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Effect of process parameters and preheating temperature on surface roughness and thickness distribution in hole flanging using Incremental Sheet metal Forming

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Abstract: Incremental Sheet metal forming is a die less method of forming which offers high formability. In this research work; effect of step depth, tool rotation speed and preheating temperature on surface roughness and thinning of flange wall is investigated in hole flanging using incremental forming. The parameter optimization is carried out by Taguchi method. Grey relational analysis is carried out to obtain best parameter combination.

Keywords: Hole flanging, Incremental Sheet metal Forming, Single Point Incremental Forming, Taguchi method

I. INTRODUCTION

Incremental forming has remained interest of research because of many advantages of it like dieless process, simple tools, use of CNC machine for forming etc. It was further explored that it offers high formability compared to conventional forming process as neck formation is suppressed. Researchers have been working on the formability study of single point incremental forming [1], [2], [3].Parameter optimization of a process gives insight about their effect on part quality, so it is important to study parametric effects in any manufacturing process. Ajay kumar et al [4], experimentally studied effect of tool shape, tool diameter, tool rotation, step size and wall angle on formability of AA2024-O in single point incremental forming. Increase in step size reduces forming depth and increase in tool rotation speed increases forming depth while forming conical frustums of constant wall angle.

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Angshuman Baruah et al performed optimization of AA5052 in incremental forming by grey relational analysis and ANOVA [5]. Feed was found to be least effective parameter and lubricant to be most effective among step size, feed, tool rotation speed and lubricant.

Formability of material also depends on its microstructure and initial grain size of sheet metal. Parnika Shrivastava et al [6] studied effect of preheating on forming load and thickness distribution in Single Point Incremental Forming (SPIF). AA1050 material was used for the study. The Aluminum sheets were preheated to temperature in the range of 230ºC-500ºC which resulted in grain size variation. As the preheating temperature increases grain size increases, hardness and yield strength of the material decreases. The results noted after performing SPIF on these sheets shows that because of preheating, forming forces decreases and better thickness distribution can be obtained. The authors also analyzed forming behavior and deformation mechanism of AA1050 sheet based on microstructure and texture on the sheet metal[7]. Tung Chen Cheng et al [8] investigated coupling effect of grain size and strain rate on formability in electromagnetic forming; it was observed that if grain size reduces probability of failure at grain boundary by grain boundary damage increases. Failure of sheet metal can take place earlier which means that formability decreases.

Hole flanging is a process of forming flange on sheet metal having precut hole on it. Some of its applications are strengthening of hole edges, aesthetic appearance, provision for tube or pipe joining. Conventionally it is carried out by punch and die which involves bending and stretching. The magnitude of deformation for hole flanging operation can be represented by Hole Expanding Limit (HEL), which is ratio of inside diameter of finished collar to the pre cut hole diameter. Study of hole flanging by conventional process using punch and die shows that HEL depends on material properties, punch geometry, initial hole diameter, surface quality of initial hole edge and friction conditions. Some authors have used the term Hole Expansion Ratio (HER) for the same parameter. Formability in hole flanging can be represented by Limit Forming Ratio (LFR)[9] which is ratio of maximum inside diameter d_{max} of flange to the initial diameter of pre cut hole d. It can also be stated that LFR is HEL_{max} that is maximum obtainable value of HEL.

Conventional hole flanging is not economical because of cost involved in making die and punch. Thus, it is not suitable for job production and prototype making.

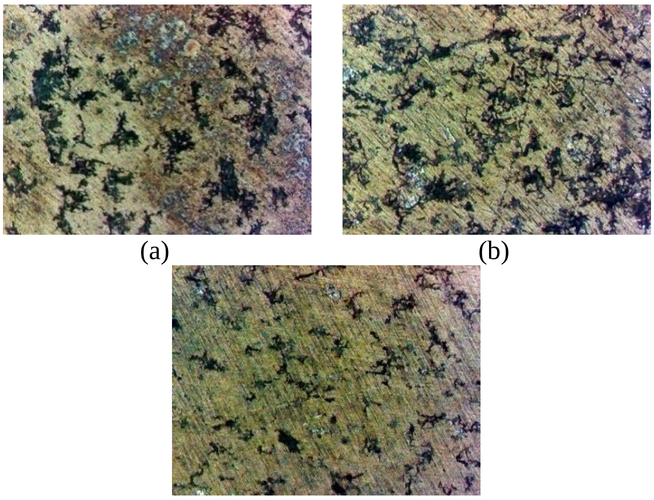
SPIF can be used to form hole flange on sheet metal with precut hole. Cui et al [10] described how ISF can be used to perform hole flanging operation. Further exploration of the process was done by using multistage approach of SPIF. Studies are also performed on hole flanging using Single Stage SPIF [11]. M.Borrego et al[12] analyzed effect of tool diameter and spindle rotation on surface roughness and thickness profile along the flange in hole flanging by single stage SPIF. It is noted that the increase in tool radius increases LFR and rotation of spindle results in better surface finish. Multistage approach offers better thickness distribution and high formability compared to single stage approach. It also increases time of operation because of requirement of more than one stage to complete the operation. However, if compared with conventional flanging operation the overall time of punch-die design and manufacturing would be far greater than the time of SPIF multistage approach which proves it to be feasible.

II. METHODOLOGY

A. Material Characterization, Preheating of sheets and grain size measurement

Sheet metal of AA1050 with 1.48 mm thickness was used in the study. For confirmation of the purchased sheet metal grade, spectroscopy was performed and the results show that it contains 99.50 % Aluminium, which confirms the grade.

The sheets were preheated in EIE 1502 muffle furnace and held for 1 hour at the temperature and subsequently cooled in the furnace. The grain size of material can be controlled by heat treatment process. Hence, in the present study three temperature conditions were considered; room temperature, 300°C and 400°C. Similar preheating temperature range was also attempted by Shrivastava et al [7]. After preheating the sheets, microstructures were observed using optical inverted microscope coupled with image analyzer software. Grain size was measured at 100 X magnification using line intercept method as per ASTM E-112/E1382-91. The average grain size of specimen a (room temperature) and b (300°C) is 13 micron and specimen c (400°C) is 26.85 micron. It is observed that the grain size could be altered when the specimen were heated beyond 300°C.



(a) (b) (c)

Fig. 1 Grain size measurement using image analyzer (100 X) of Aluminium 1050 sheets (a) Room temperature (13µ) (b) heated to 300°C (13µ) and (c) heated to 400°C (26.85µ)

B. Hole flanging using Incremental Sheet metal Forming

For the hole flanging operation Jyoti 3 axis Vertical Milling Centre was used. Fig.1 shows schematic diagram of the operation. It includes a fixture developed which eliminates the requirement of work zero setting for every new experiment and which can be fixed on vice. For achieving the objective of studying effect of parameters on formability and surface quality, it was decided to fix the tool size and final flange diameter. Preliminary experiments were done to find successfully obtainable flange diameter. The size of sheet blank, precut hole and final diameter of hole flange were fixed as given in Table I for the final experiments.

TABLE-I: Sheet and tool dimensions

Sheet blank dimensions mm	Precut hole diameter mm	Final diameter of flange mm	Sphere head tool diameter mm
100 x 100 x 1.48	30	50	10

Multistage approach of SPIF with four stages was used to generate hole flange. Before the beginning of hole flanging operation, hole was cut on the sheet by end mill tool which eliminates separate hole drilling process.

C. Design of Experiment using Taguchi's method

Taguchi's method was used to design experiments. Three levels of parameters were considered and L9 orthogonal array was selected. Table II shows the levels of parameters.

TABLE-II: Parameters values

Parameters/Levels	1	2	3
Step depth(mm)	0.15	0.20	0.25
Tool rotation speed(rpm)	0	500	1000
Preheating temperature (°C)	0	300	400

III. RESULTS AND DISCUSSION

Experiments were performed using the selected orthogonal array. After forming flanges on different parts, surface roughness was measured on the inside surface of flange along the height at four different places, the values were then averaged to get a single value of surface roughness. Thickness measurement was done by scanning the parts with a 3D scanner.

TABLE-III: L9 Orthogonal array with response values

Sr. No.	Step depth (mm)	Preheating temperature (°C)	Tool Rotation	Surface roughness (Ra)	Thinning along flange (%)
1	0.15	0	0	2.46	28.05
2	0.15	300	500	1.92	43.09
3	0.15	400	1000	1.39	46.72
4	0.20	0	1000	1.66	49.54
5	0.20	300	0	2.23	30.66
6	0.20	400	500	1.93	33.16
7	0.25	0	500	2.21	38.18
8	0.25	300	1000	1.97	37.80
9	0.25	400	0	2.03	25.12

Taguchi method uses S/N ratio calculation to find effect of parameters on response and most effective parameter for particular response. Equation (1) , (2) and (3) can be used to calculate S/N ratio using smaller the better, nominal the better and larger the better method respectively.

$$SN_S = 10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (1)$$

$$SN_T = 10\log\left(\frac{\bar{y}^2}{s^2}\right) \quad (2)$$

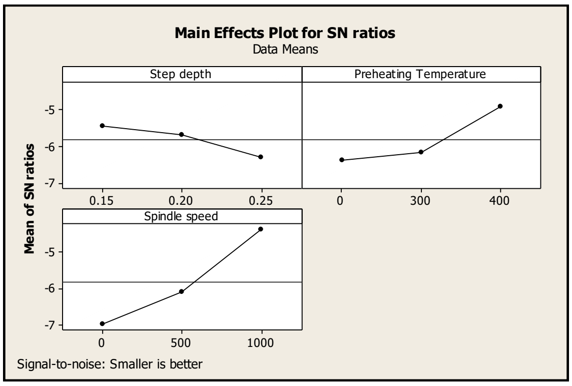
$$SN_L = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (3)$$

S/N ratios are calculated for surface roughness and thinning percentage based on the response values obtained from experiments using equation (2) as it is desired to have low surface roughness and low thinning percentage. SNRA1 shows S/N ratios for surface roughness and SNRA2 shows S/N ratios for thinning percentage in table IV.

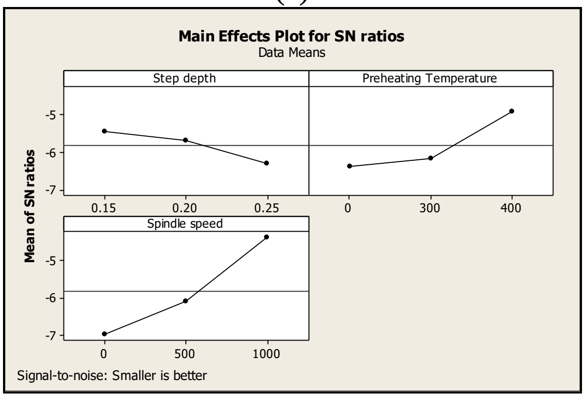
TABLE-IV: Calculated S/N Ratio values

Exp.No.	SNRA1	SNRA2
1	-7.80221	-28.9587
2	-5.66301	-32.6875
3	-2.87902	-33.3901
4	-4.41436	-33.8991
5	-6.9661	-29.7314
6	-5.71864	-30.4123
7	-6.90617	-31.6367
8	-5.88932	-31.5498
9	-6.14992	-28.0004

The S/N ratios are plotted on plots of parameter values vs means of S/N ratios. The parameter value giving highest mean of S/N ratio gives best result.



(a)



(b)

Fig. 2 parameter values vs mean of S/N ratio (a) surface roughness (b) thinning percentage

It is observed from the plots for surface finish that best values of step depth, preheating temperature and tool rotation speed are 0.15 mm, 400°C, and 1000 rpm. From the plots for thinning percentage it is observed that best values of step depth, heating temperature and tool rotation speed are 0.25mm, 400°C, and 0 rpm respectively.

The increase in step depth results into requirement of high amount of force as more amount of material is to be deformed [4]. Because of this resistance thinning of sheet reduces which is observed in results, shown in fig.5 (b). If the material is stretched by moving the tool to close distances along the depth, smooth surface should be obtained which is observed in results shown in fig.5 (a). From the results of tensile tests it is observed that preheating the sheet metals increases its ductility. Above plots shows that better surface roughness can be obtained by preheating the sheet metals. When the tool is rotated; friction between tool and material increases and local heating takes place while forming operation [4] which causes smooth flow of material and decrease the surface roughness. It is observed that increasing preheating temperature results in less thinning here because height of flange is fixed. It means that further forming is still possible and increase in flange height can be achieved. However, compared to other parameters this effect is less. Tool rotation speed is most effective parameter for surface roughness and thinning percentage both. The surface roughness decreases with increase in tool rotation speed which is in line with the results obtained by [12]. Thinning percentage increases with increase in tool rotation speed because the rotation of tool increases material flow.

TABLE-V: Level means of S/N ratios for surface roughness

Level	Step depth mm	Preheating temperature °C	Tool rotation speed rpm
1	-5.448	-6.374	-6.973
2	-5.700	-6.173	-6.096
3	-6.315	-4.916	4.394
Delta	0.867	1.458	2.579
Rank	3	2	1

TABLE-VI: Level means of S/N ratios for thinning percentage

Level	Step depth mm	Preheating temperature °C	Tool rotation speed rpm
1	-31.68	-31.50	-28.90
2	-30.35	-31.32	-31.58
3	-30.40	-30.60	-32.95
Delta	1.28	0.90	4.05
Rank	2	3	1

To get the most effective parameter, the level means of parameters are calculated. Delta is calculated by subtracting lowest level mean from highest level mean and based on delta values, parameters are given ranks; highest rank to parameter having highest delta value and then in descending order. The most effective parameter to surface roughness is Tool rotation speed and least effective is step depth. For thinning percentage, most effective parameter is Tool rotation speed and least effective is preheating temperature. It is noted that because of tool rotation thinning increases but surface roughness decreases.

So to get better surface roughness without tool rotation, preheating of sheet can be done.

IV CONCLUSION

Preheating of sheet metal varies its grain size. The variation of grain size affects forming behavior of the metal. By considering preheating temperature as a parameter in orthogonal array along with tool rotation speed and step depth, the experiments were performed. From the analysis of the obtained response value by Taguchi method it is observed that most effective parameter affecting surface roughness and thinning is tool rotation speed. It is observed that lowest surface roughness can be obtained by tool rotation speed of 1000 rpm. Opposite to that, lowest thinning can be obtained by performing the hole flanging operation without rotating the spindle. The results obtained can be correlated with the already known effect of increase in grain size on elongation. As the grain size increases the elongation increases, same effect is reflected in the results that as the grain size increases the thinning decreases, which indirectly confirms that better formability can be obtained with increase in grain size.

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