

IMPLICATION OF PROCESS PARAMETERS OF SINGLE POINT INCREMENTAL FORMING FOR CONICAL FRUSTUM CUPS FROM AA 1070 USING FEA

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Abstract

Simulation of single point incremental deep drawing process for AA1070 sheet with the help of finite element software and Taguchi experimental techniques. Blank thickness, step depth, tool radius and coefficient of friction are the process parameters for the conical frustum cups. It has been found that the tool radius and coefficient of friction are highly influential in controlling the formability of cups.

Keywords: Single Point Incremental Deep Drawing Process, AA1070, Conical Cups, Blank Thickness, Tool Radius, Step Depth, Coefficient of Friction, Conical Frustum Cups.

1. INTRODUCTION

Some classic sheet metal forming processes are stamping, drawing, and pressing. In these processes, commonly used in the industry, a blank of sheet metal is clamped around the edges, while the middle section is forced by a punch into a die to stretch the metal into the desired shape. For high volume production, the traditional deep drawing process is highly efficient since the production time of each part is considerably short and the high cost of the die and punch can be shared among a large number of parts. The conventional deep drawing was successfully implemented for several materials such as AA1050 alloy [1], AA1070 alloy [2], AA1080 alloy [3], AA1100 alloy [4], AA2014 alloy [5], AA2017 alloy [6], AA2024 alloy [7], AA2219 alloy [8], Ti-Al-4V alloy [9], EDD steel [10], gas cylinder steel [11]. However, for prototyping or small batch production, the manufacturing time, as well as the cost, of the die and punch is a large burden. Single point incremental forming does not require any dedicated dies or punches to form a complex shape and is therefore well adapted to rapid prototyping, as confirmed by several authors [16-18].

The present work was to predict formability of single point incremental deep drawing of AA1070 sheet for conical cups. The investigation was to optimize the process parameters such as blank thickness, step depth, coefficient of friction and tool radius. The design of experiments was carried out using Taguchi technique. The single point incremental deep drawing was implemented using the finite element analysis software code namely ABAQUS.

2. MATERIALS AND METHODS

In the present work, AA1070 sheet metal was used to make conical frustum cups. The levels chosen for the controllable

process parameters are summarized in table 1. Each of the process parameters was chosen at three levels. The orthogonal array, L9 was preferred to carry out experimental and finite element analysis (FEA). The obligation of parameters in the OA matrix is given in Table 2.

Table -1: Control parameters and levels

Factor	Symbol	Level-1	Level-2	Level-3
Blank thickness, mm	A	1.0	1.2	1.5
Step depth, mm	B	0.50	0.75	1.00
Tool radius, mm	C	4.0	5.0	6.0
Coefficient of friction	D	0.05	0.10	0.15

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

The finite element modeling and analysis was established using ABAQUS software. The rectangular sheet blank was created with desired diameter and thickness using CAD tools. The sheet was meshed with S4R shell elements [15] as shown in fig.1. The cylindrical single point tool was also modeled with appropriate inner and outer radius and corner radius using CAD tools (Fig. 1). The mechanical interface

between the contact surfaces was implicated to be frictional contact and modeled as Coulomb’s friction model [19]. In the present work, profile tool path technique was used as shown in fig.2. In profile tool path which was generated using CAD/CAM software [20], tool moves in one plane till it reaches to its initial point. Thereafter it moves vertically downward direction by specified step depth. After reaching to next plane tool continues its motion in the same direction as that of earlier cycle. This process continues till the complete geometry is formed.

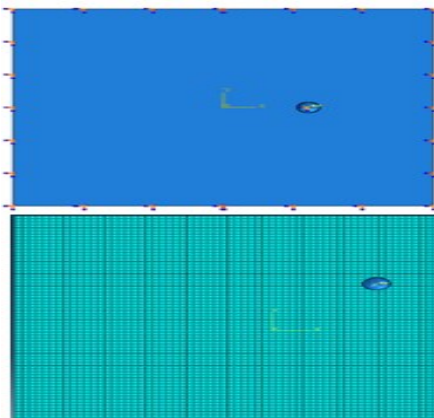


Fig -1: Modeling of sheet and single point tool.

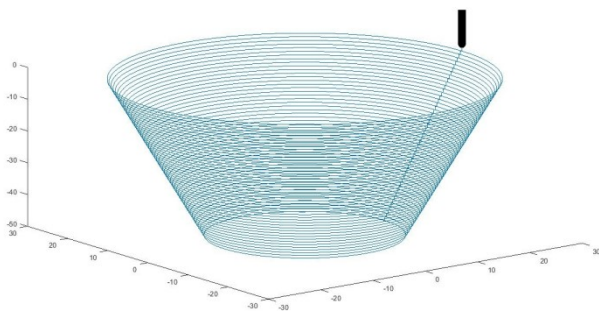


Fig -2: Profile tool path

3. RESULTS AND DISCUSSION

In the present work, the significance of process parameters should have at least 90% of confidence. Hence, the process parameters which had an absolute Fisher’s ratio larger than 3.4579 were believed to influence the average value for the forming characteristic under null hypothesis, parameters which had Fisher’s ratio less than 3.457 were believed to have no effect on the average.

3.1 Effect of Process Parameters on Effective Stress

In table -3, the percent contribution indicates that the major influences are of tool radius, coefficient of friction and step depth. Fig-3(a) presents the effective stress induced in AA1070 alloy during incremental deep drawing process as a function of blank thickness. The effective stresses was increased linearly with the sheet thickness. The effective stress was increased with the increase of step depth initially from 0.50 to 0.75 mm and then it was decreased from 0.75 to 1.0 mm (Fig-3b). The effective stress was low for tool radius of 5 mm as shown in Fig-3(c). Fig-3(d) describes the

effective stress as a function of coefficient of friction. The effective stress was decreased with the increase of coefficient of friction. The principal stresses S_{11} , S_{22} and shear stress S_{12} are shown in Figs- 4, 5 and 6, respectively.

Table -3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	604.9	606.3	610.8	6.32	1	6.33	844.00	7.16
B	603.5	611.2	607.3	9.86	1	9.87	1316.00	11.17
C	606.4	600	615.6	40.98	1	40.99	5465.33	46.43
D	613.8	608	600.2	31.03	1	31.04	4138.66	35.16
e				0.03	4	0.008	1.00	0
T	2428.6	2425.5	2433.9	88.23	8			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.

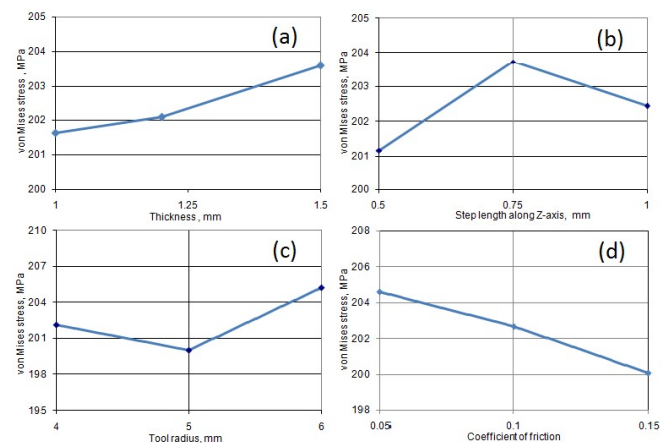


Fig -3: Effect of process parameters on von effective stress.

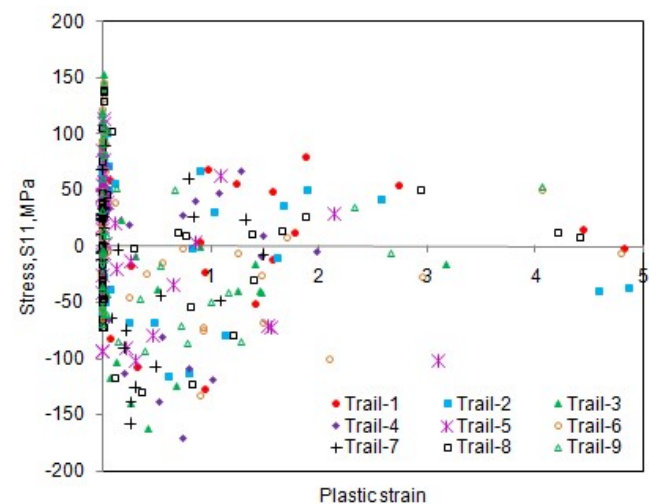


Fig -4: Effect of process parameters on S_{11} .

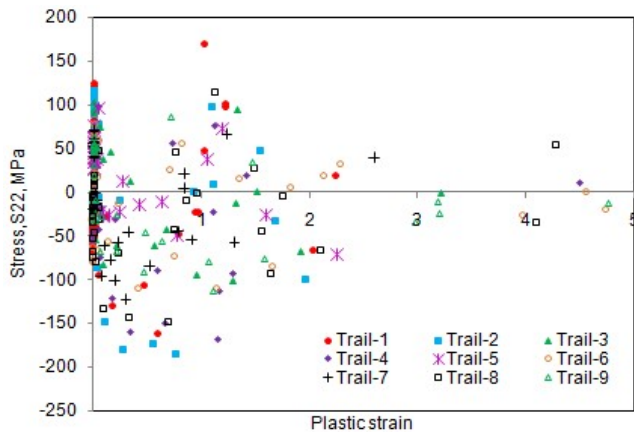


Fig- 5: Effect of process parameters on S_{22} .

The compressive stresses induced in the blank sheet were higher in number than the tensile stresses. The plastic deformation was compressive for the strain less than 2.0. The shear stress developed in the blank sheet is nearly 40% to 50% of S_{11} or S_{22} .

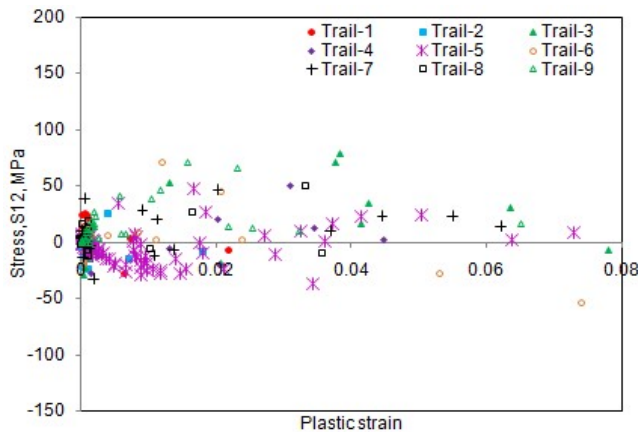


Fig- 6: Effect of process parameters on S_{12} .

3.2 Effect of Process Parameters On Strain Rate

In table -4, the percent contributions in the decreasing order of influence are 47.20%, 34.35%, 14.46% and 3.99%, respectively, for tool radius, sheet thickness, step depth and coefficient of friction. The strain rate was low for the sheet thickness of 1.2 mm and step depth of 0.75 mm (Fig -7a and 7b). The strain rate was increased with increase of tool radius (Fig -7c). The effect of coefficient of friction on strain rate was very minimal. The values of strain rate show severity of plastic deformation during the SPIF deep drawing of AA1070.

Table -4: ANOVA summary of the strain rate

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	58.56	35.98	44.22	87.04	1	87.04	91621.05	34.35
B	54.45	40.02	44.29	36.64	1	36.64	38568.42	14.46
C	30.97	51.84	55.95	119.61	1	119.61	125905.26	47.2
D	43.35	50.68	44.73	10.11	1	10.11	10642.10	3.99
e				-0.004	4	-0.001	1.00	0
T	187.33	178.52	189.19	253.4	8			100

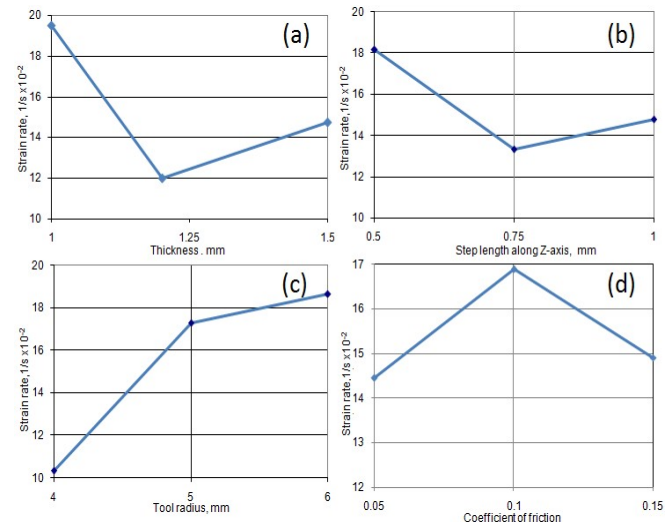


Fig-7: Effect of process parameters on strain rate.

3.3 Effect of Process Parameters On Thickness Reduction

In table -5, the percent contribution indicates that the parameter C, tool radius, all by itself contributes the most towards the variation in the thickness reduction: almost 74.38%. The sheet thickness (A) controls 14.09% of the total variation observed in thickness reduction. The step depth (B) and coefficient of friction (D) had negligible influence on the reduction of sheet thickness. As seen from Fig -8, the reduction of thickness was increased with increase of sheet thickness (Fig -8a), with increase of step depth (Fig -8b) and with increase of tool radius (Fig -8c).

Table -5: ANOVA summary of the thickness reduction

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	254.03	257.58	257.8	2.97	1	2.98	752.31	14.09
B	255.167	256.29	257.95	1.29	1	1.3	328.19	6.14
C	250.95	258.39	260.06	15.70	1	15.71	3966.05	74.38
D	256.46	255.18	257.77	1.11	1	1.11	280.22	5.24
e				0.016	4	0.004	1.00	0
T	1016.61	1027.45	1033.58	21.1	8			100

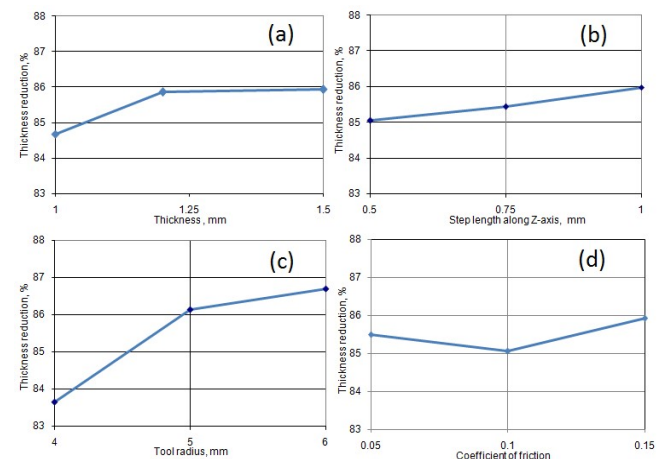


Fig-8: Effect of process parameters on thickness reduction.

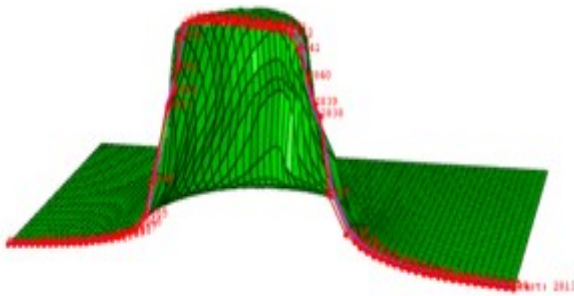


Fig- 9: Location of thickness reduction in the deformed cup.

The variation of thickness was considered at the center-line of the deformed cup as shown in Fig -9. As observed from Fig -10, the majority of thickness reduction takes place in the walls of the cup but not in the flange or bottom of the cup. The elements located at the mid regions of the walls are elongated higher than those present at the top and bottom of the cup walls.

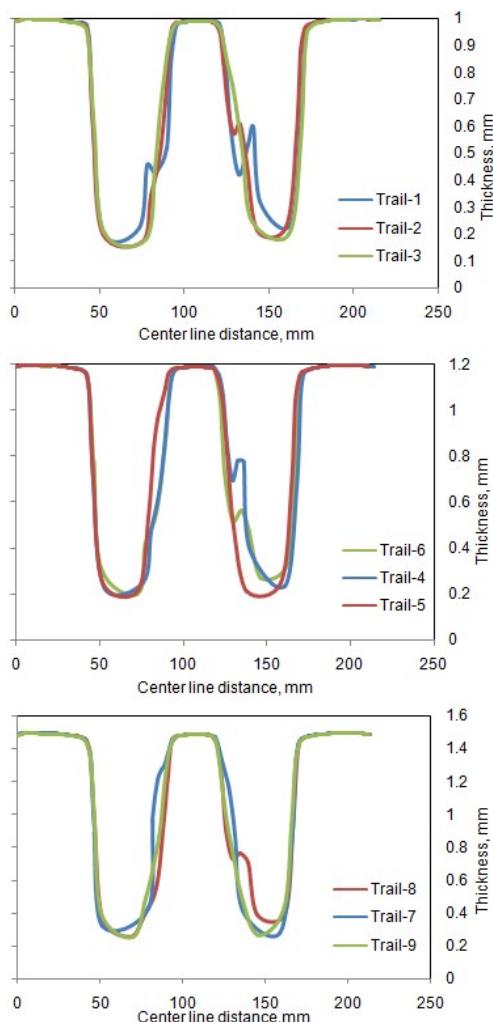


Fig- 10: Effect of process parameters on thickness reduction.

3.4 Formability of SPI Deep Drawing Process

The formability diagrams of the cups are shown in Figs -11, 12 and 13. Tension is highly dominated during the formation of blank sheet. For the trials 1, 2 and 3, the von

Mises stresses are respectively, 202 MPa, 201 MPa and 202 MPa. For the trials 4, 5 and 6, the von Mises stresses are, respectively, 196 MPa, 208 MPa and 202 MPa. For the trials 7, 8 and 9, the von Mises stresses are, respectively, 205 MPa, 202 MPa and 203 MPa. The safe tensile and compressive strain should be less than 0.4 to prevent the rupture in the cups. The formability of 7th trial was excellent as compared to the rest of the trials.

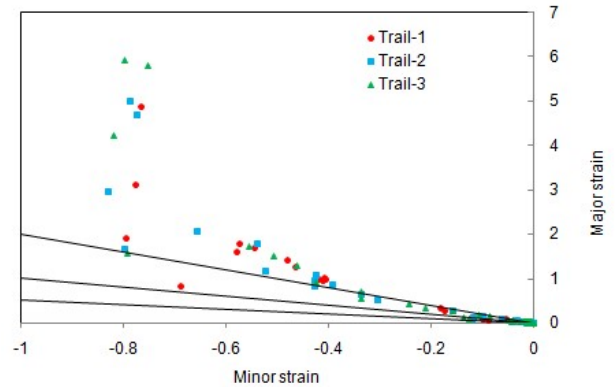


Fig -11: Forming limit diagram for trials 1, 2, 3.

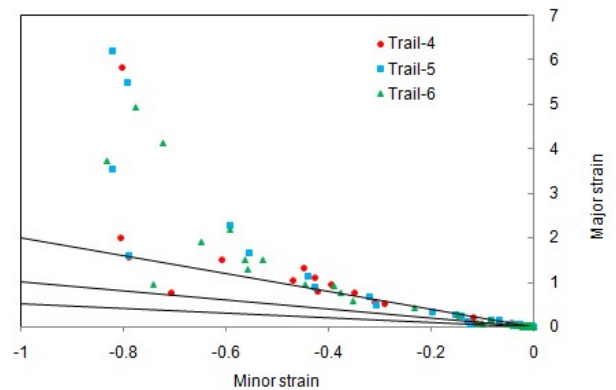


Fig -12: Forming limit diagram for trials 4, 5, 6.

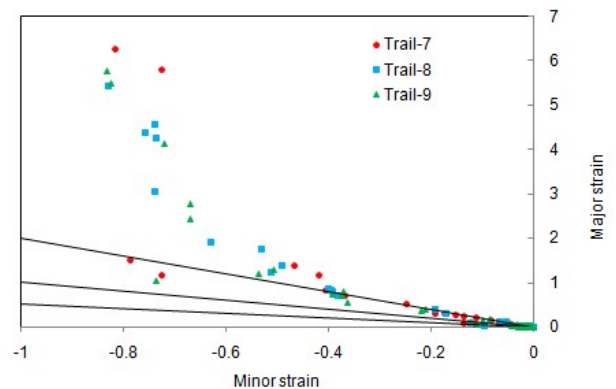


Fig-13: Forming limit diagram for trials 7, 8, 9.

It is observed from Fig -14 that the high stresses are induced at the bottom corners, along the edges and walls of the cups. In all the cases the von Mises stress was higher than the ultimate tensile strength of the sheet material. When the stress induced in the sheet was higher than the tensile strength there is likelihood of fracture of cups due to uniaxial tension in deep drawing process [21-23].

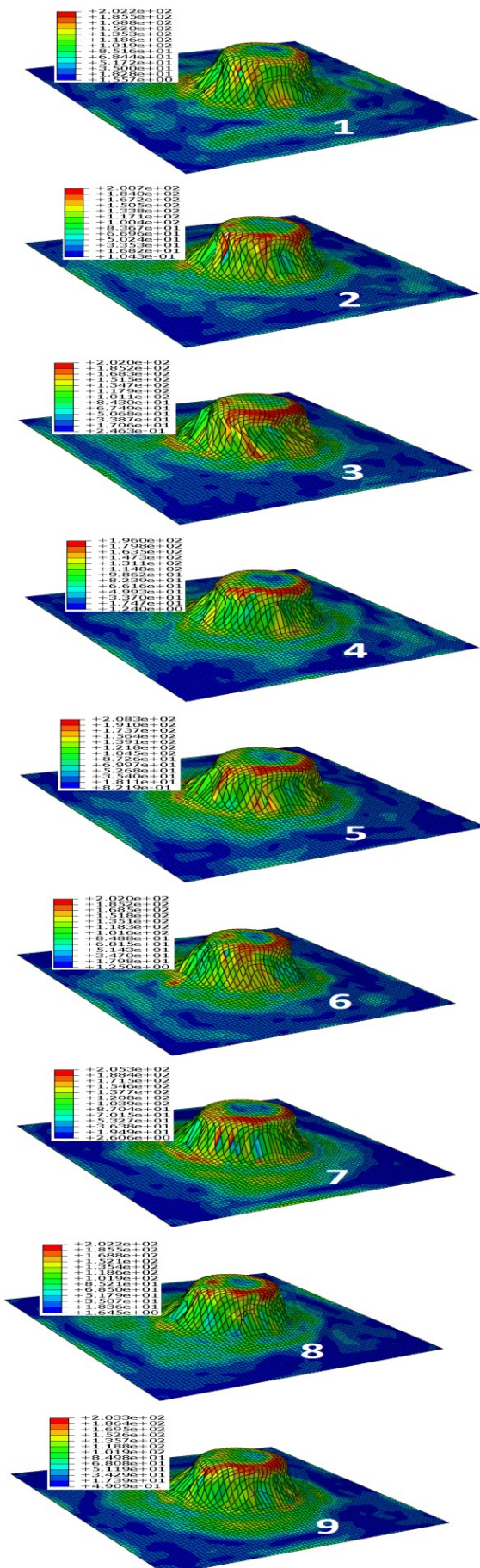


Fig -14: Raster images of von Mises stress in the cups

4. CONCLUSION

In the present work, the finite element analysis and Taguchi techniques are successfully implemented to simulate single point incremental deep drawing process for conical cups from AA1070 alloy sheet. The major parameters, which influence the formability of conical cups, are the tool radius and coefficient of friction.

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