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PARAMATER OPTIMISATION FOR WARM DEEP DRAWING OF INCONEL-600 CYINDRICAL CUP

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Abstract: In the present work, a statistical approach based on Taguchi technique and finite element analysis were adopted to determine the parametric significance on the formability of cylindrical cup using warm deep drawing process. The process parameters were thickness, punch velocity, coefficient of friction and temperature. A forming limit diagram (FLD) have be drawn out of the results to analyse the fracture phenomenon. The Sheet thickness and coefficient of friction have been found influencing the quality of the cup drawn from Inconel-600.

Keywords: Finite Element Analysis, Forming Limit Diagrams, Warm Deep drawing, Simulation

I. INTRODUCTION

The deep drawing process is a forming process which occurs under a combination of tensile and compressive forces. A flat Sheetmetal blank is formed into a hollow body open on one side or a hollow body is formed into a hollow body with a smaller cross-section.

In deep drawing, the majority of the deformation occurs in a flange region of the cup. The metal is subjected to three types of stresses. The stress influences thickness variation in the drawn cup. The primary deformation zone is bending around the die radius, while thesecondary deformation zone is uni-axial stretching in the cup wall (plane strain) which causes thinning of metal. The third deformation zone is the cup bottom which is subjected to bi-axial tension and hence the final thickness of cup is almost equal to the initial sheet thickness.

Chennakesava Reddy [1] et al. (2012) investigated on the experimental characterization on the warm deep drawing process of extra-deep drawing (EDD) of steel and have shown that the extent of thinning at the punch corner radius is lower in warm deep drawn cup of EDD steel at 200°C. Ayres [2] investigated the potential of warm forming by deep drawing a circular cup and observed that the cup's height increased with increasing forming temperature and/or decreasing punch speed for an AA5182-O alloy. Reddy [3] had simulated the cup drawing process with an implicit finite element analysis. The effect of local thinning was observed on the vertical walls of the cup. The strain was found to be maximum at the thinner sections. Devender et al.[4] worked on the formability of cold deep drawing process of Nickel 201 during the fabrication cylindrical cups and have shown that the surface expansion ratio increased with an increase in the strain rate. The plastic deformation increased with the extended yield strength and resulted in decrease ofdamage in the cup. Reddy [5] investigated on the formability of warm deep drawing process of AA1050-H18 assessed during the fabrication of pyramidal cups and concluded that the damage in the pyramidal cups decreased with an increase in the thickness of the sheet and temperature. The effective stress increasedalong with increase in friction. This is due to the increase in normal pressure between die and blank. Various experimental and numerical investigations of cup drawing were carried out to study the stresses and strains in cold and warm drawing environments [6-10]. In the finite element simulations, a forming limit diagram (FLD) has been successfully drawn to analyse the fracture phenomena by comparing the strain status. Optimization of the process parameters such as punch velocity, coefficient of friction, temperature etc., was accomplished based on their degree of importance on the sheet metal forming characteristics.

Inconel-600 is a nickel-based, non-magnetic high temperature alloy with an exceptional combination of high strength, hot and cold workability, and resistance to ordinary form of corrosion. This alloy also displays successful heat resistance and autonomy over aging or stress corrosion throughout the annealed region to heavily cold worked condition range.

II. MATERIALS AND METHODS

Inconel 600 alloy was used to fabricate cups by the process of deep drawing. The tensile and yield strengths of this alloy range from 550-690MPa and 205-310 MPa respectively. The elastic modulus is 207 GPa at room temperature. The Poisson's ratio is 0.31. The percent elongation of the material is 40. The controlparameters are those parameters which an individual can control during the design of the product and process of manufacturing. The chosen control parameters levels were in the operational range of Inconel 600 alloy using deep drawing process. Each of the four control parameters were studied at three levels. The summary of the chosen control parameters is given in table 2.A L9 orthogonal array (OA) was selected for the present study. The parameters assigned to the various columns of OA matrix is given in table 1.

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

Table 1: L9 Orthogonal Array and Control parameters

2.1 Fabrication of Deep Drawn Cups

The size of the blank was calculated by equating the surface area of the finished drawn cup with the area of the blank. The diameter meter 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 $15 > d/r > 10$ (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, $F = \pi dt\,[D/d - 0.6]\,\sigma_y$ (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 punch must have a corner radius exceeding a minimum of three times the blank thickness (t). However, the punch radius should not exceed a quarter of the cup diameter (d).

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

Factor	Symbol	L1	L2	L3
Punch Velocity	A	2	3.5	5
Coefficient of friction	B	0.2	0.3	0.4
Temperature	C	600	700	800
Thickness	D	0.80	1.00	1.20

Table 2: Control Parameters and Levels

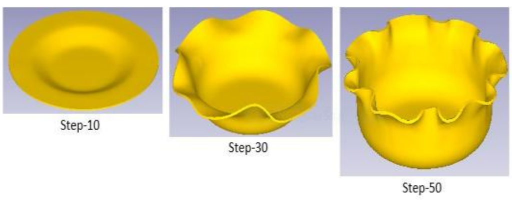

Figure 1: Cup Drawing at Different Steps

For smooth flow of material the die edge should have generous radius preferably four to six times the sheet thickness but never less than three times the blank thickness because lesser radius would impede material flow while excess radius would increasethe pressurearea 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 contribute to some flange thickening and thinning of walls of the cup which is inevitable. The space for drawing the cup is kept bigger than the sheet thickness which is called die clearance.

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

The sheets of Inconel 600 alloy were cut to the required blank size. The blank specimens were heated in a muffle furnace to the preferred temperature as per the design of experiments. The blank pressure was calculated using necessary equation. The cups were fabricated using a hydraulically controlled deep drawingmachine.

2.2 Finite Element Modelling and Analysis

The finite element modelling and analysis was doneusing DEFORM 3D software. The circular sheet blank was modelled with the required diameter and thickness. The cylindrical top punch and cylindrical bottom hollow die weremodelled with relevant inner and outer radius and corner radiususing equation (7). Using equation (9) the clearance between the punch and die was calculated. The sheet blank was meshed with tetrahedral elements as shown in figure 2.The modelling parameters of deep drawing process were as follows:

No. of elements for the blank: 14475 tetrahedron
No. of nodes for the blank: 4991
Top die polygons: 9120
Bottom die polygons: 9600

The progressive blank deformation is shown in figure 1. Blank and punch, die and blank holder were coupled as contact pair. The interaction between the contact surfaces was assumed to be mechanical frictional contact. The finite element analysis was chosen to find the effective stress, damage of the cup, effective strain, and height of the cup. For the purpose of validating the results of experimentation,the finite element analysis was acknowledged to run using DEFORM 3D software according to the design of experiments.

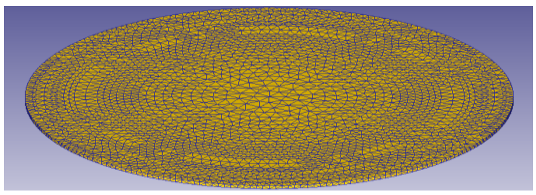

Figure 2: Tetrahedral Mesh of Sheet Blank

III. RESULTS AND DISCUSSION

3.1 Influence of control factors on Effective Stress

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. The percent contribution indicates that the factor A (Punch Velocity) contributed15.16% of variation; Factor B (Coefficient of Friction) 2.07% of variation, C (Temperature) 80.01% of variation and D (Sheet Thickness) 2.76% of variation on the effective tensile stress.

From the table 3 it can be clearly stated that the control parameter C(Temperature) was a very influential in controlling the induced stress in cup drawing operation. The effective stress strictly decreased from 2168.35 to 1758.18 MPa with increasing temperature from 600 to 800°C as shown in figure 3(c). This is owing to the softening of the alloy with increase in temperature from 600 to 800°C. With an increase in punch velocity, the stress induced in the cup decreases persistently as shown in figure 3(a). The effective stress of the cups decreased from 2043.1 to 1867.84 MPa with increasing punch velocity from 2 to 5 mm/s.

	S1	S2	S3	SS	v	V	F	P
A	6129.30	5955.56	5603.54	47836.57	1	47836.57	15436789.36	15.16
B	5934.38	5783.80	5970.22	6523.28	1	6523.28	2105052.67	2.07
C	6505.05	5908.81	5274.54	252439.46	1	252439.46	81461834.95	80.01
D	5950.88	5764.68	5972.85	8721.20	1	8721.20	2814318.15	2.76
e				0.00	4	0.00	0.00	0.00
T	24519.62	23412.85	22821.15	315520.51	8			100.00

Table 3: ANOVA summary of the EffectiveStress

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 influence of coefficient of friction on the effective stress is shown in figure 3(b). The influence of coefficient of friction on the effective stress was very less compared to other parameters. The effective stress of cups having thickness 1mm was found to be minimum of 1921.94 MPa as shown in figure 3(d).For sheet thickness of 0.8 mm the maximum induced stress was 2277.07 MPa. For sheet thickness of 1mm the maximum induced stress was 2169.04 MPa. Andfor sheet thickness of 1.2mm the maximum induced stress was 2058.95 MPa (figure 4).

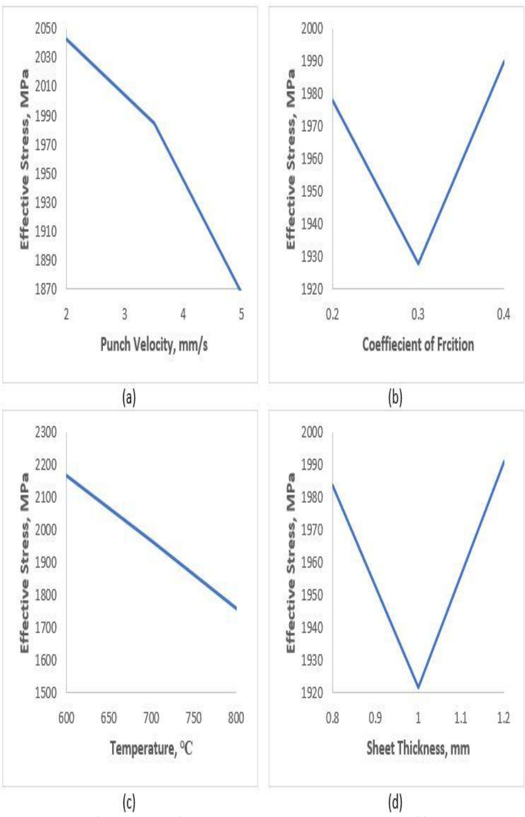

Figure 3: Influence of Process parameters on Effective Stress

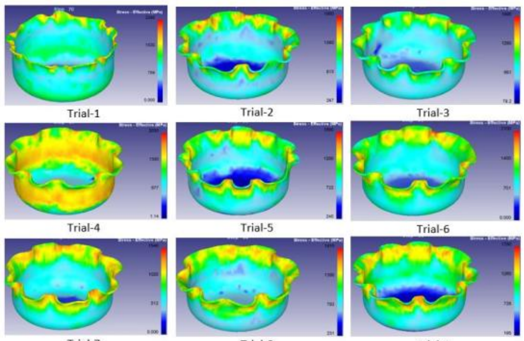

Figure 4: Effective Stress under different operating conditions

3.2 Influence of control factors on Damage of Cup

The ANOVA summary of damage of cup is given in table 4. The Fisher's test column ascertains the parameters A, B, C and D accepted at 90% confidence level influencing the variation in the impact strength. The percent contribution would indicate that the thickness (D) of the sheet onlycontributed 28.30% of the variation, temperature parameter (C) 32.41% of variation, coefficient of friction (B) 19.41% of variation and punch velocity (A) 20.89% of variation.

Factor	S1	S2	S3	SS	v	V	F	P
A	4.21	1.84	1.81	1.26	1	1.26	-59.32	20.89
B	4.12	1.67	2.06	1.17	1	1.17	-55.08	19.41
C	4.59	1.55	1.71	1.96	1	1.96	-92.27	32.41
D	4.45	1.85	1.56	1.71	1	1.71	-80.50	28.30
e				-0.02	4	-0.01	0.47	-1.01
T	17.38	6.90	7.14	6.08	8			100.00

Table 4: ANOVA Summary of Damage of cups

The effect of control factors on the damage of cup are shown in figure 6.As the punch velocity increased the damage decreased sharply till 3.5mm/s of punch velocity and there onwards almost constant as shown in figure 6(a). The damage of cups was highest for the coefficient of friction of 0.2 with a value of 1.37 as shown in figure 6(b). Then the damage factor reduced to a value of 0.56 at the coefficient of 0.3 and slightly increased for coefficient 0.4. The damage of the cups was found to be low at temperature of 700°C as shown in figure 6(c). The damage of cups was found to be high for the blank thickness of 0.8mm with a value of 1.48 and reducedrapidly for 1mm sheet with a value of 0.6. Damage of the cups further kept reduced for 1.2mm sheet, but significant change was not found as shown in figure 6(d).

The damage of the cups under different trial conditions are shown in figure7. For the cups drawn with trials conditions of 1, 5 and 9the damage of cups was 3.17%, 0.60% and 0.67% respectively. For the cups drawn with trials conditions of 2, 6 and 7 the damage of cups was0.47%, 0.82 %and 0.54% respectively. For the cups drawn with trials conditions of 3, 4 and 8 the damage of cups was 0.55%, 0.40% and 0.59% respectively. The reasons for the damage of the cups might be on account of high coefficient of friction 0.4 and low punch velocity. The other possible reasons for the damage of cup under trial condition 1 (3.17%)were due to low sheet thickness and low punch velocity.Further reasons for the damage of cups might be due to the small punch radius and die corner radius.

Figure 8 depicts the forming limit diagram with damages in the cylindrical cups drawn from Inconel 600 sheets of different thickness. The cylindrical cups drawn under trials 1, 5 and 9 with sheet thickness 0.8mm were most damaged on account of biaxial tension and compression induced in the blank material as shown in figure 8(a). Less damage was observed in the trials 3, 4 and 8 except wrinkles due more compressive stresses as shown in figure 8(c). The cylindrical cups drawn under trials 2, 6 and 7 with sheet thickness 1mm were damaged due to uniaxial tension and stretching as shown in figure 8(b). Least damage occurred in the trial 4 because of highest sheet thickness and low coefficient of friction. Conversely highest damage occurred in trial 1 due to low temperature and least sheet thickness.

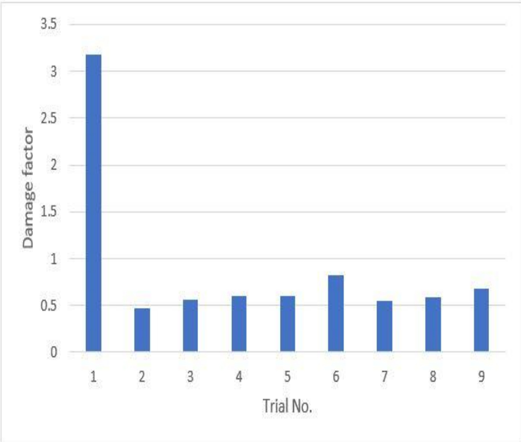

Figure 5: Damage under different trials

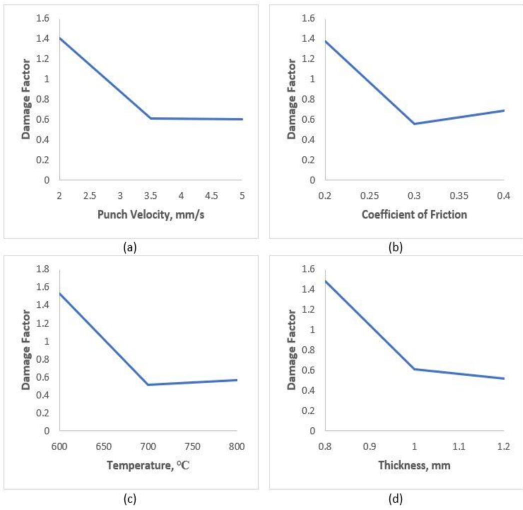

Figure 6: Influence of control parameters on Damage of cup

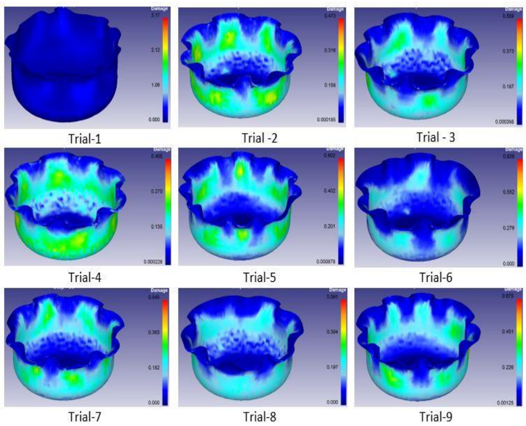

Figure 7: Damage of the cup under different operating conditions

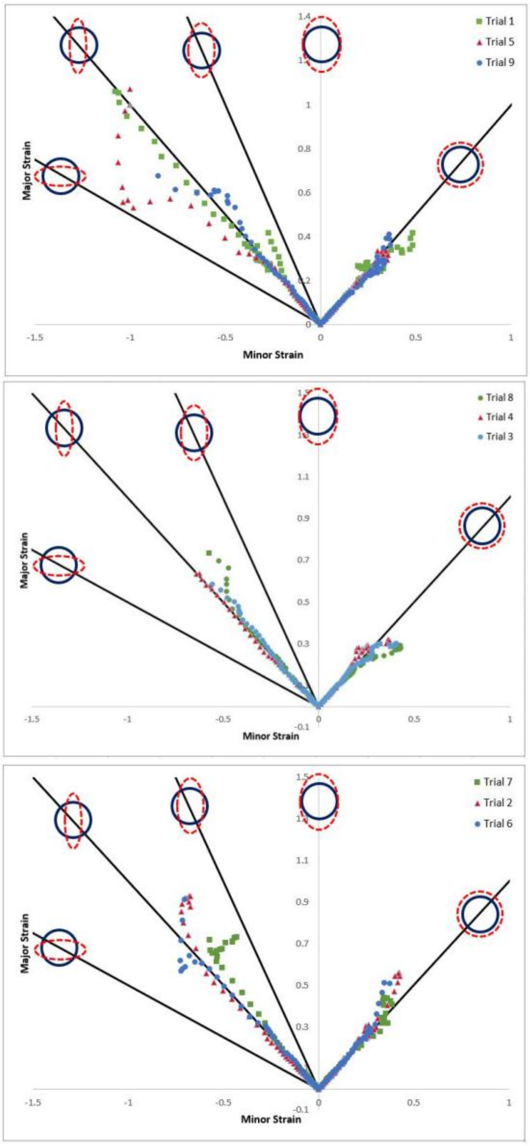

Figure 8: Forming Limit Diagrams for different sheet thicknesses

3.3 Influence of control factors on Effective Strain

Factor	S1	S2	S3	SS	v	V	F	P
A	3.45	3.77	3.31	0.05	1	0.05	3.57	15.34
B	3.67	3.66	3.19	0.05	1	0.05	3.57	15.34
C	3.54	3.32	3.67	0.02	1	0.02	1.43	6.14
D	4.17	3.17	3.19	0.22	1	0.22	15.69	67.49
e				-0.01	4	0.00	0.00	-4.31
T	14.83	13.92	13.35	0.33	8			100.0

Table 5: ANOVA Summary of Strain Effective

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.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. The percent contribution would indicate that the factor A (Punch Velocity) contributed 15.34% of variation, Factor B (Coefficient of Friction) 15.34% of variation, C (Temperature) 6.14% of variation and D (Sheet Thickness) 67.49% of variation on the effective tensile stress.

The effective strain decreased sharply from 0.8mm sheet to 1mm and thereafter almost constant as shown in figure 9(d). The least effective strain was found for 1mm sheet with a value of 1.05. The characteristic equation that narrates super plastic behaviour is usually written as $\sigma = K.\ \dot{\epsilon}^{m}$.m, where σ is the flow stress, K is a material constant, $\dot{\epsilon}$ is the strain rate and m is the strain-rate sensitivity index of the flow stress. The m-value is a function of the forming parameters, such as the strain rate and the temperature. The m-value is also connected with the microstructural characteristics. The effective strain reached a peak value of 1.25 for punch velocity of 3.5mm and reduced further with increase in velocity as shown in figure 9(a). For coefficient of friction values of 0.2 and 0.3, much difference in effective strain was not found. But for coefficient of friction 0.4, least value of effective strain 1.06 was observed. The effective strain initially decreased with increase in temperature to a value of 1.1 at 700°C and later increased along with temperature to a value of 1.22 at 800°C. Effective Strain in cups for different trail conditions is shown in figure 10.

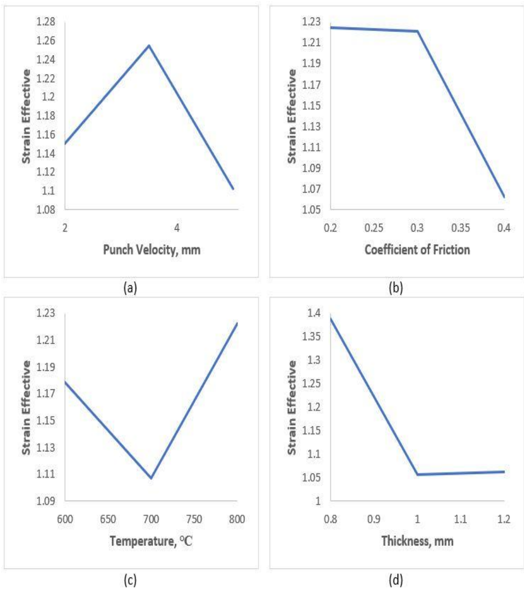

Figure 9: Influence of control parameters on Strain Effective

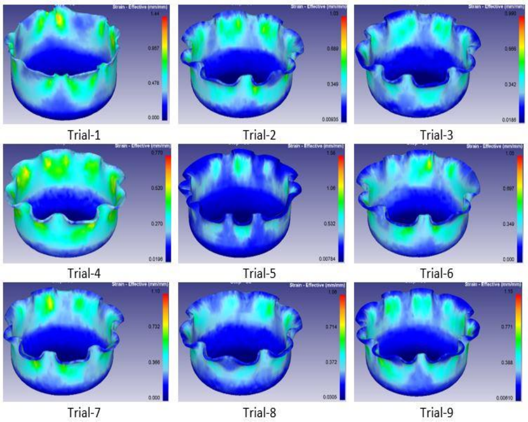

Figure 10: Strain Effective under different operating conditions

3.4 Influence of control factors on Cup Height

The ANOVA summary of height of the cup is given in table 6. The Fisher's test column ascertains the parameters A, B, C and D accepted at 90% confidence level influencing the variation in the elastic modulus. The percent contribution would indicate that the thickness of the sheet only contributed 22.40% of the variation, Coefficient of friction parameter 31.35% of variation, temperature 23.51% of variation and punch velocity 22.66% of variation.

Factor	S1	S2	S3	SS	v	V	F	P
A	80.23	75.96	75.51	4.51	1	4.51	264.05	22.66
B	80.77	75.45	75.48	6.24	1	6.24	365.34	31.35
C	80.28	75.96	75.46	4.68	1	4.68	274.00	23.51
D	80.21	75.50	75.99	4.46	1	4.46	261.12	22.40
e				0.02	4	0.00	0.00	0.08
T	321.48	302.86	302.46	19.91	8			100.00

Table 6: ANOVA Summary of Cup Height

The effect of control parameters on height of cup is given in figure 10. The height of cup was maximum when punch velocity was 2mm/s and least when punch velocity was 5mm/s as shown in figure 12(a). Height of cup was maximum when coefficient of friction was 0.1 as shown in figure 12(b). The height of the cup rapidly decreased from 0.8mm to 1mm sheet and then there was negligible change in height of the cup as shown in figure 12(c).

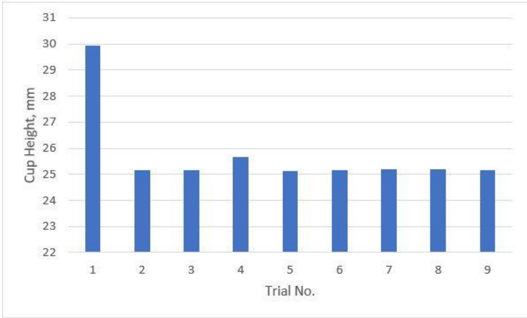

Figure 11: Cup height under different trials

Also, the height of the cup sharply reduced from with increase in temperature initially and later remained almost constant as shown in figure 12(d).
The cup heights under various trail conditions are shown in figure 11.

IV. CONCLUSION

The major process parameters which could the influence the deep drawing capability of Inconel-600 cylindrical cups, were punch velocity and temperature. The damage of the cups was found to be less with the sheet thickness of 1.2mm. Effective stress continuously decreased with increase in temperature. Effective strain was found to be less with 1.2mm sheet and with 0.4 coefficient of friction. The cup with punch velocity 3.5mm/s, coefficient of friction 0.2, temperature 700 °C and sheet thickness 1.2mm was found to be best drawn cup.

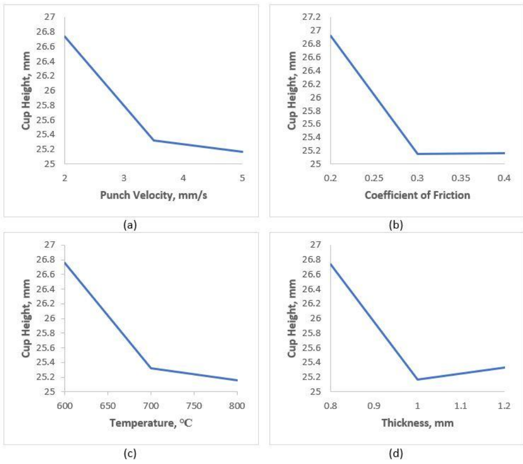

Figure 12: Influence of control parameters on Cup Height

REFERENCE

[1] Chennakesava Reddy A., Kishen Kumar Reddy T., VidyaSagar M. (2012) Experimental characterization of warm deep drawing process for EDD steel, Int. J. of Multidisciplinary Res. & Adv. Eng. 4:53-62.

[2] Ayres RA. Alloying aluminum with magnesium for ductility at warm temperatures (25 to 250 °C). Metal Mater Trans A 1979;10(7):849–54

[3] A. Chennakesava Reddy, Evaluation of local thinning during cup drawing of gas cylinder steel using isotropic criteria, International Journal of Engineering and Materials Sciences, vol.5, no.2, pp.71-76, 2012.

[4] G. Devendar, A. Chennakesava Reddy, Formability Limit Diagrams of Cold Deep Drawing Process for Nickel 201 Cylindrical Cups, International Journal of Science and Research (IJSR), ISSN (Online): 2319-7064

[5] A. C. Reddy, Formability of Warm Deep Drawing Process for AA1050-H18 Pyramidal Cups, International Journal of Science and Research, vol. 4, no. 7, pp. 2111-2119, 2015.

[6] A.C. Reddy, Parametric Optimization of Warm Deep Drawing Process of 2014T6 Aluminum Alloy Using FEA, International Journal of Scientific & Engineering Research, Volume 6, Issue 5, May-2015

[7] Srinivas Reddy Thummala, B. Nageshwar Rao, A.C.S. Reddy, Parametric Optimization of Warm Deep Drawing Process Aluminium Alloy 1100, International Journal of Engineering Development and Research, Volume 5, Issue 4.

[8] A.C. Reddy, Finite Element Analysis of Warm Deep Drawing Process for 2017T4 Aluminum Alloy: Parametric Significance Using Taguchi Technique, International Journal of Advanced Research (2015), Volume 3, Issue 5, 1247-1255

[9] Balla Yamuna, A.C. Reddy, Finite Element Analysis of Warm Deep Drawing Process for Conical Cup of AA1080 Aluminum Alloy, International Journal of Advanced Research (2015), Volume 3, Issue 6, 1309-1317

[10] Balla Yamuna, A.C. Reddy, Parametric Merit of Warm Deep Drawing Process for 1080A Aluminium Alloy: Validation through FEA, International Journal of Scientific & Engineering Research, Volume 6, Issue 4, April-2015

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