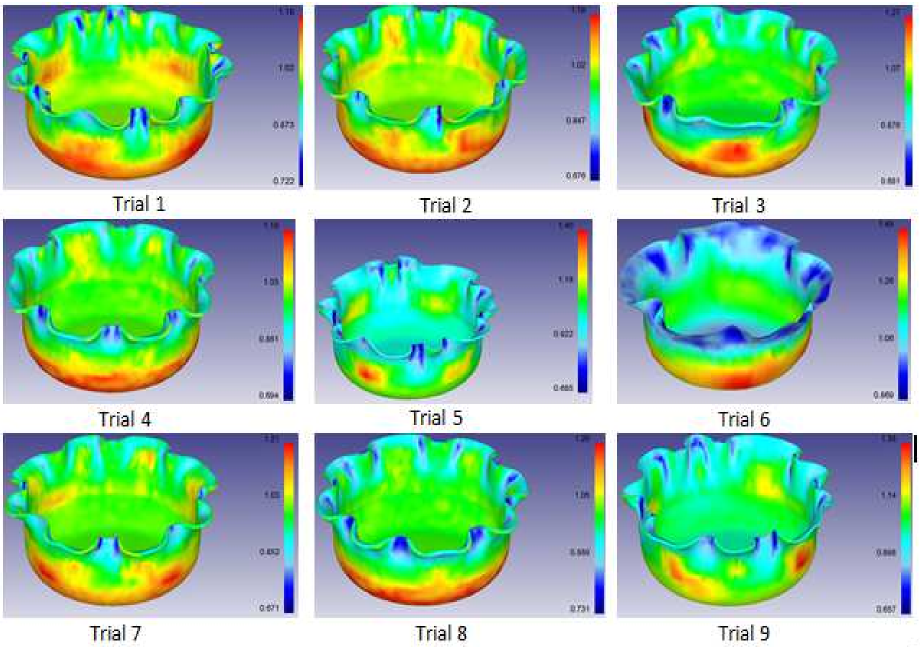

Figure 5: SER in Cylindrical Cups Under Different Operating Conditions.

Influence of Control Factors on the Height of Cylindrical 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 per cent contribution would indicate that the factor C, temperature, contributed 57% towards the variation. The Punch velocity (A), Coefficient of friction (B), thickness (D) offered 0.76%, 0.84 %, 41.40% of variation on the cup height respectively.

Table 5: ANOVA Summary of the Cylindrical Cup Height

	Factor	S1	S2	S3	SS	v	V	F	P
Punch Velocity	A	25.13	25.13	25.14	0.000045	2	0.000023	0.02	0.76
Coefficient of Friction	B	25.13	25.13	25.13	0.00005	2	0.000025	0.03	0.84
Temperature	C	25.16	25.13	25.11	0.003398	2	0.001699	3.98	57.00
Thickness	D	25.11	25.15	25.14	0.002468	2	0.001234	2.12	41.40
	e				0.017887	0	0.000298	0.00	
	T	100.53	100.54	100.52	0.023848	8			100.0

The effect of control parameters on height of cup is given in figure 6. The height of cup was maximum when punch velocity was 5mm/s and the least when punch velocity was 3.5mm/s as shown in figure 6(a). The height of cup was maximum 25.135mm when the coefficient of friction was 0.2 to 0.3 and reaches to 25.130mm when co efficient of friction is 0.4 as shown in figure 6(b). The height of the cup rapidly decreased from 600°Cto 700°C then there was negligible change in height of the cup up to 800°C as shown in figure 6(c). The cup height increased at 1mm thickness as shown in figure 6(d).

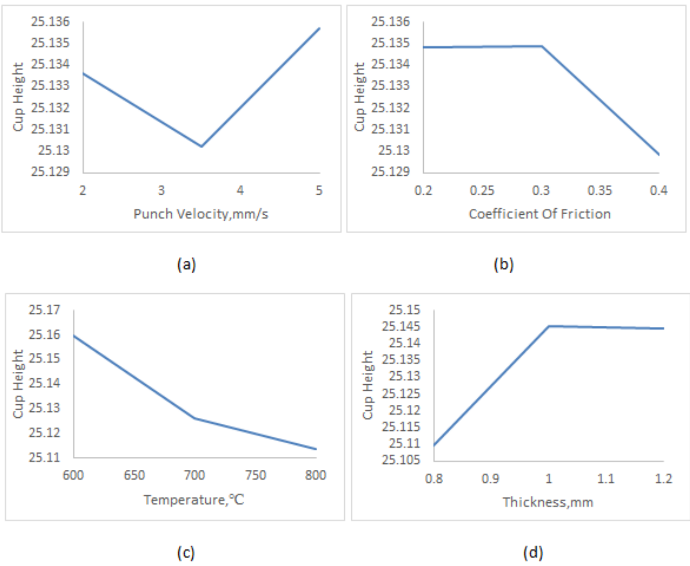

Figure 6: Effect of Control Parameters on Height of Cup.

The height of the cylindrical cups under different trial conditions are shown in figures 7. For the cups drawn in trail conditions 5, 9 the cup height values were 25.085mm, 25.1mmrespectively. The height of cups drawn with trail conditions 5, 9 was less because of low sheet thickness of 0.8mm. The heights of cups drawn with trail conditions 1,2,3,4,6,7,8 were 25.139mm,25.14mm,25.12mm,25.13mm,25.165mm,25.13mm,25.17mm respectively and these trail conditions had relatively more cup height as the thickness of sheet was high.

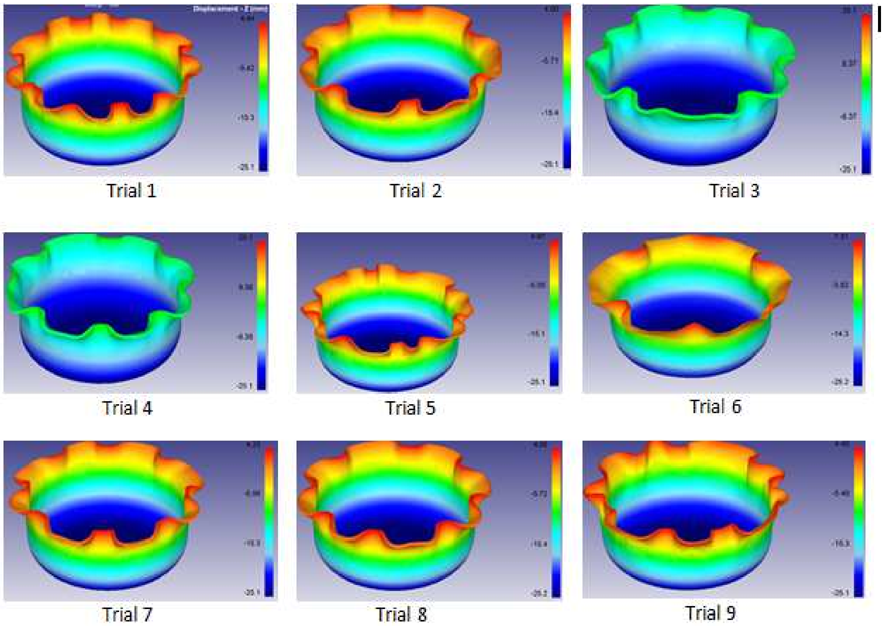

Figure 7: Height of the Cylindrical Cups Under Different Trial Conditions.

CONCLUSIONS

The major parameters which influenced damage of the cup were Temperature and thickness. The damage of the cup was least when punch velocity is 3.5mm/s, coefficient of friction is 0.4, Temperature is 700°Cand thickness is1mm. The Four major parameters have influenced surface expansion ratio of the cup. The surface expansion ratio of the cup was maximum at punch velocity 2mm/s, coefficient of friction 0.3, Temperature 700°C, thickness 1mm. The major parameters which influenced height of the cup were Temperature and Thickness.

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