International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296

Evaluation of Process Parameters of Conical Cups in Incremental Deep Drawing Process

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Abstract: ***The aim of the present work was to evaluate the effect process parameters of conical cups made of AA7075 alloy in incremental deep drawing process. The design procedure for the finite element analysis was carried out as per Taguchi's techniques using ABAQUS software code. The friction coefficient of incremental deep drawing was the critical process parameter influencing the effective stress induced during the formation of conical cups. von Mises stresses induced in the cups are within the limit of ultimate strength of AA7075.The sheet thickness had influenced the reduction of sheet thickness during the cup formation to the extent of 83.78%.***

Keywords: Conicalcups, AA7075 alloy, finite element analysis, single-point incremental forming process.

1. Introduction

The need of manufacturing industry lead to many developments in sheet forming techniques among which, incremental sheet forming process emerged from the development of deep drawing process which limits to simple shapes. In incremental sheet forming (figure 1) the strains achieved are more than in any other conventional process. In incremental sheet forming the sheet is deformed by series of small incremental deformations using a round tipped tool. Sheet undergoes localized plastic deformation beneath the tool in predetermined path till the final part is obtained.

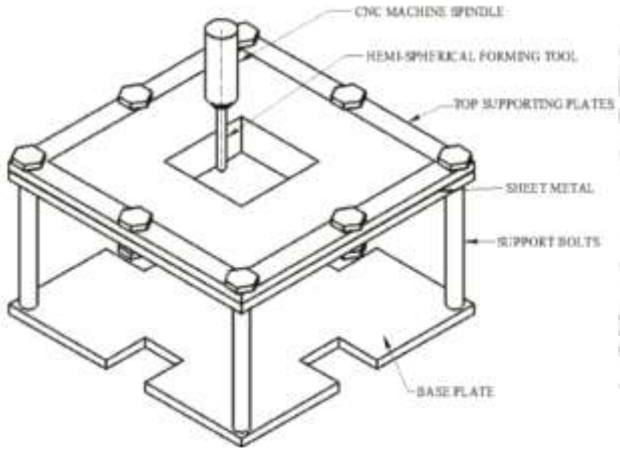

Figure 1: Single point incremental forming process.

In a series of research on deep drawing process, a rich investigation have been carried out on warm deep drawing process to improve the super plastic properties of materials such as AA1050 alloy [1], [2], [3], [4], [5,] [6], AA2014 alloy [7], AA2017 alloy [8], AA2024 alloy [9], AA2219 alloy [10], AA2618 alloy [11], AA3003 alloy [12], AA5052 alloy [13], AA5049 alloy [14], AA5052 alloy [15], AA6061 alloy [16], Ti-Al-4V alloy [17], EDD steel [18], gas cylinder steel [19].As the days passed by, traditional methods have been extended to incremental sheet forming to fabricate variety of cups through plastic deformation of sheet material with and without dies.

The effect of step depth, feed rate and diameter of the tool on maximum wall angle were studied in cold incremental sheet forming of titanium sheet [20]. Peteck et al. [21] observed that for conical tool path at smaller wall angles (below 50°) the deformation peak could not be seen. They also observed that deformation of sheet increases with wall angle. They observed that maximal attainable wall angle by forming of the cone-shaped part prior to the crack occurrence is 70°.Tisza et al. [22] stated that due to the special incremental nature of deformation process, significantly higher deformation can be achieved compared to conventional sheet metal forming processes and it also follows from its unique deformation characteristics that materials with lower formability in conventional forming may be manufactured in an economic way. Nagarajan et al. [23], investigated complex sheet prototype forming of an industrial component on AA 7075. They observed that thinning was higher at the steeper wall angle region from both experimental and finite element analysis. The plastic instability caused by the thinning of the material may be the reason for the fracture in AA7075.

The aim of the current work was to estimate the formability of AA7075 alloy to fabricate conical cups using single point incremental deep drawing process. Finite element analysis (FEA) was implemented to estimate various process parameters of deep drawing process.

2. Material and methods

AA7075 alloy sheet was used in this study of single point incremental sheet forming to fabricate conical cups.The composition of AA7075 alloy is given in Table 1. The mechanical properties of AA7075 alloy are given in Table 2.

Table 1: Chemical composition of AA7075 alloy

Element	% weight
Aluminium	90
Copper	1.6
Magnesium	2.5
Zinc	5.6

Table 2: Mechanical properties of AA7075 alloy

Material	AA 7075
Density	2810 Kg/m^3
Yield Strength	503 MPa
Ultimate Tensile strength	572 MPa
Poisson's Ratio	0.33
Modulus of Elasticity	71.7 GPa

Plasticity data was obtained by conducting tensile test of AA7075 alloy, from which the data is represented in figure 2. The obtained values were taken as material properties-plasticity for simulation of SPIF process.

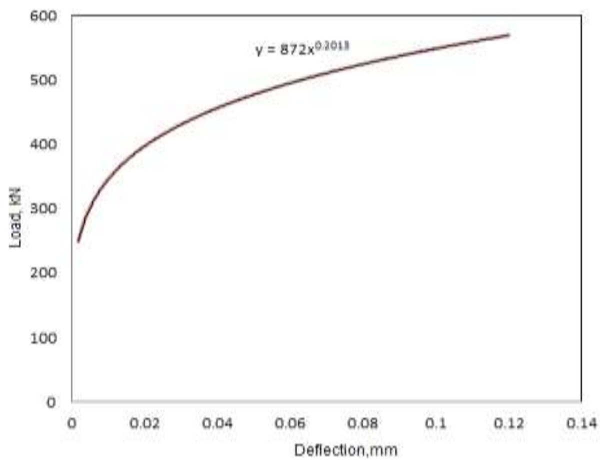

Figure2: Load vs. Deflection of AA7075 alloy.

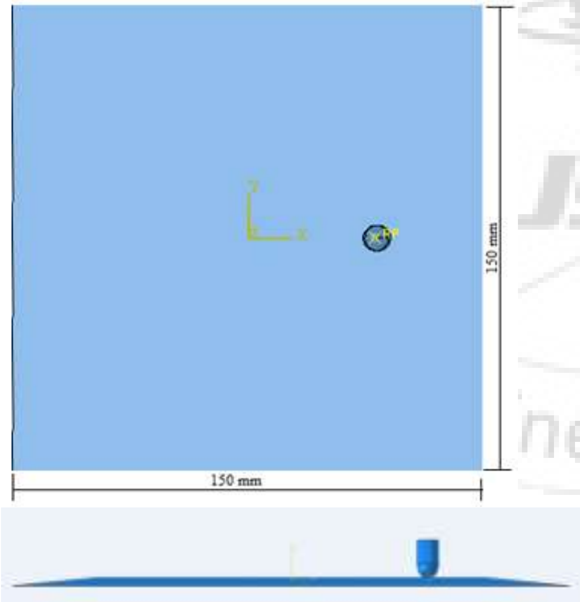

Figure3: Modeled sheet and Tool.

The finite element method (FEM) has become an important tool for the numerical solutions of engineering problems. It is the piecewise approximation of object where the object is divided into number of small elements, the integration of all such small elemental analysis finally give the solutions [23]. The finite element modelling of SPIF process was carried out using ABAQUS (6.14) software to fabricate conical cups. In geometric modelling a square sheet of dimensions 150 mm×150 mm and tool of cylindrical rod with hemispherical end as mentioned in Table 3. The sheet and tool were modelled as deformable, analytical rigid body respectively and assembled together as shown in figure 3. In order to reduce the complexity of the model the other parts like tool holder, work holder were simulated by boundary conditions, hence this is a simplified model. Tool was given a reference point for governing tool motion. Contact was the interaction between tool and the sheet. Since the sheet undergoes the localized deformation at the contact, modelling of contact should be correct. The contact was modelled as frictional contact. Coefficient of friction was considered as per design of experiments in Table 3.

Meshing is the process of discretizing the component. Here the sheet was meshed as shown in figure 4 with quad dominated S4R shell elements [24]. Element size has impact on computational time and results. Fine mesh gives the good results with greater computational time. Coarse mesh leads to inconsistent results, penetration and convergence problems during simulation process. A fine mesh of 2mm was generated for consistent results.

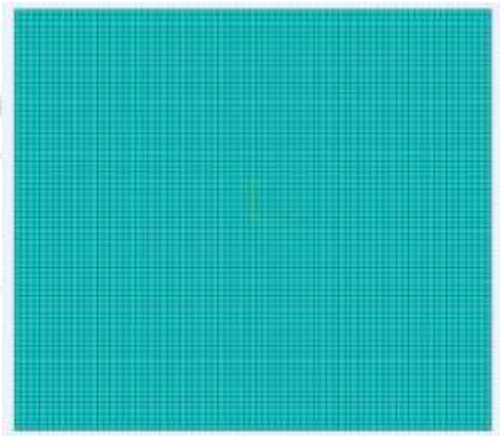

Figure 4: Meshed sheet.

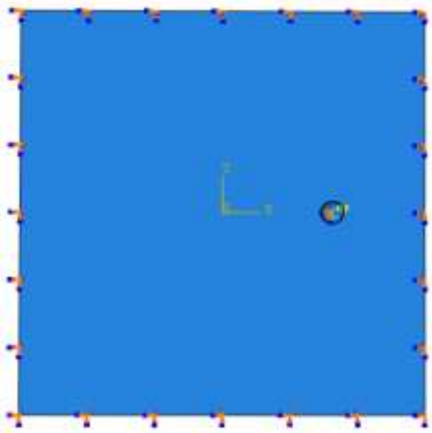

Figure 5: Boundary Conditions.

A simplified model was created by eliminating tool holder and work holder, but they are simulated by the boundary conditions. Edges of the sheet are fixed and tool was given four degrees of freedom, three translatory along x, y, z directions and one rotational around tool axis as shown in figure 5. The motion of the tool was controlled by amplitude data in smooth step form. The tool path generated by the CAM package [25] for conical cup is as shown in the figure 6.

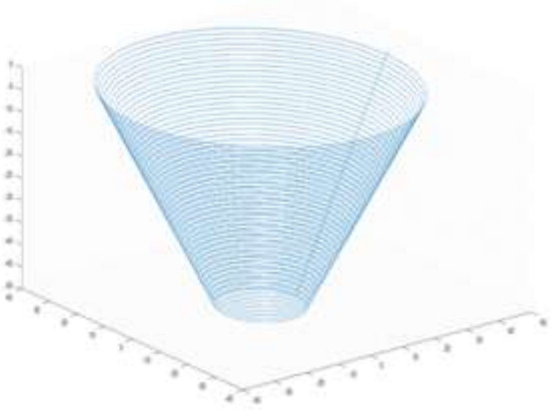

Figure 6: Tool path profile.

The finite element analysis was carried out as per Taguchi's techniques. The levels of process parameters are given in Table 3. The assignment of process parameters is given in Table 4.

Table 3: Process Parameters and levels

Factor	Symbol	Level-1	Level-2	Level-3
Sheet thickness, (mm)	A	0.8	1	1.2
Step depth, (mm)	B	0.5	0.75	1
Tool radius, (mm)	C	4	6	8
Coefficient of friction	D	0.05	0.1	0.15

Table 4: Orthogonal array (L9) and control parameters

Trial 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

3. Results and Discussion

The maximum equivalent stresses induced in the conical cupsare 364.649, 275.148, 273.417, 261.591, 316.912, 292.078, 321.139, 284.677 and 369.817 MPa for trials 1 to 9 (figures 7-9) respectively. Maximum equivalent stress is observed in the walls of cup of trial 9as shown in figure 8. Corresponding maximum equivalent plastic strain obtained for trials 1 to 9 are3.0729, 2.614, 2.6766, 3.1115, 2.707, 2.972, 3.217, 3.275 and 2.825; it is observed maximum equivalent plastic strain in the walls of cup 8.

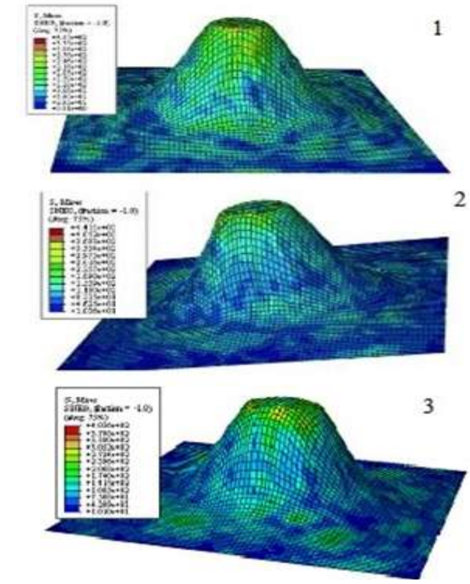

Figure 7: Equivalent stress induced in sheet thickness of 0.8 mm.

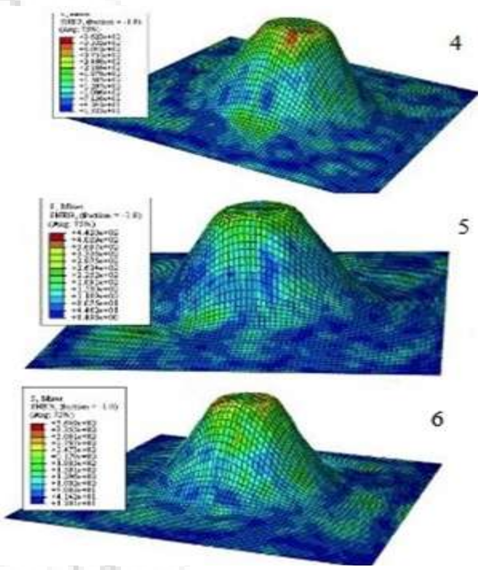

Figure 8: Equivalent stress induced in sheet thickness of 1.0 mm.

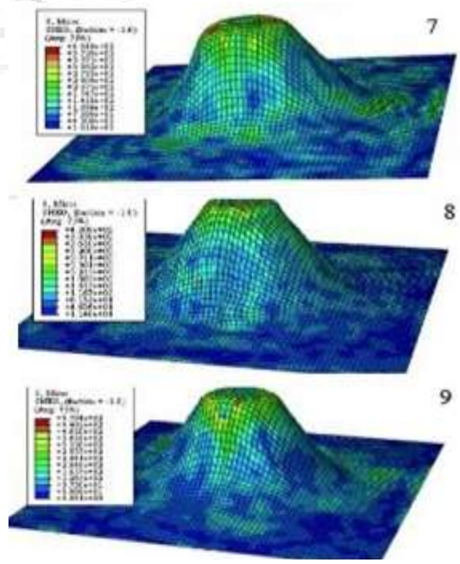

Figure 9: Equivalent stress induced in sheet thickness of 1.2 mm.

The strain variation along the wall of conical cup at respective step depths is shown in figure 10. The friction coefficient(D) of incremental deep drawing has maximum influence of 76% on the plastic deformation of cups as given in Table 5. The sheet thickness (A) has also influenced to the extent of 15%. Rest of the process parameters could not influence the plastic deformation of the conical cups.

The variation of sheet thickness along the walls of the conical cup is shown in figure 11. It is also observed that the reduction in wall thickness of the cups is greatly influenced by the sheet thickness (A) of incremental deep drawing process to the extent of 83.78% as given in Table 6. The other process parameters had no effect on the reduction of sheet thickness. Unexpectedly the error component is of 16.22% for which the reason was unknown.

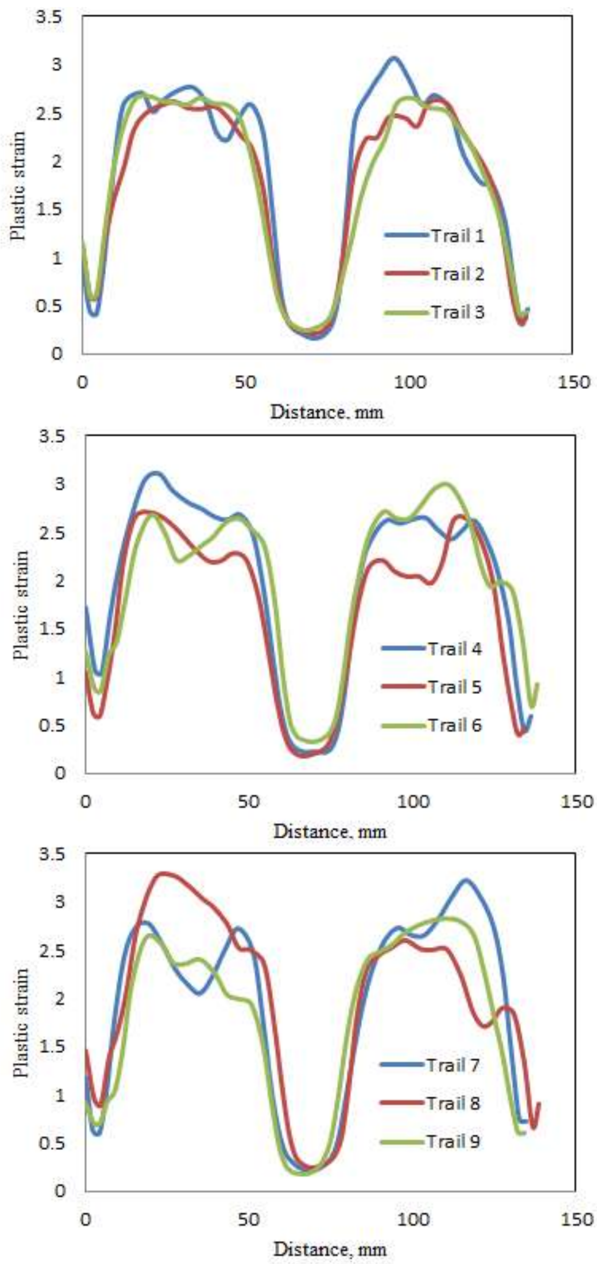

Figure 10: Plastic strain induced along the walls of cup.

The conical and its cut-section is shown in figure 12.The stress-based formability diagrams of the conical cups are shown in figures 13(a), 13(b) and 13(c). The formability of the conical cups is dominated by the compressive stress. The lowest and highest von Mises stresses are respectively 261.591 and 369.817 MPa for the trails 4 and 9 of the conical cups. The ultimate strength of AA7075 alloy is 572 MPa. All the trial conditions are in safe limits of AA7075 alloy.

Table 5: ANOVA analysis of equivalent stress

Factor	S1	S2	S3	SS	v	V	F	P
A	913	871	976	1861	1	1861	7146839	15
B	947	877	935	952	1	952	3655348	8
C	941	907	911	237	1	237	910755	2
D	1051	888	820	9441	1	9441	36255486	76
E				0	4	0	0	0
T	3853	3542	3642	12491	8			100

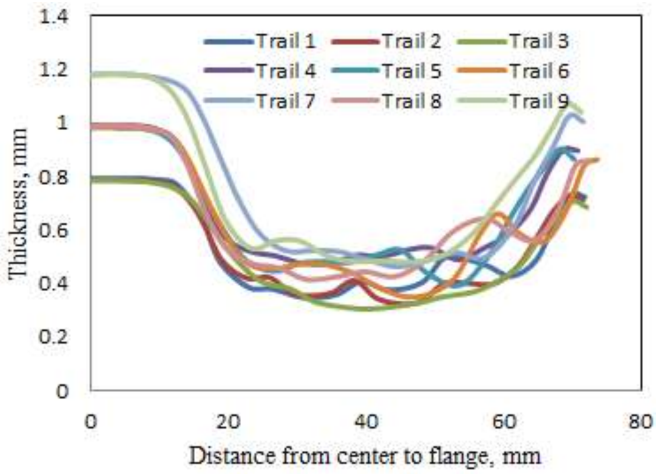

Figure 11: Variation of sheet thickness along the walls of cup

Table 6: ANOVA analysis of thickness reduction

Factor	S1	S2	S3	SS	v	V	F	P
A	0.99	1.22	1.31	0.02	1	0.02	3.26	83.78
B	1.21	1.13	1.18	0.00	1	-	-	0.00
C	1.13	1.20	1.20	0.00	1	-	-	0.00
D	1.26	1.17	1.09	0.01	1	-	-	0.00
e				-0.01	7	0.00	0.00	16.22
T	4.59	4.72	4.78	0.02	8			100.00

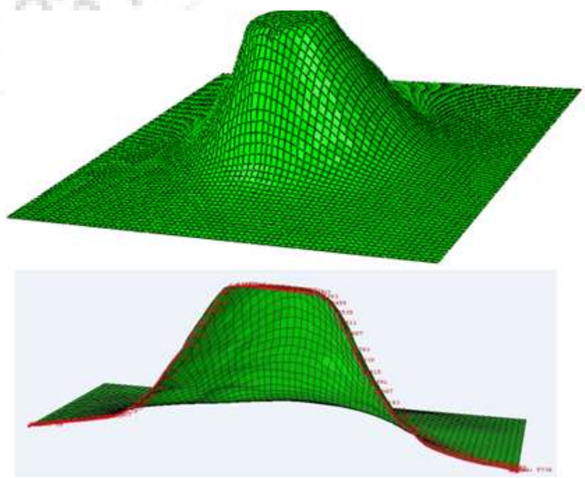

Figure 12: Formation of conical cup.

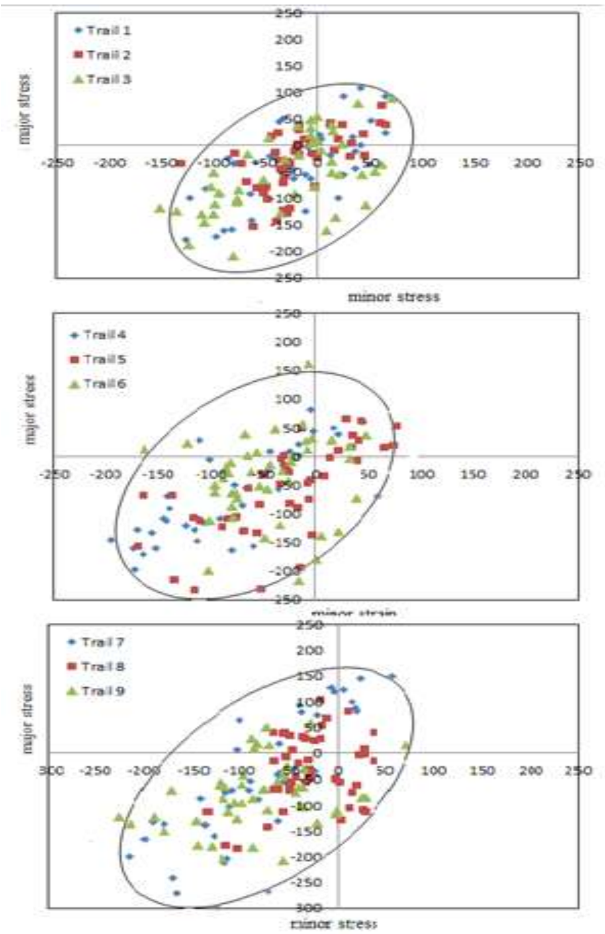

Figure 13: Formability of conical cups.

4. Conclusions

The finite element analysis was carried out as per Taguchi's techniques using ABAQUS software code.The friction coefficient (D) of incremental deep drawing had maximum influence on the effective stress induced in theconicalcups to the extent of 76%. The sheet thickness had only influenced the reduction of sheet thickness during the conical cup formation. The lowest and highest von Mises stresses respectively 261.591 and 369.817 MPa for the trails 4 and 9 of the conical cups are within the limits of the ultimate strength of AA7075(572 MPa).

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