ISSN NO. 2320-5407

Journal homepage:http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Finite Element Analysis of Warm Deep Drawing Process for Conical Cup of AA1080 Aluminum Alloy

Balla Yamuna[1], A. C. Reddy[2]

1. PG Student, Department of Mechanical Engineering, JNTUH College of Engineering, Kukatpally, Hyderabad, India.
2. Professor, Department of Mechanical Engineering, JNTUH College of Engineering, Kukatpally, Hyderabad, India.

Manuscript Info

Manuscript History:

Received: 15 April 2015
Final Accepted: 22 May 2015
Published Online: June 2015

Key words:

Warm deep drawing,AA1080,blank thickness, temperature, strain rate, coefficient of friction, damage.

***Corresponding Author**

Balla Yamuna

Abstract

In this present work, a statistical approach based on Taguchi techniques and finite element analysis were adopted to determine the influence of sheet thickness, temperature, coefficient of friction and strain rate on the formability of cups from AA1080 aluminum alloy using warm deep drawing process. The successful conical cups of 1.5mm blank thickness were obtained with operating conditions of 300°C, temperature; 0.05, coefficient of friction; and 500, strain rate.

INTRODUCTION

Many investigations have been carried out to obtain an optimal blank shape that can be deformed into the near-net shape. Chung et al. (1997) have proposed a direct design method based on an ideal forming theory to get an initial blank shape. Toros et al. (2008) have developed an analytical model to evaluate deep drawing process at elevated temperatures and under different blank holder pressure (BHP) and identified that temperature, punch speed, BHP, and friction are the main factors that influence formability. Chennakesava Reddy et al. (2012) have carried out the experimental characterization on the warm deep drawing process of extra-deep drawing (EDD) steel. The results of the experimentation conclude that the extent of thinning at punch corner radius is lower in the warm deep-cup drawing process of EDD steel at 200 ^{0}C. Chennakesava Reddy et al. (2012) in another 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. Reverse superplastic blow forming of a Ti-6Al-4V sheet has been simulated using finite element method to achieve the optimized control of thickness variation (Chennakesava Reddy, 2006). The strain hardening rate and fracture toughness are usually affected by strain rate and temperature. Chennakesava Reddy (2011) has used Taguchi technique which can save the cost of experimentation to optimize the extrusion process of 6063 aluminum alloy. Industrial pure aluminum cannot be heat strengthened, through increased intensity of cold deformation, the only form of heat treatment is annealing. AA1080 is highly resistant to chemical attack and weathering. It is easily worked and welded. This is excellent for chemical processing equipment and other uses where product purity is important, and for metal pressings of all types where ductility is critical also, it is a soft workable alloys having high purity which gives excellent corrosion resistant.

The objective of the present work is to optimize the warm deep drawing process of AA1080 aluminum alloy using Taguchi technique for the conical cups. In this present work, a statistical approach based on Taguchi and ANOVA techniques was adopted to determine the merit of each of the process parameter on the formability of deep drawn conical cups. All the experimental results have been verified using D-FORM software.

1. Materials and Methods

AA1080 aluminum alloy was used to fabricate deep drawing cups. The tensile and yield strengths of this alloy are 120 MPa and 80 MPa respectively. The elastic modulus is 70 GPa. The poisson's ratio is 0.33. The percent elongation is 8. The control parameters are those parameters that a manufacturer can control the design of the product, and the design of process. The levels chosen for the control parameters were in the operational range of AA1080 aluminum alloy using deep drawing process. Each of the four control parameters was studied at three levels. The chosen control parameters are summarized in table 1. The orthogonal array (OA), L9 was selected for the present work. The parameters were assigned to the various columns of O.A. The assignment of parameters along with the OA matrix is given in table 2.

1.1 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:

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

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

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:

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

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:

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

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.

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

where μ is the coefficient of friction.

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

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

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

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

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

1.2 Finite element analysis

The finite element modeling and analysis was carried using D-FORM 3D software. The circular sheet blank was created with desired diameter and thickness. The conical top punch, bottom hollow die were modeled as shown in figure 1 with appropriate inner and outer radius and corner radius using UNIGRAPHICS software. The clearance between the punch and die was calculated using Eq. (4). The sheet blank was meshed with tetrahedral elements (Chennakesava, 2008). The modeling parameters of deep drawing process for 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.

The conical cup operation during different steps is shown in figure 2. The contact between blank and punch, die and blank holder were coupled as contact pair. The mechanical interaction between the contact surfaces was assumed to be frictional contact. The finite element analysis was chosen to find the effective stress, height of the cup, and damage of the cup. The finite element analysis was conceded to run using D-FORM 3D software according to the design of experiments for the purpose of validating the results of experimentation.

2. Results and Discussion

Two trials were carried out with mesh sizes for each experiment.

2.1 Influence of control factors on effective Stress

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. The percent contribution indicates that the factor A, blank thickness, all by itself contributes 43.72% towards the variation. The strain rate (D) contributes over a third (30.58%) of the total variation observed. B (temperature) supports 9.09% of variation, and C (coefficient of friction) gives 16.61% of variation on the effective stress.

The influence of control factors on the effective stress is shown figure 3. The effective stress of the conical cups having thickness of 1.2mm is found to be maximum of 252.23MPa as shown in figure 3(a). The effective stress of the conical cups is established to be minimum of 104.53MPa at temperature of 300^{o}C as shown in figure 3(b). The effective stress decreases as the coefficient of friction is increased as shown in figure 3(c). The effective stresses induced in the conical cups under different trial conditions are shown in figure 4. The effective stress is of 229.37MPa for the strain rate of 100. The effective stress is low for either below or above of 100 strain rate as shown in figure 3(d). The equivalent stresses induced in the trials 1 and 2 are 158.31MPa and 108. 27MPa respectively. The equivalent stresses induced in the trials 4 and 5 are 162.51MPa and 161.18MPa respectively. The equivalent stress induced in the trial 7 is 147.64MPa. The equivalent stresses induced in the trials 3 and 8 are 35.97MPa and 45.78MPa respectively. The conical cups are successful with trials 3 and 8. Even though the equivalent stress induced in the trial 9 is 86.23MPa, the conical cup is failed due to high temperature of 500^{o}C and low strain rate of 10.

2.2 Influence of control factors on height of conical cup

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. The percent contribution indicates that the factor D, strain rate, contributes half (51.25%) towards the variation. The coefficient of friction (C) contributes over a one-fourth (27.32%) of the total variation observed. The blank thickness (A) and temperature (B) offer 2.02% and 19.24% of variation on the cup height.

The influence of control factors on the cup height is shown figure 5. The cup height of the conical cups having thickness of 1.5mm is found to be maximum as shown in figure 5(a). The cup height of the conical cups is found to be maximum of 57.87mm at temperature of 300^{o}C as shown in figure 5(b). The cup height increases as the coefficient of friction is increased as shown in figure 5(c) except for the coefficient of friction less than 0.075. The cup height increases with an increase of strain rate as shown in figure 5(d) except for the strain rate less than 100. The height of the conical cups under different trial conditions are shown in figure 6. For the conical cups drawn with trials conditions of 1, 6 and 9, the cup heights are 26.53mm, 21.72mm and 29.60mm respectively. For the conical cups drawn with trials conditions of 2, 4 and 7, the cup heights are 34.92mm, 45.45mm and 42.56mm respectively. The height of the conical drawn is 61.99mm for trial condition of 5. For the conical cups drawn with trials conditions of 3 and 8, the cup heights are 76.09mm and 76.44mm respectively.

2.3 Influence of control factors on damage of conical cup

Table 5 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. The percent contribution indicates that the factor A, blank thickness, over half (47.16%) of the total variation. The coefficient of friction (C) contributes over a one-third (30.51%) of the total variation observed. B (temperature) assists 16.62% of variation, and D (strain rate) gives 5.66% of variation on the cup damage.

The effect of control factors on the damage of cup is shown in figure 7. The damage of cups is found to be high for the blank thickness of 1.2mm as shown in figure 7(a).). The damage of the cups is found to be low at temperature of 300^{o}C as shown in figure 7(b). The damage of cups is highest for the coefficient of friction of 0.075

as shown in figure 7(c). As the strain rate increases the damage also increases as shown in figure 7(d). The damage of the conical cups under different trial conditions are shown in figure 8. For the conical cups drawn with trials conditions of 1, 2 and 5, the damage of cups are 4.56%, 5.99% and 4.24% respectively. For the conical cups drawn with trials conditions of 4, 6 and 9, the damage of cups are 37.96%, 19.32%and 9.42% respectively. For the conical cups drawn with trials conditions of 3 and 8, the damage of cups are 0.24% and 0.07% respectively. The reasons for the damage of the conical cups are on account of room temperature (30^{o}C) drawing operations, high coefficient of friction (0.075) and high strain rate of 500. The other possible reasons for the damage of cups under trial conditions of 1, 2, 4, 5, 6 and 7 are owing to the small punch radius. The other possible reason for the damage of cup under trial condition of 9 is due to the small punch radius and die corner radius. The forming limit diagram, as shown in figure 9, shows that the cups drawn with all the trials have wrinkles. It is also observed from figure 4 that the von Mises stresses for the cups drawn under trials 1, 2, 4, 5, 6, 7 and 9 exceed the yield strength (80 MPa) of the material, thus these cups undergo the plastic deformation. For the remaining cups the von Mises stress is less than the yiled strength of the material.

3. Conclusions

The successful conical cups of 1mm blank thickness were obtained with operating conditions of 500^{o}C, temperature; 0.1, coefficient of friction; and 500, strain rate. The successful conical cups of 1.5mm blank thickness were obtained with operating conditions of 300^{o}C, temperature; 0.05, coefficient of friction; and 500, strain rate.

Acknowledgment

The authors wish to thank University Grants Commission (UGC), New Delhi, India for financial assisting this project.

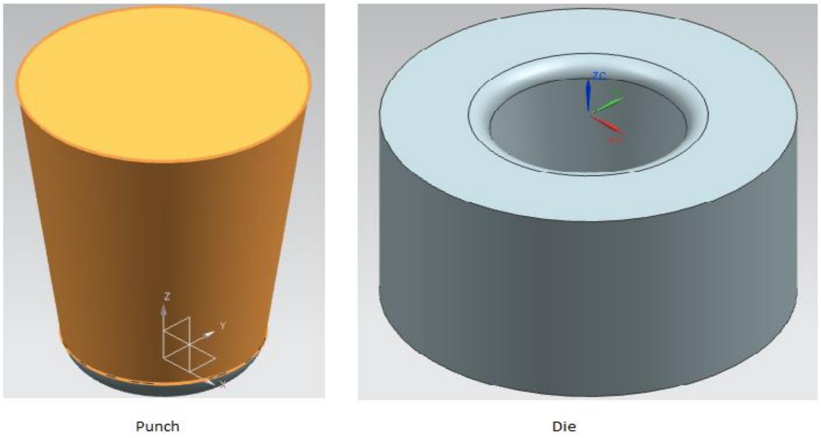

Figure 1: Punch and die

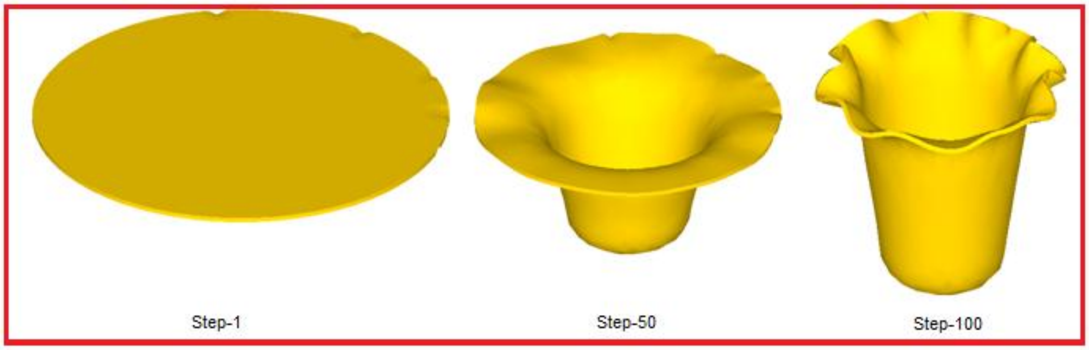

Figure 2: Conical cup drawing at different steps.

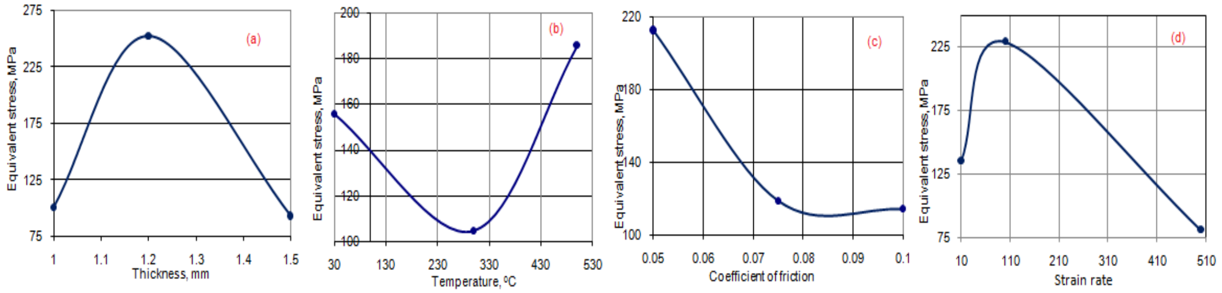

Figure 3: Effect of control factors on the effective stress.

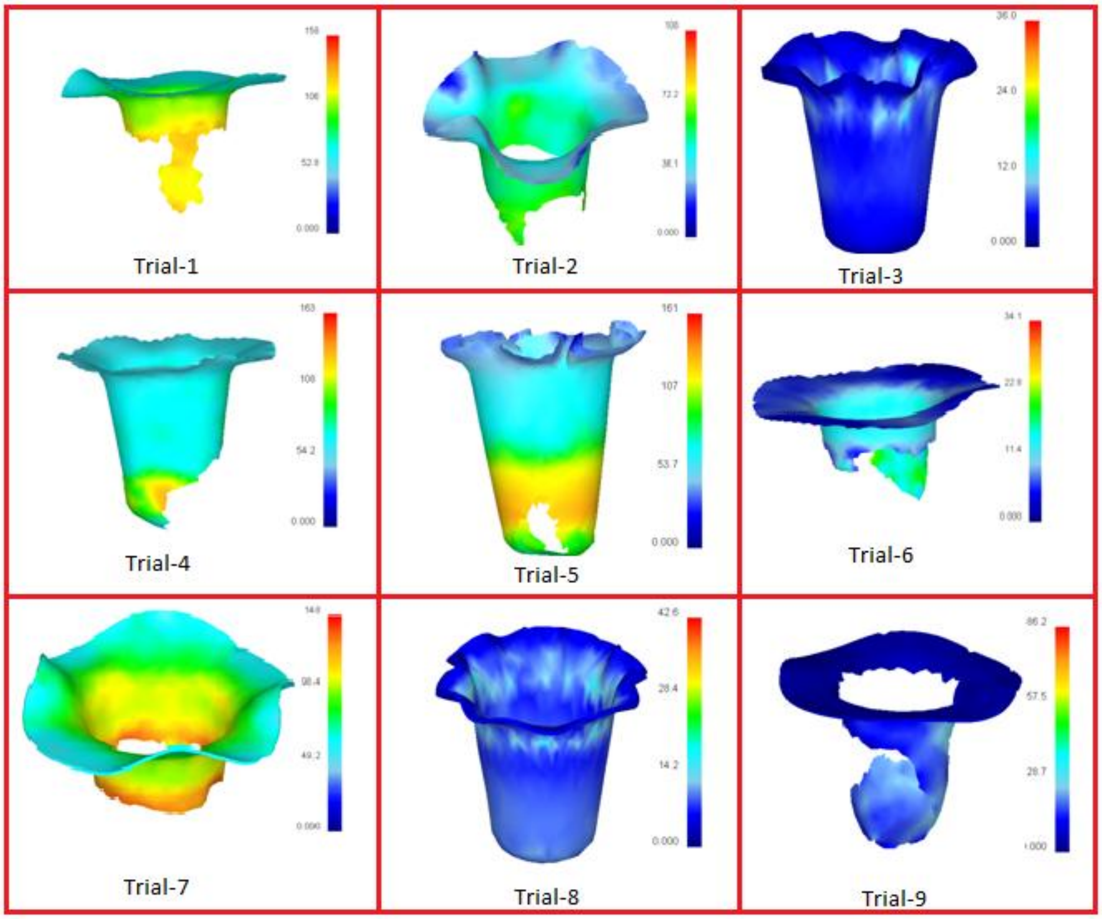

Figure 4: Effective stress in conical cups under different operating conditions.

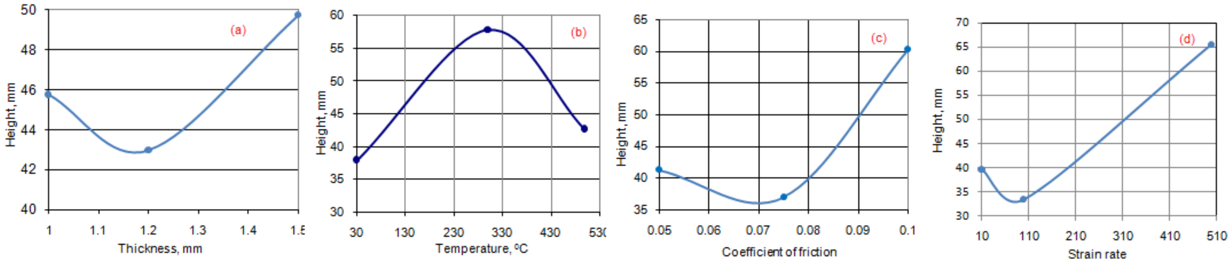

Figure 5: Effect of control factors on the cup height.

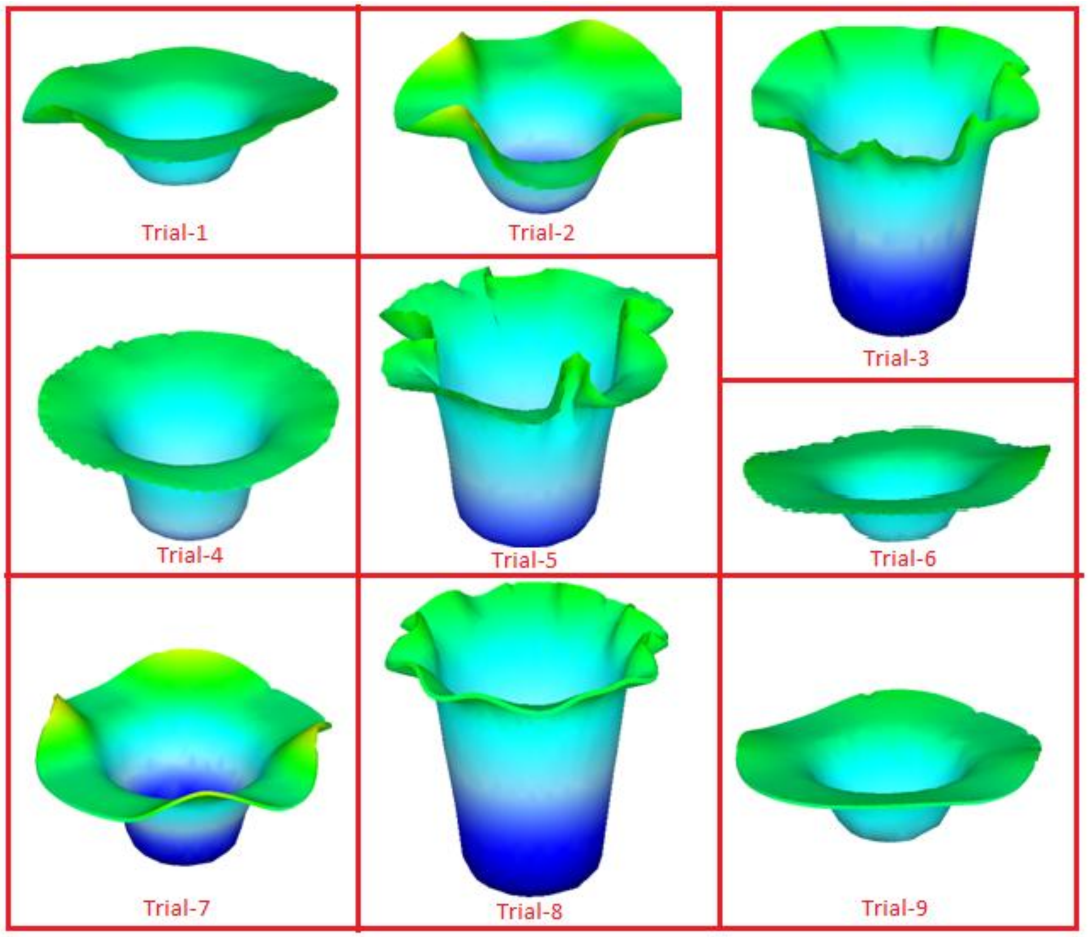

Figure 6: Heights of conical cups under different operating conditions.

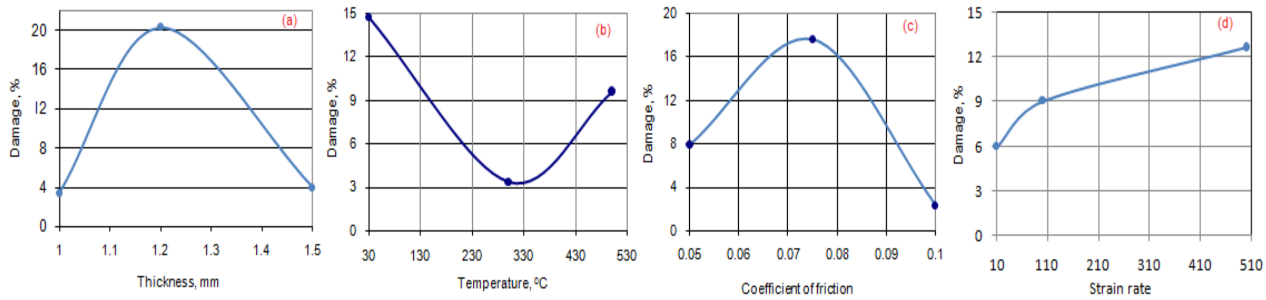

Figure 7: Effect of control factors on the damage of cup.

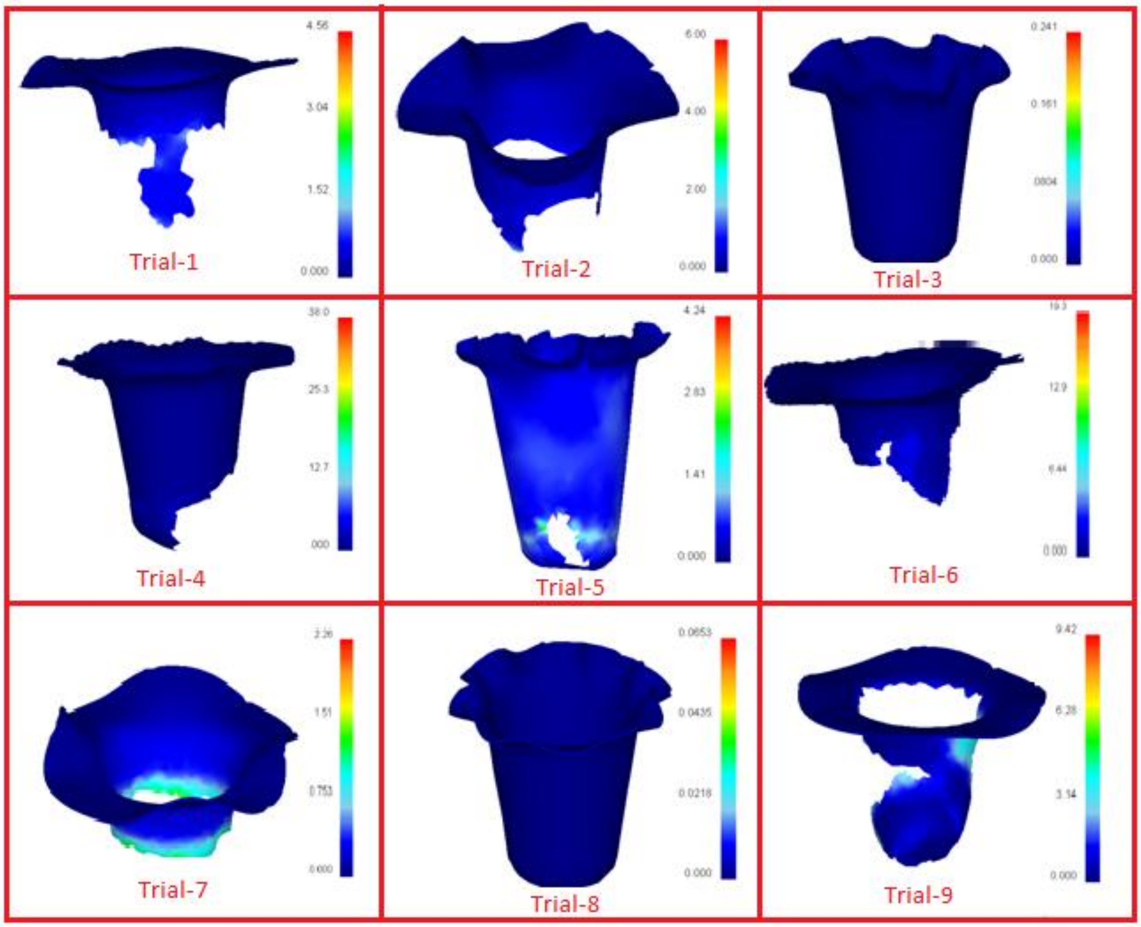

Figure 8: Damage in conical cups under different operating conditions.

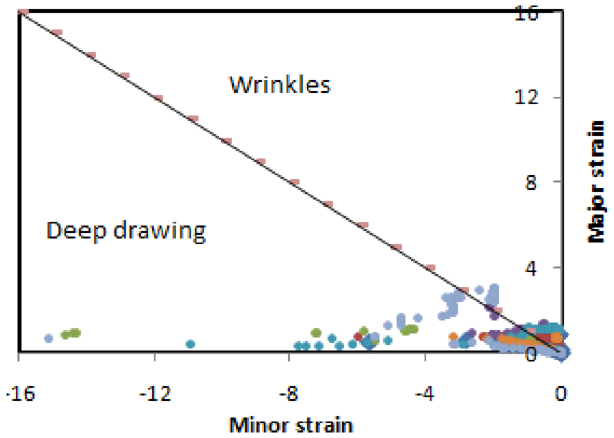

Figure 9: Forming limit diagram of cups.

Table 1: Control Parameters and Levels

Factor	Symbol	Level–1	Level–2	Level–3
Thickness, mm	A	1.00	1.20	1.50
Temperature, 0C	B	30	300	500
Coefficient of Friction	C	0.05	0.075	0.1
Strain rate	D	10	100	500

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

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	602.0581	1513.367	558.9238	96850.29	2	48425.15	35090.69	43.72
B	934.0912	627.1694	1113.088	20130.98	2	10065.49	7293.833	9.09
C	1274.748	713.5093	686.0915	36792.04	2	18396.02	13330.45	16.61
D	813.3955	1376.242	484.7112	67758.69	4	16939.67	12275.12	30.58
Error				9.649883	7	1.38	1	0
T	3624.293	4230.287	2842.814	221541.6	17			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.

Table 4: ANOVA summary of the conical cup heights.

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	274.58	257.98	298.36	137.32	2	68.66	96.70423	2.02
B	227.76	347.19	255.97	1298.92	2	649.46	914.7324	19.24
C	247.52	221.84	361.56	1843.69	2	921.85	1298.38	27.32
D	237.63	200.64	392.65	3459.3	4	864.82	1218.056	51.25
Error				4.9668	7	0.71	1	0.17
T	987.49	1027.65	1308.54	6744.197	17			100

Table 5: ANOVA summary of the conical cup damages.

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	20.49533	122.0285	23.63	1111.17	2	555.59	6173.222	47.16
B	88.50198	20.05429	57.5976	391.64	2	195.82	2175.778	16.62
C	47.19161	105.376	13.58627	718.88	2	359.44	3993.778	30.51
D	35.90361	54.33902	75.91124	133.65	4	33.41	371.2222	5.66
Error				0.63106	7	0.09	1	0.05
T	192.0925	301.7978	170.7251	2355.971	17			100

References

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.

Chennakesava Reddy, A. (2012). Evaluation of local thinning during cup drawing of gas cylinder steel using isotropic criteria, Int. J. of Eng. & Mat. Sci., 5:71-76.

Chennakesava Reddy, A. (2006). Finite element analysis of reverse superplastic blow forming of Ti-Al-4V alloy for optimized control of thickness variation using ABAQUS, J. Manuf. Eng., 1: 06-09.

Chennakesava Reddy, A. (2011). Optimization of Extrusion Process of Alloy 6063 Using Taguchi Technique, Int. J. of Multidisciplinary Res. & Adv. Eng., 3:173-190.

Chennakesava R Alavala, (2006). "FEM: Basic Concepts and Applications," PHI Learning Pvt. Ltd.

Chung, K., Barlat, F., and Brem, J.C. (1997). Blank shape design for a planar anisotropy sheet based on ideal forming design theory and FEM analysis, International Journal of Mechanical Sciences, 39:617–633.

Toros S, Ozturk F., and IlyasKacar. (2008). Review of warm forming of aluminum–magnesium alloys, J.Mater. Process. Technol., 207:1–12.