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DIE LESS SINGLE POINT INCREMENTAL FORMING PROCESS OF AA6082 SHEET METAL TO DRAW PARABOLIC CUPS USING ABAQUS

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ABSTRACT

Aim of the current project work was to decide the formability of AA6082 alloy to manufacture parabola cups using single point incremental forming (SPIF) process. The finite element analysis has been carried out to model the single point incremental forming process using ABAQUS software code. The process variables of SPIF were sheet thickness, step depth, tool radius and coefficient of friction. The process variables have been optimized using Taguchi techniques. The major process variables influencing the SPIF of parabola cups were sheet thickness and step size.

Keywords: *AA6082 alloy, parabola cup, single point incremental forming, finite element analysis, step depth, tool radius, sheet thickness, coefficient of friction.*

I. INTRODUCTION

Deep drawing process is extensively employed for variety of cups using sheet materials by dies. In a series of research on deep drawing process to fabricate variety of cup shapes, rich investigation have been carried out to improve the superplastic properties of materials such as AA1050 alloy [1], AA2017 alloy [2], AA3003 alloy [3], AA5049 alloy [4], Ti-Al-4V alloy [5], gas cylinder steel [6]. Matsubara in [7] analyzed numerically controlled (NC) machine tool for forming flat metal sheets into convex shapes. In single point incremental forming (SPIF) process, the sheet material is clamped along its edges and a hemispherical headed tool is moved along a predefined geometrical path so that it deforms the sheet locally along the path. The important process variables, which impact the SPIF process capability, are tool diameter, step depth, feed rate, rotational speed of the spindle, sheet thickness, lubrication and tool path [8-13].

The current work was to study the formability of parabola cups of AA6082 alloy using SPIF. For this purpose the design of experiments was executed as per Taguchi technique. The process parameters of SPIF were sheet thickness, step depth, tool radius and coefficient of friction. The formability was evaluated using finite element method.

II. MATERIAL AND METHODS

In the present work, ABAQUS (6.14) software code was used for the numerical simulation of SPIF process to fabricate truncated pyramidal cups. The material was AA6082 alloy. The SPIF process parameters were chosen at three levels as summarized in table 1. The orthogonal array (OA), L9 was preferred to carry out experimental and finite element analysis (FEA) as given in table 2.

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Table 1: Process parameters and levels

Factor	Symbol	Level–1	Level–2	Level–3
Sheet 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

The sheet and tool geometry were modeled as deformable and analytical rigid bodies, respectively, using ABAQUS. They were assembled as frictional contact bodies. The sheet material was meshed with S4R shell elements. The fixed boundary conditions were given to all four edges of the sheet. The boundary conditions for tool were x, y, z linear movements and rotation about the axis of tool. True stress-true strain experimental data were loaded in the tabular form as material properties. The tool path geometry was generated using CAM software [14] was imported to the ABAQUS as shown in figure 1. The elastic-plastic deformation analysis was carried out for the equivalent stress, strain and strain rates and thickness variation.

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

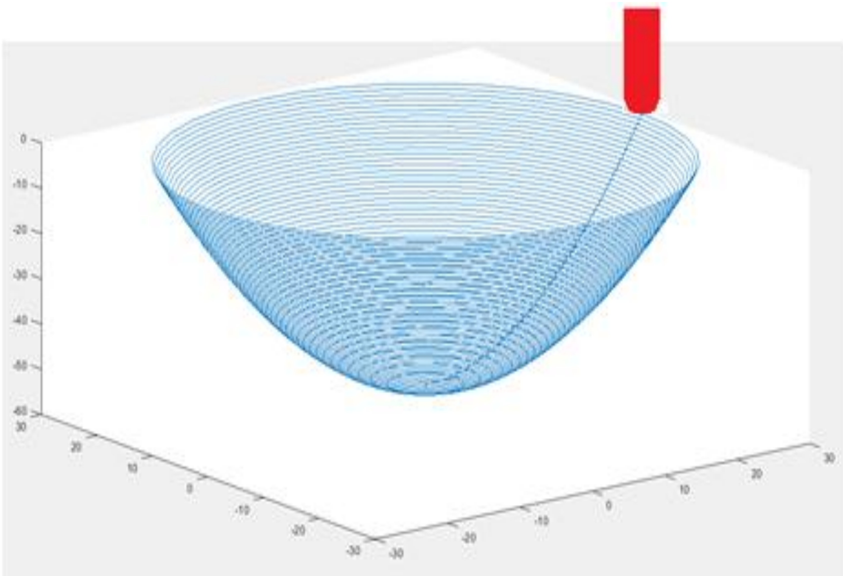

Figure 1: Tool *path generation*

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III. RESULTS AND DISCUSSION

The influence of process variables on the von Mises stress, strain rate and thickness reduction are debated. The formability limit diagrams are also created.

3.1 Influence of process parameters on effective stress

Table 3 gives the ANOVA (analysis of variation) summary of von Mises stress data. The percent contribution specifies that sheet thickness, A legacies 66.08%, step depth, B contributes 15.64%, tool radius, C gives 8.42% and coefficient of friction, D adds 9.87% of total variation on the von Mises stress.

Table 3: ANOVA Summary of the Effective Stress.

Source	Sum 1	Sum 2	Sum 3	SS	v	V	P
A	1262.57	1350.88	1361.91	1976.54	2	988.27	66.08
B	1339.83	1294.53	1340.98	467.89	2	233.94	15.64
C	1344.94	1306.10	1324.31	251.74	2	125.87	8.42
D	1335.41	1300.91	1339.03	295.10	2	147.55	9.87
e				0.00	0		0.00
T	5282.75	5252.43	5366.23	2991.26	8		100.00

Note: *SS is the sum of square, v is the degrees of freedom, V is the variance, P is the percentage of contribution and T is the sum squares due to total variation.*

Fig.2 presents the influence of SPIF process variables von Mises stress induced in AA6082 alloy. The von Mises stress is increased with increase of sheet thickness (Fig.2a). As the thickness of sheet increases the force required to undergo plastic deformation of the sheet materials also increases. Hence, an increases in the von Mises stress. Also, Fig.2a defines the von Mises stress as a function of step depth. The von Mises stress decreases initially with decrease of step depth from 0.5 to 0.75 and later on it increases for a change in step depth from 0.75 to 1.0 mm. The von Mises stress is minimum for tool radius of 5 mm and friction coefficient of 0.15 as shown in Fig.2b.

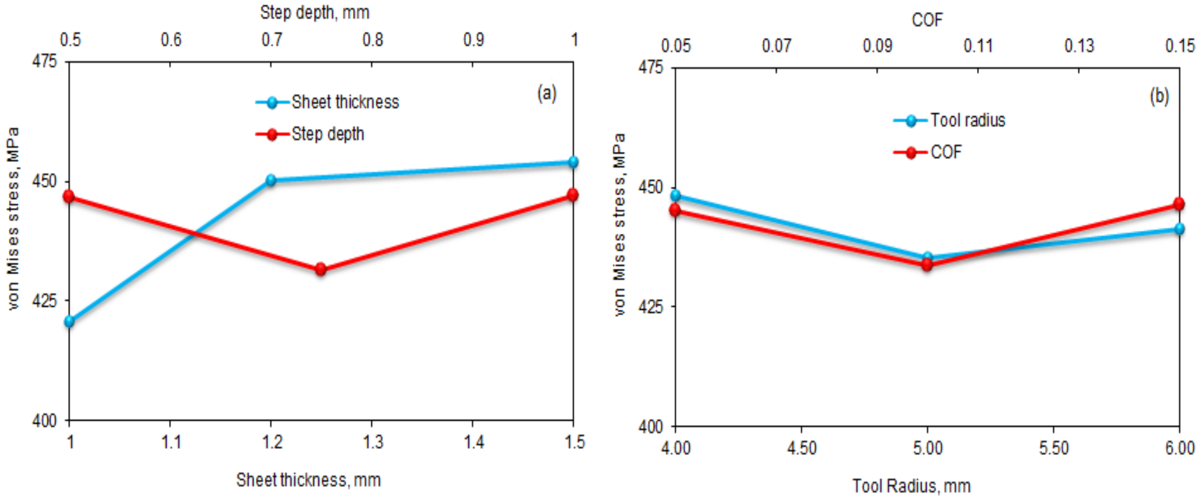

Figure 2: Influence of Process Parameters on von Mises Stress.

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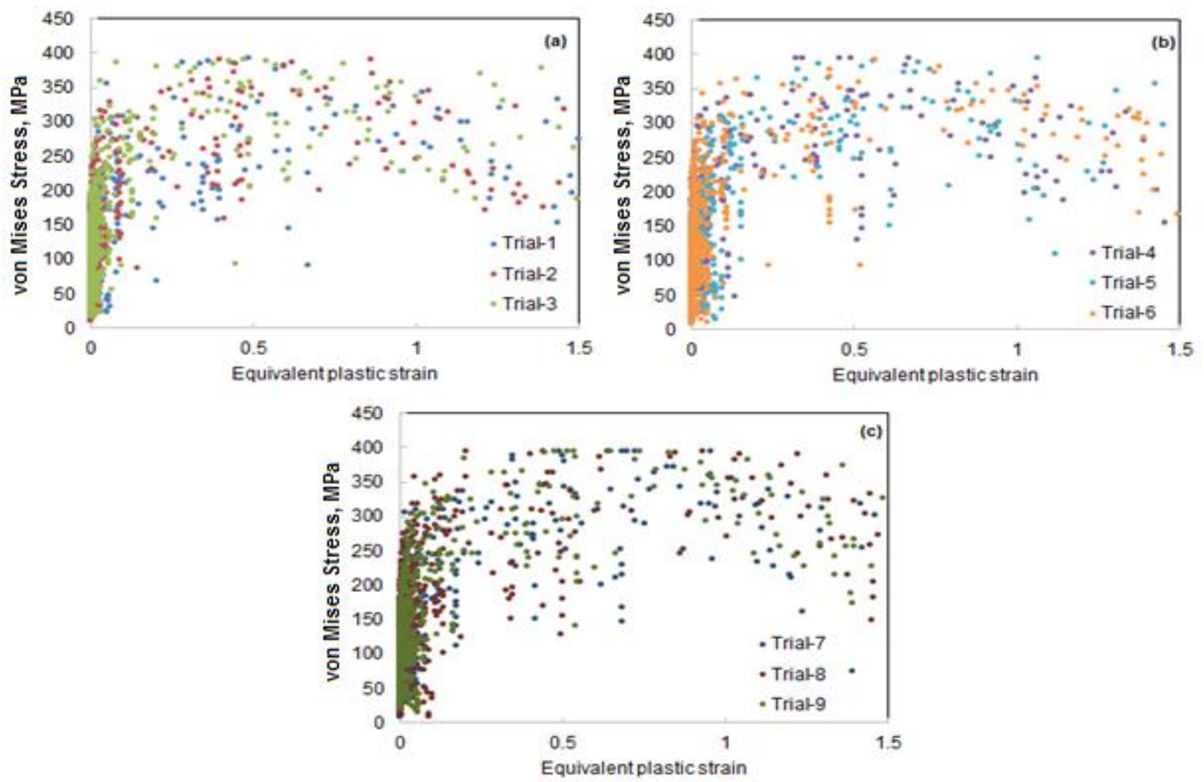

Figure 3: Effect of process parameters on S11.

For the trials 1, 2 and 3, the von Mises stresses are, respectively, 393.5, 388.4 and 391.6 MPa. For the trials 4, 5 and 6, the von Mises stresses are, respectively, 395.4, 393.3 and 393.3 MPa. For the trials 7, 8 and 9, the von Mises stresses are, respectively, 395.4, 393.6 and 395.4 MPa. The ultimate tensile strength of AA6082-T6 alloy is 300 MPa which exceeds in all the cases (figure 4).

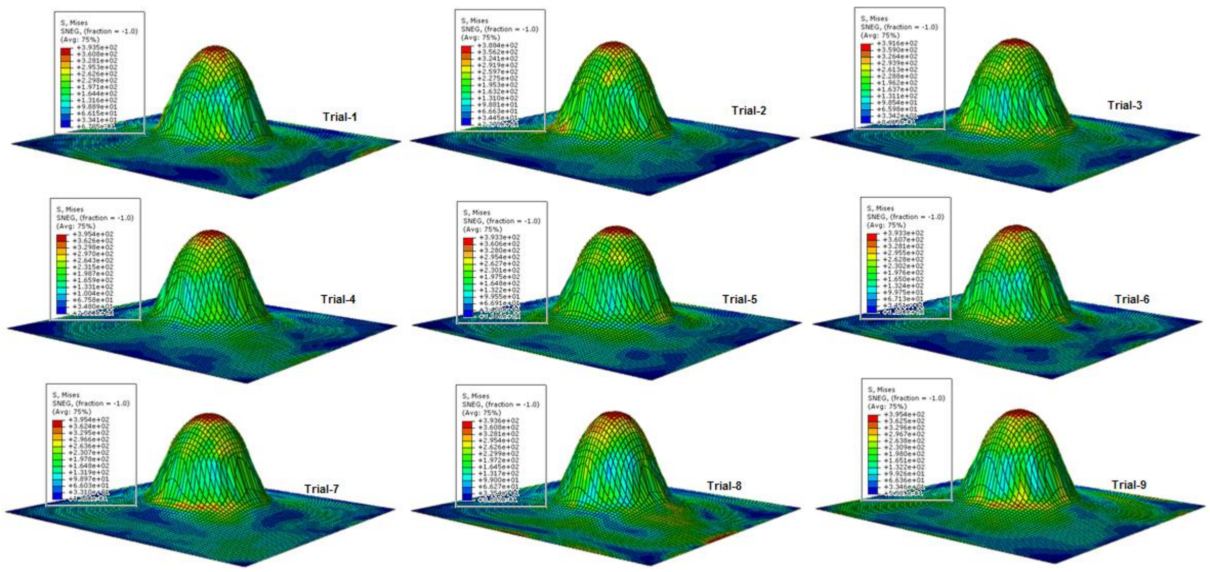

Figure 4: Raster images of von Mises stress in the cups.

3.2 Influence of parameters on strain rate

The ANOVA summary of the strain rate is given in Table 4. The percent contribution column establishes the major contributions 2.21%, 80.25%, 6.97% and 10.57% of sheet thickness, step depth, tool radius and coefficient of friction, respectively, towards variation in the strain rate.

Table 4: ANOVA summary of the strain rate

Source	Sum 1	Sum 2	Sum 3	SS	v	V	P
A	0.1173578	0.1273567	0.1283926	2.476E-05	2	1.238E-05	2.21
B	0.1664699	0.1076449	0.0989922	0.0008987	2	0.0004494	80.25
C	0.1132666	0.1249572	0.1348832	7.805E-05	2	3.903E-05	6.97
D	0.13	0.1326307	0.1089958	0.0001184	2	5.919E-05	10.57
e				3.469E-18	0		0
T	0.53	0.49	0.47	0.00	8		100.00

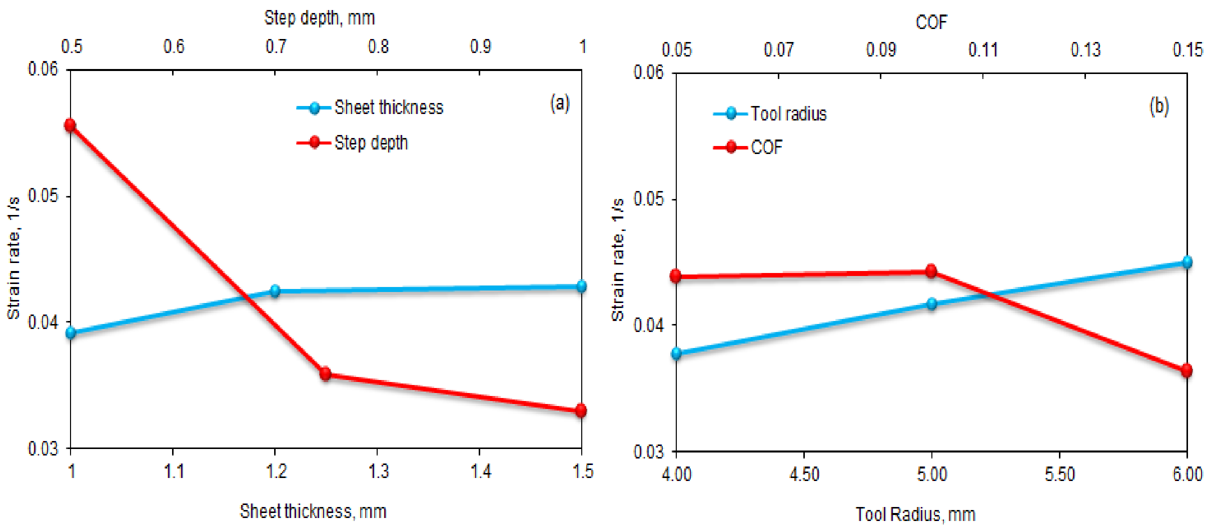

Figure 5: Influence of process parameters on strain rate.

The strain rate increases with increase of sheet thickness (Fig.5a) and tool radius (Fig.5b). The strain rate is decreased with increase of step depth (Fig.5a) and coefficient of friction (Fig.5b). For smaller step size local deformation plays an important role than stretching. As the tool radius increases, the area under the tool exposed to the plastic deformation also increases. Hence, increase in tool radius enhances the strain rate. The cup formation depends on the shear stress developed during the plastic deformation of sheet material. The frictional shear stress is directly proportional to the coefficient of friction as per Coulomb's law of friction ($\tau = \mu F_n$, where F_n is the normal pressure).

3.3 Influence of parameters on thickness reduction

The ANOVA summary of the thickness reduction is given in Table 5. The thickness reduction during the cup drawing is only dependent on sheet thickness only. The other process variables have negligible influence on the thickness reduction.

Table 5: ANOVA summary of the thickness reduction

Source	Sum 1	Sum 2	Sum 3	SS	v	V	P
A	1.19	1.54	1.90	0.08	2.00	0.04	99.47
B	1.55	1.54	1.54	0.00	2.00	0.00	0.05
C	1.56	1.55	1.52	0.00	2.00	0.00	0.44
D	1.55	1.54	1.55	0.00	2.00	0.00	0.04
e				0.00	0.00		0.00
T	5.86	6.16	6.51	0.08	8.00		100.00

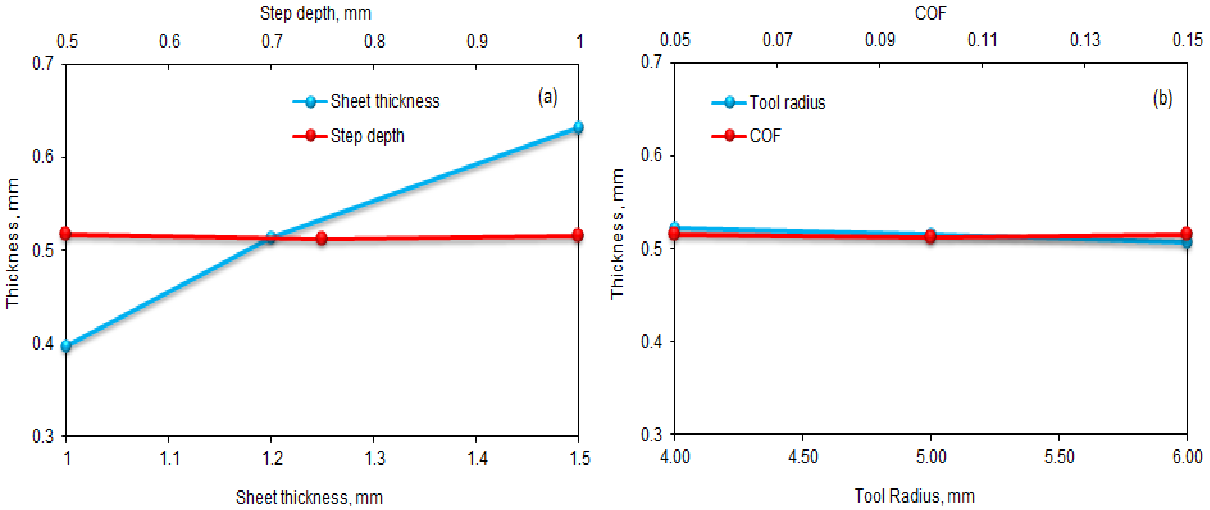

Figure 6: Influence of process parameters on thickness reduction.

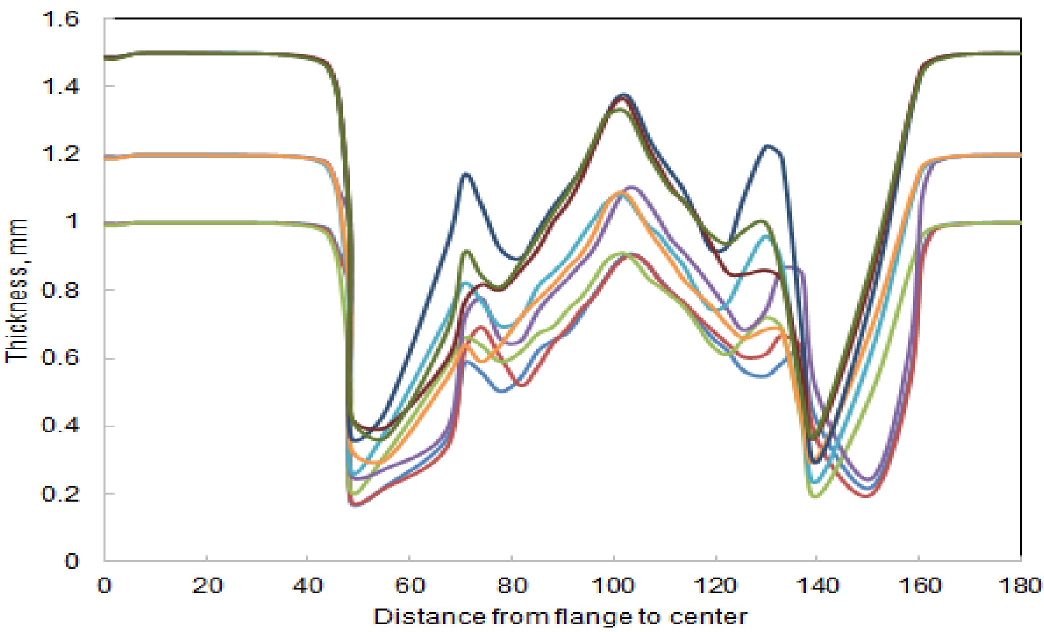

Figure 7: Location of thickness reduction in the deformed cup.

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The major process variable which influence the reduction of sheet thickness, is sheet thickness (Fig.6). The reduction of thickness was considered at the center-line of the deformed cup as shown in Fig.7. As observed from Fig.7, 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.

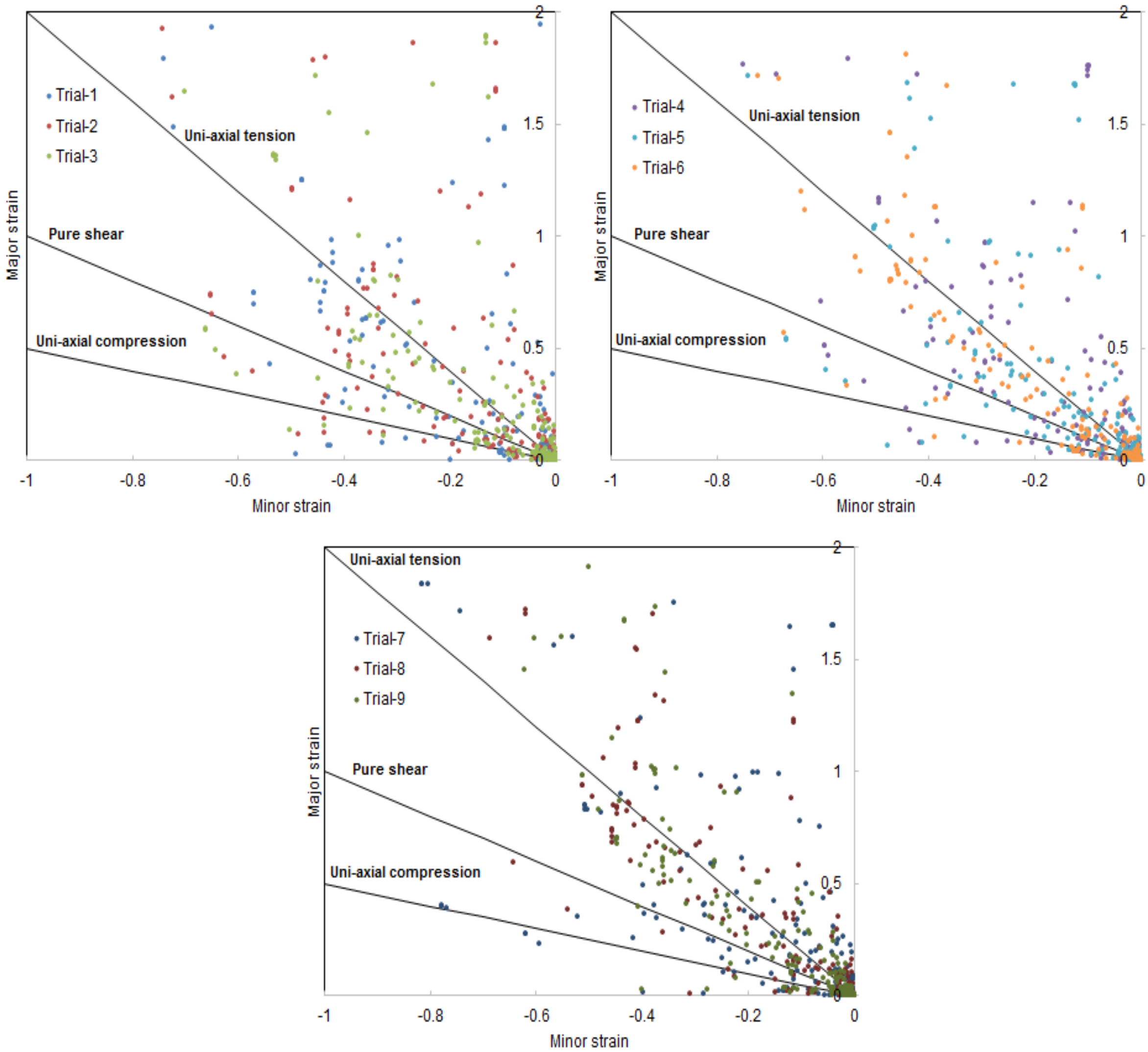

Figure 8: Forming limit diagrams: (a) for trials 1, 2, 3 (b) for trials 4, 5, 6 (c) for trials 7, 8, 9.

3.4 Formability of SPIF process

The formability diagrams of the cups are shown in Fig.8. During initial stages of SPIF, the shear and compressive stresses were dominating the formability of parabola cups of AA6082 alloy. At later stages of plastic deformation the tension is highly predominant resulting the stretching of sheet.

IV. CONCLUSIONS

The major SPIF process parameters which influence the formability of parabola cups of AA6082 alloy were sheet thickness and step depth. The optimal process parameters could be sheet thickness of 1.5 mm, step depth of 0.5 mm, tool radius of 4.0 mm and coefficient of friction of 0.10.

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