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Micromechanical Plastic Behavior of AA5454 Alloy used for Fabrication of Pyramidal Cups

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Abstract: ***The present work was to estimate plastic behavior ofAA5454 alloy to fabricate pyramidal cups. The design procedure for the finite element analysis was carried out as per Taguchi's techniques using ABAQUS software code. The step depth of incremental deep drawing was the critical process parameter influencing the plastic deformation of pyramidal cups. von Mises stresses induced in the cups are within the range of 240 – 300 MPa which is the limits of ultimate strength of AA5454.***

Keywords: Pyramidal cups, finite element analysis, single-point incremental forming process

1. Introduction

The conventional deep drawing process does not permit the production of complex shapes for various applications of industries. There is a need for process which reduces the processing time and can also be used for production in small lots. Single Point Incremental Forming(SPIF) process (figure 1) serves all the above needs has emerged as the fast-growing process over the decade.In incremental sheet forming the sheet is deformed by series of small incremental deformations using a hemispherical tool. Sheet undergoes localized plastic deformation in predetermined path till the final part is obtained.

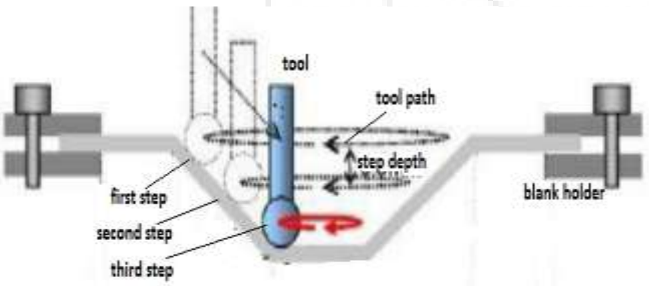

Figure 1: Single point incremental forming process.

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].Kopac et al. [20] have given importance to the tool movement along the tool path, i.e. tool path from center to the end of the sheet has good effect and also concluded that the optimal inclination of walls on the product are 45^0, bigger angles may cause errors, cracks, and product failure. Kim and Park et al.[21] identified that the sheet metals deform by shear-dominant deformation. The formability differs according to the direction of the tool movement because of theplane anisotropy. Silva et al. [22] constructed a closed-form analytical model that is capable of dealing with the fundamentals of single-point incremental forming (SPIF) and explaining the experimental and numerical results published in the literature over the past couple of years. Osman and Engler[23] have studied on the effect of homogenisation conditions on recrystallisation in the AA5454 alloy. Results indicate that the conditions of homogenisation heat treatment and roughing rolling are critical for the generation of a suitablerecrystallised microstructure in AA 5454 hot strip.

The present work was intended to investigate theformability of AA5454 alloy to fabricate pyramidal 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

AA5454 alloy sheet was used in this study of single point incremental sheet forming to fabricate pyramidal cups.The composition of AA5454 alloy is given in Table 1. The mechanical properties of AA5454 alloy are given in Table 2.

Table 1: Chemical composition of AA5454 alloy

Element	% Weight
Aluminium	96.3
Magnesium	2.7
Manganese	0.8
Chromium	0.12

Table 2: Mechanical properties of AA 5454 alloy

Density	2690 Kg/m^3
Yield Strength	303 MPa
Poisson's Ratio	0.33
Modulus of Elasticity	70.3 GPa

Plasticity data was obtained by conducting tensile test of AA 5454 alloy, from which the data is represented in figure 2. The obtained values were taken as material properties-plasticity for simulation of SPIF process.

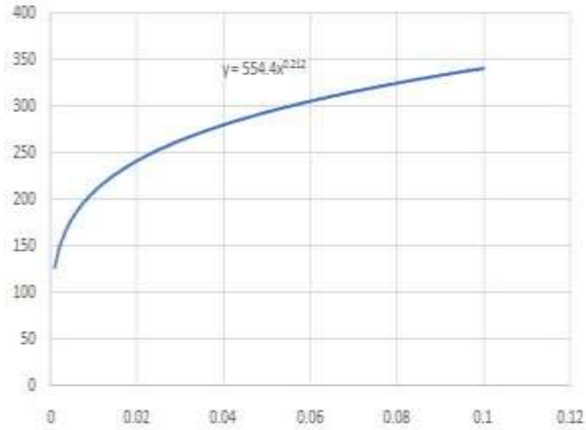

Figure 2: Load vs. Deflection of AA 5454 alloy.

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 [24]. The finite element modelling of SPIF process was carried out using ABAQUS (6.14) software to fabricate pyramidal cups. In geometric modelling a square sheet of dimensions 150 mm×150 mm and tool of cylindrical rod having hemispherical end was created 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 at different levels as per design of experiments in Table 3.

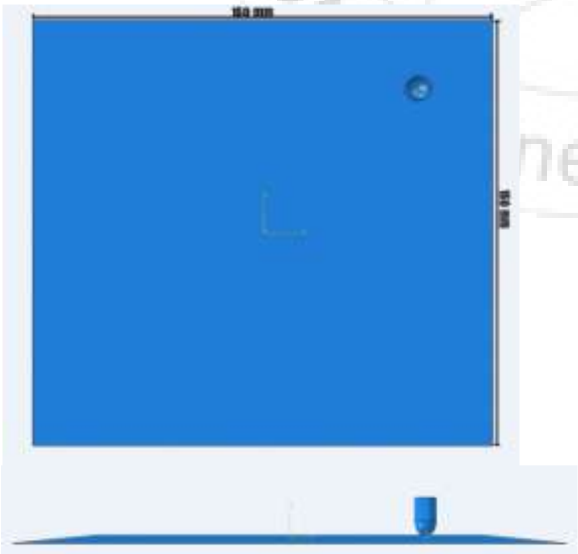

Figure 3: Modeled sheet and Tool.

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.

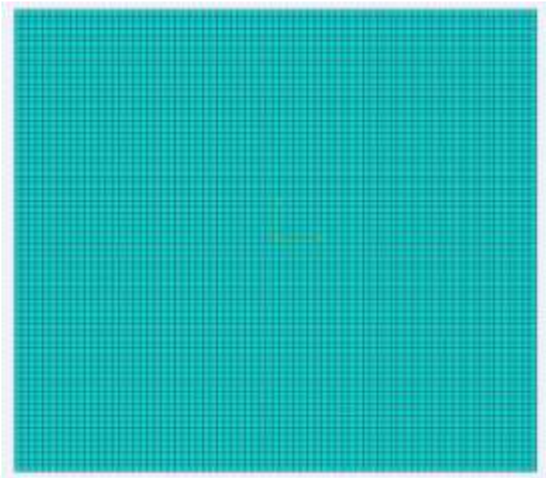

Figure 4: Meshed sheet.

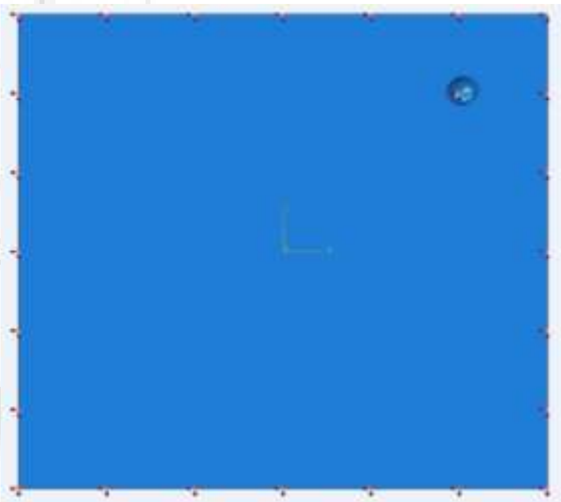

Figure 5: Boundary Conditions.

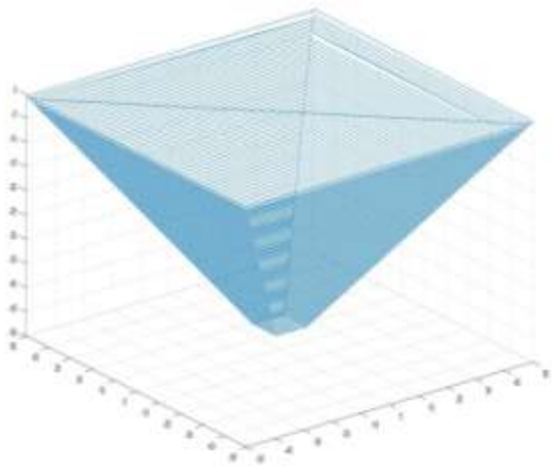

Figure 6: Tool path profile.

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 pyramidal cup is as shown in the figure 6.

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

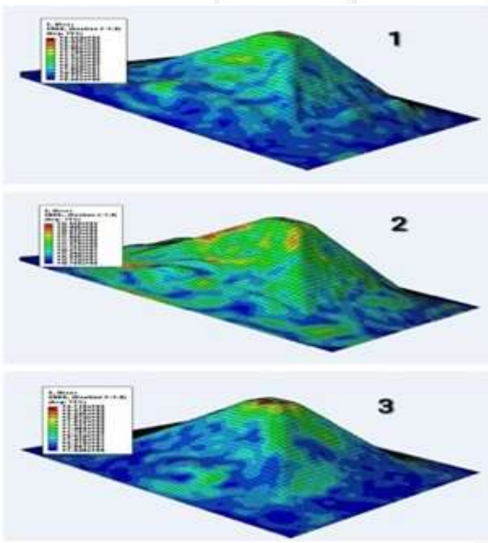

Figure 7: Equivalent stress induced in sheet thickness of 0.8 mm.

3. Results and Discussion

The maximum equivalent stresses induced in the pyramidal cupsare 235.924, 249.399, 248.005, 236.331, 226.774, 271.932, 237.322, 258.626 and 285.645 MPa for trials 1 to 9 respectively (figures 7-9). Maximum equivalent stress is observed in the walls of cup of trial 9. Corresponding maximum equivalent plastic strain obtained for trials 1 to 9 are1.845, 1.663, 1.308, 1.892, 1.7621, 1.459, 1.903, 3.184, 1.466; it is observed maximum equivalent plastic strain in the walls of cup 8.

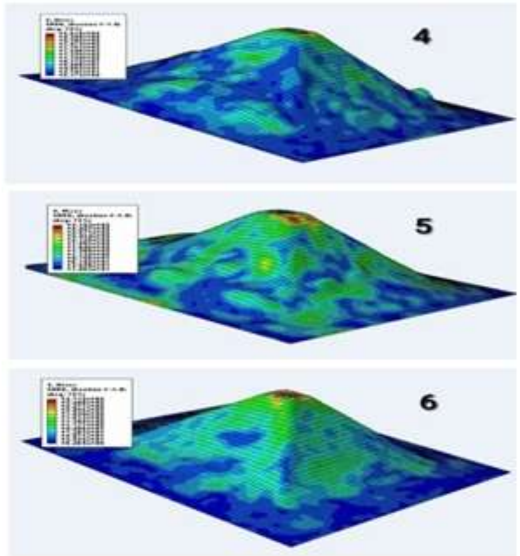

Figure 8: Equivalent stress induced in sheet thickness of 1.0 mm.

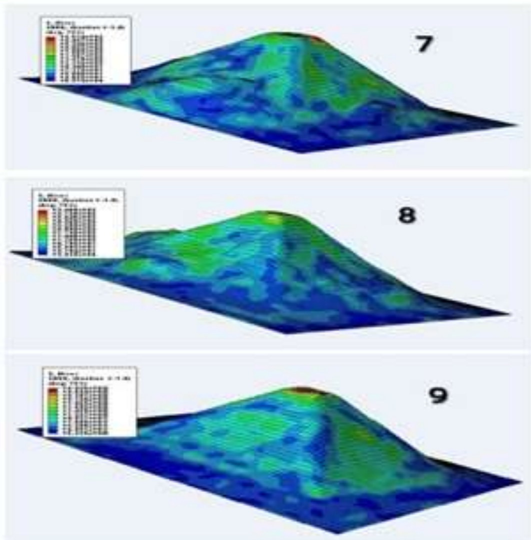

Figure 9: Equivalent stress induced in sheet thickness of 1.2 mm.

The strain variation along the wall of hyperbolic cup at respective step depths is shown in figure 10. The step depth (B) of incremental deep drawing has maximum influence of 57% on the plastic deformation of cups. The tool radius (C) has also influenced to the extent of 25%. The sheet thickness has contributed to the extent of 17%. The friction coefficient did not influence the plastic deformation of the cups.

The variation of sheet thickness along the walls of the cup is shown in figure 11. It is also observed that the reduction in wall thickness of the cups is greatly influenced by the step depth (B) of incremental deep drawing process to the extent of 55%. The friction coefficient has the influence of 22%. This is due to the fact that the friction generates heat resulting the softening of AA5454 alloy.

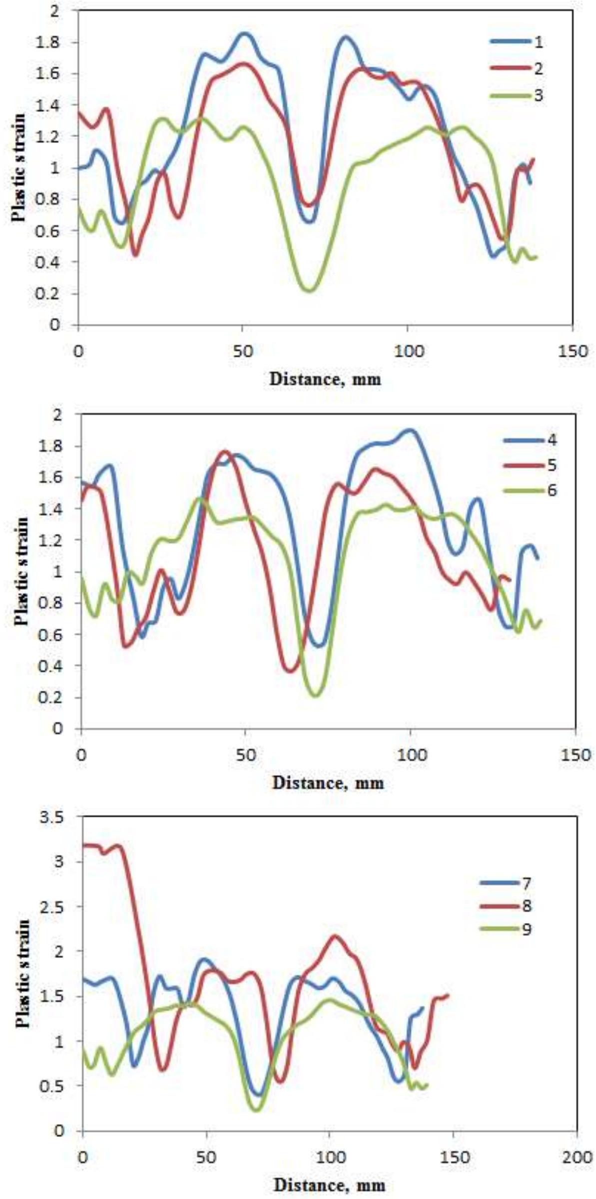

Figure 10: Equivalent plastic strain induced along the walls of cup.

Table 3: ANOVA analysis of equivalent stress

Factor	S1	S2	S3	SS	v	V	F	P
A	733	735	782	500	1	500	126961	17
B	710	735	806	1652	1	1652	419383	57
C	766	771	712	722	1	722	183244	25
D	748	759	743	42	1	42	10764	1
e				0	4	0	0	0
T	2958	3000	3042	2915	8			100

The stress-based formability diagrams of the cups are shown in figures 12(a), 12(b) and 12(c). The formability of the pyramidal cups (figure 13) is dominated by the compressive stress. The lowest and highest von Mises stresses are respectively 226.774 and 285.645 MPa for the trails 9 and 5 of the pyramidal cups. The ultimate strength of AA5454 alloy is in the range of 240 – 300 MPa. All the trial conditions are in safe limits of AA5454 alloy.

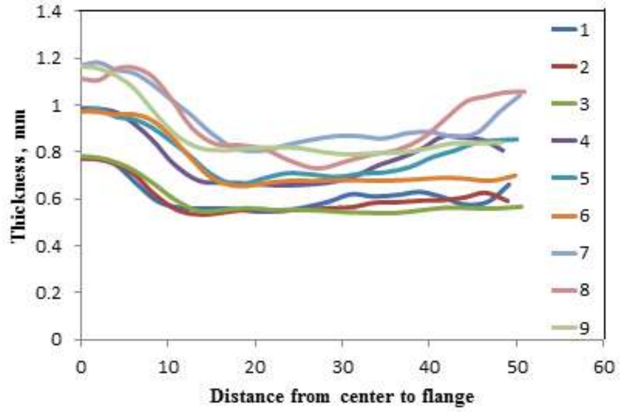

Figure 11: Variation of sheet thickness along the walls of cup.

Table 3: ANOVA analysis of thickness reduction

Factor	S1	S2	S3	SS	V	V	F	P
A	1.55	1.70	1.76	0.01	1	0.01	18.08	11.04
B	1.64	1.42	1.96	0.05	1	0.05	90.41	55.22
C	1.62	1.85	1.55	0.01	1	0.01	18.08	11.04
D	1.81	1.71	1.51	0.02	1	0.02	36.16	22.09
e				0.00	4	0.00	0.00	0.61
T	6.62	6.69	6.78	0.09	8			100.00

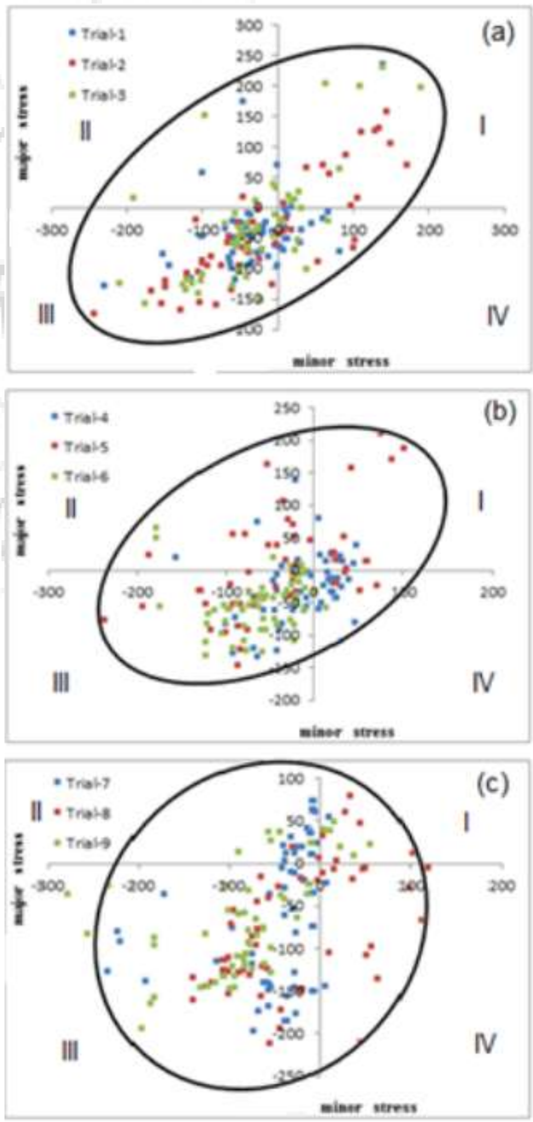

Figure 12: Formability of pyramidal cups.

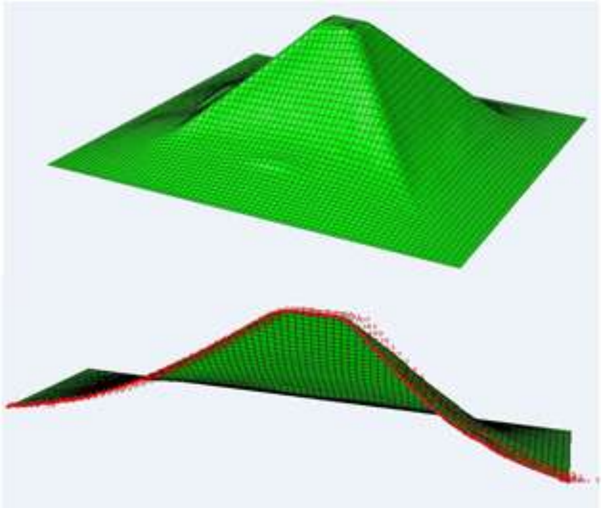

Figure 13: Formation of pyramidal cup.

4. Conclusions

The finite element analysis was carried out as per Taguchi's techniques using ABAQUS software code.The step depth (B) of incremental deep drawing has maximum influence on the plastic deformation of pyramidal cups. The lowest and highest von Mises stresses respectively 226.774 and 285.645 MPa for the trails 9 and 5 of the pyramidal cups are within the limits of the ultimate strength of AA5454 (240 – 300 MPa).

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