Analysis of Influence of Process Parameters in Multi Point Incremental Forming of GI sheets

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***Abstract* - In this study, it is proposed to analyse the influence of the process parameters on formability of the GI sheet of grade 80GSM and to obtain the condition for maximum formability. The study on incremental sheet metal forming is conducted using multi point incremental forming (MPIF) tool on GI sheet in cold working condition. MPIF offers advantage over single point incremental forming (SPIF) due to its reduced processing time by increasing tool contact with workpiece. The methodology involves using of grid circle method to analyse formability. The procedure utilized was cylindrical forming process and parameters chosen were feed rate, spindle speed and step depth. To analyse the data and to optimize the condition, Taguchi L18 orthogonal array was used as design of experiment (DOE). The research gap involves limited study of forming process using multi point tool and GI sheet as material. Incremental forming provides greater advantage for rapid prototyping. Optimization of process parameters using MPIF tool helps to reduce material wastage and time in forming process.**

***Index Terms* – Formability, Multi point incremental forming, Process Parameters, ANOVA, Fracture**

I. INTRODUCTION

Incremental forming is an emerging and widely implemented technology in sheet metal forming. Conventional forming methods like die stamping has several limitations which includes high tooling cost, unable to rapid prototype and influence of high springback. Ailing Wang et al.[1] showed that springback effect significantly dominates if blank and die temperature are not optimized. Mohamed S. Mohamed et al.[2] correlated failure mechanism of die stamping with forming rate, gives insight of tearing occurring in the process. But upcoming of incremental forming technologies counters these limitations. Ossama Mamdouh Badr et al.[3] compared springback in samples formed by simple bending using a die and by incremental forming steps, it was observed that incremental process showed lower level of springback. Due to low cost and higher process flexibility, SPIF is widely used in industries and its wide and real life applications are discussed in [4].

SPIF has a limitation since it has a high forming time due to low area of contact between tool and workpiece. Spherical tip of tool should cover entire area of metal with feed and step depth to produce required part which leads to higher time consumption. Due to this reason, multipoint tool was introduced. Due to higher area of contact, multipoint tool could finish the process in less time compared to that of single point tool. The study of MPIF is currently in developing stage and has not yet become widespread. M. Shafeek et al.[5] studied the MPIF process on titanium grade 2 sheets and optimized the condition for maximum formability, It was also concluded that increased contact between sheet and tool result in formation of more microvoids, which enhances formability. [6] Compared the results from multipoint tool and single point tool, concluded that higher formability and surface finish were obtained by using multipoint tool. From SEM images obtained from [6] more intergranular fracture was observed due to high stress induced by the single point tool.

Study of MPIF was conducted on commercial GI sheet of 80 GSM. GI is preferred since it has a very high application in automobiles, construction, piping and many more, which provides an advantage of corrosion resistant. In the process, we also had to observe whether using MPIF on GI sheets will remove zinc coating. Favorably after forming, the coating was sufficiently present on the material, making it suitable for applications. Majority of studies focus on conical flanging [5], where the diameter of feed reduces with consecutive step depth. This method also helps to deform the sheet to large extend without fracture, enables to study the result easily. We conducted the study with cylindrical forming process, were diameter of feed remains constant with step depth. Cylindrical forming is useful for purpose like creating extension in flanges. The multipoint tool is attached to 3 axis CNC machine, programmed it with different values for feed rate, spindle speed and step depth.

For calculating formability, we employed the widely used approach of circle grid analysis [5],[8],[9],[10] where circles are laser engraved in micron level depth on material and the elongation of circle after the process is measured and calculated to quantify formability. To optimize the condition and to understand the influence of process parameters, we used Taguchi method in our design of experiment. Nazarul Abidin Ismail et.al.[11] used Taguchi method to optimize process parameters - step depth, robot speed and wall angle for achieving excellent surface roughness. Zhaobing Liu et.al.[12] used Taguchi method to optimizing process parameters for maximum formability. Analysis of Variance (ANOVA) method is used to study the effect of three parameters - feed rate, spindle speed and step depth on formability and to identify the percentage contribution of each parameter in it. Ultimately, the study will contribute to advancements in sheet metal forming process.

II. TOOL AND METHOD

Incremental forming commonly uses single point hemispherical end tool. The diameter of hemispherical end varies based on accuracy needed for the process. For higher accuracy, smaller diameter tool is used, but it increases the process time. In contrast, larger diameter tool completes the work faster, but accuracy may be low. L.Carrino et al.[13] shown that for better formability result, punch radius should be large as possible, but manufacturing parts with geometrical complexity will be difficult to form and forming forces become greater. We conducted the study with MPIF tool (Fig.1) with six points equipped with EN 36 steel balls, characterised by high strength and hardness. The diameter of ball used is 12mm. The tool contains mainly three parts (Fig.2): mandrel, mid cap and base plate, all of them are made of EN 24 steel which has a high wear resistant characteristic.

The operation was done on GI sheet of 80 GSM. The thickness of sheet used is 1mm and dimension of 150mmx150mm was used which fits in the blank

Fig 1: MPIF tool

Fig 2: MPIF tool components

holder. Forming process was carried out at College of Engineering Trivandrum using BFV Agni BW45 CNC milling machine. The experimental setup is shown in Fig.3. Fixture is clamped on the worktable using allen key bolts. Sheet metal is firmly mounted in-between the blank holder. The CNC machine is programmed to carry out a cylindrical forming process with diameter of 80mm. The feed rate, spindle speed, and step depth are adjusted for each workpiece. As lubricant, coconut oil was used. Step depth(Δz) is given which during each revolution which deforms the sheet in downward direction. The process is terminated when the fracture just started to become visible.

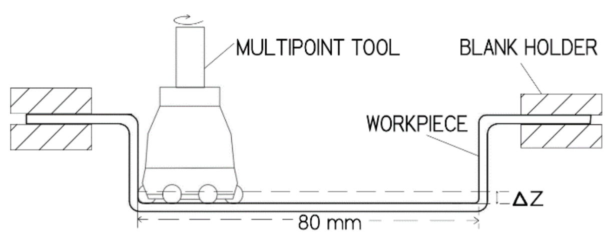

Fig 3: Schematic representation of MPFI process

III. METHODOLOGY

For calculating formability, we used circle grid analysis method. GI sheets were cut into dimension of 150mmx150mm. Circle grid of diameter 2mm is laser engraved on 18 GI sheets with engraving depth of

15µm. Due to biaxial stretching in forming process, the circle will get elongated to elliptical shape Fig.4 . After the process, the grid in elliptical shape can be measured to calculate major true strain (ε1) and minor true strain (ε2). In Fig.4, 2mm is the original diameter of circle, 'a' and 'b' respectively denotes major axis and minor axis of ellipse that is being formed, then the equation for

$$\varepsilon 1 = \ln(a/2) \qquad (1)$$

$$\varepsilon 1 = \ln(b/2) \qquad (2)$$

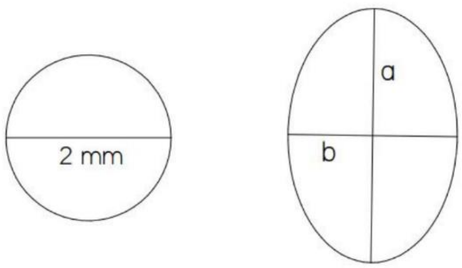

Fig 4: Circle grid before and after elongation

For sheet metal, formability(F) can be quantified as

$$F = \varepsilon 1 + \varepsilon 2 \quad [14],[15] \quad (3)$$

Factors	Level 1	Level 2	Level 3
Feed rate(mm/min)	500	700	-
Spindle speed (RPM)	250	350	450
step depth(mm)	0.2	0.3	0.4

Table 1: Factors and levels considered for the process

For analysing the dependence of formability on different process parameters, we used Taguchi's L18 orthogonal array and it was performed using "minitab" software. L18 was selected over lower combinations like L9 to consider more influencing factors and to reduce error. We considered three factors and gone for mixed level design with one factor has two levels and other two factors have three levels (Table 1).

For experiment, the three factors chosen were feed rate, spindle speed and step depth, which has a significant influence on incremental forming process [5],[16]. By varying these parameters, incremental operation was conducted on 18 GI sheets (Fig 5). Several studies taken tool diameter and sheet thickness as parameters. Since we are performing operation on specially designed multipoint tool and same type of sheet is preferred for the entire process, we have not selected those parameters. Incremental forming were performed on 9 sheets with feed rate as 500 mm/min and rest of the sheet where formed with 700 mm/min. While choosing level of spindle speed, it was limited to maximum of 450 RPM, since further increase in RPM results in increased surface roughness. Study conducted by Vishal Gulati et.al [17] shows that at higher spindle speed of around 500 RPM high friction occurs, leading to surface roughness and lubricant film breakdown. Levels of step depth was selected with a minimum value of 0.2mm, below which the process

Sheet no.	Feed rate (mm/min)	Spindle speed (RPM)	Step depth (mm)	major axis (a) (mm)	minor axis (b) (mm)	$\varepsilon 1$	$\varepsilon 2$	Formability (F)
1	500	250	0.2	7.45	2.33	1.31507	0.15272	1.46779
2	500	250	0.3	7.11	2.25	1.26835	0.11778	1.38614
3	500	250	0.4	6.9	2.34	1.23837	0.15700	1.39538
4	500	350	0.2	7.35	2.4	1.30155	0.18232	1.48387
5	500	350	0.3	6.82	2.46	1.22671	0.20701	1.43373
6	500	350	0.4	6.95	2.2	1.24559	0.09531	1.34090
7	500	450	0.2	7.41	2.46	1.30968	0.20701	1.51670
8	500	450	0.3	7.21	2.43	1.28232	0.19474	1.47707
9	500	450	0.4	6.88	2.38	1.23547	0.17395	1.40942
10	700	250	0.2	7.25	2.47	1.28785	0.211071	1.49893
11	700	250	0.3	7.26	2.36	1.28923	0.16551	1.45475
12	700	250	0.4	6.92	2.19	1.24127	0.09075	1.33202
13	700	350	0.2	7.73	2.4	1.35196	0.18232	1.53428
14	700	350	0.3	7.44	2.4	1.31372	0.18232	1.49605
15	700	350	0.4	7.19	2.22	1.27954	0.10436	1.38390
16	700	450	0.2	7.26	2.59	1.28923	0.25851	1.54774
17	700	450	0.3	7.52	2.39	1.32442	0.17815	1.50257
18	700	450	0.4	6.84	2.4	1.22964	0.18232	1.41196

Table 2: Formability at various process parameters

will not be feasible as the operation time increases. Maximum value was taken to be 0.4mm, more than this was not preferred since most of the studies concluded that formability decreases with step depth [15],[18]. In each sheet, incremental forming is done until the point where fracture is observed (Fig.6). The formability value at various process parameters is shown in Table 2.

Fig 5: 18 formed GI sheets

Fig 6: Fracture in formed sheet

IV. RESULTS AND DISCUSSION

The result obtained from each process were given as input to Taguchi method in 'minitab' software to analyse the influence of process parameters. The data obtained were plotted in graph (Fig 7). In the mean of means graph, there obtained a clear trend of formability vs feed rate, spindle speed and step depth. As feed rate increases, it shows an increase in formability value and highest formability is obtained at a feed rate of 700mm/min. But it is to be noted that the slope of graph is less and the change in feed rate do not have significant impact on formability. Study conducted by I. Bagudanch et al. [19] also shows that formability increases with increase in feed rate which supports our observation on the same.

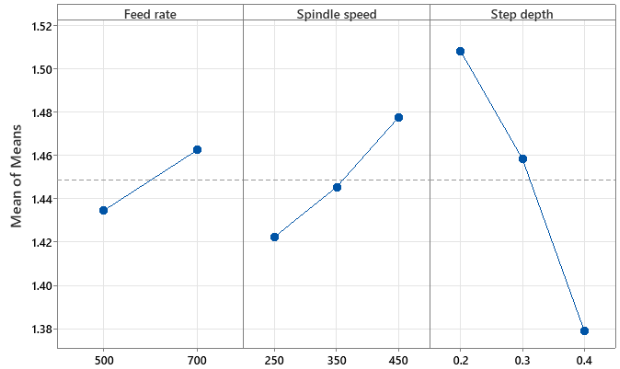

Fig 7: Formability Vs feed rate, spindle speed, step depth (results from *minitab software*)

The trend of formability vs spindle speed shows a linear relation. The value of formability increases with increase in spindle speed and the change is significant. Maximum formability is obtained at 450 rpm. further increase in spindle speed cause wrinkling in sheet metal. The increase in formability with spindle speed may be due to increase in heat produced due to friction [20]. Studies[21],[22] also supports that in incremental forming, formability increases with spindle speed.

Apart from feed rate and spindle speed, step depth inversely affects formability. Increase in step depth results in reduction of formability value causing early fracture in biaxial stretching. This may be due to localized thinning due to limited material redistribution at higher step depth. The influence is also significant than any other parameters since it has a steeper slope.

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Feed rate	1	0.003506	4.93%	0.003506	0.003506	5.64	0.035
Spindle speed	2	0.009184	12.90%	0.009184	0.004592	7.39	0.008
Step depth	2	0.051021	71.69%	0.051021	0.025511	41.04	0.000
Error	12	0.007460	10.48%	0.007460	0.000622		
Total	17	0.071171	100.00%				

Fig 8: ANOVA (results from *minitab software*)

To find the percentage influence of each parameter, Analysis of Variance (ANOVA) is carried out in the minitab software on the basis of obtained result. It is to be noted that the p value of all three factors is less than 0.05 which means that each process parameter has statistically significant effect on formability of sheet metal and there is very low probability that observed effect is due to random chance. Based on the result, it is clear that step depth has the highest influence which contributes around 72%. Then comes spindle speed with percentage influence of around 13% and the least significance is by feed rate which has a percentage influence of just around 5%.

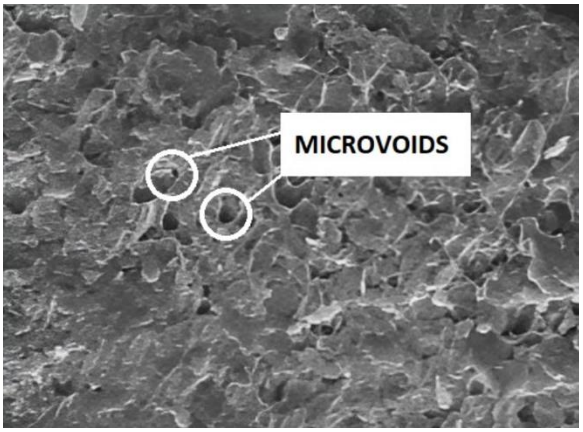

Fig 9: SEM image of fractured surface

SEM analysis were conducted on fractured cross section of specimen with feed rate 500mm/min, spindle speed 250rpm and step depth 0.2mm. The intention is to find whether the type of fracture obtained from the process is ductile or brittle in nature. Sample was subjected to analysis with magnification level of 30µm at 1000x magnification. The region appears to be dimple structured with several microvoids present in it which shows the clear evidence of ductile fracture. The result also verifies the findings of [7], which indicates that necking occurs when tools with larger radii are used, suggesting a ductile fracture in sheet metal. Ductile fracture occurs due to the shearing force from multipoint tool with large radius. At regions of higher strain, the fracture is based on void mechanism which eventually leads to cracking.

V. CONCLUSION

This research work studies the effect of process parameters on MPIF process on GI sheets. From statistical analysis, it was found that the considered process parameters feed rate, spindle speed and step depth has an impact on formability of material. Formability increases with increase in feed rate, but it has the least influence. Formability also increases with increase in spindle speed and has higher effect than feed rate. Step depth has maximum effect on formability, but it has an inverse relation, ie. increase in step depth reduce formability. SEM analysis of fractured section shows dimple structure with microvoids, which indicates that the failure is based on ductile fracture. The experimental work will be useful for multipoint applications in industries and will also serve as a foundation for further research in this field.

VI. REFERENCES

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