Optimization of Process Parameters on Forming Force for Incremental Forming of SS316

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Abstract. The single point incremental Forming is a versatile process with a good future for the products of mass customization. The process eliminates the design and manufacturing of a die, which is also unique for each and every individual part. The incremental forming operation can be done using a Computer Controlled Machine (CNC) machine. In the present work, the input effects of various process parameters on forming force is determined. The process parameters selected for the present experimental work are sheet thickness, Tool Spindle speed, feed rate and diameter of tool. The experiments are conducted on a CNC machine by using a partial die. The experiments are done according with Taguchi's design of experiments by choosing L9 Array. A Total of 09 experiments are conducted by changing the selected process parameters as per L9. The axial force and radial force required for the incremental forming are measured. ANOVA technique is applied to find the effects of each selected process parameters on the forming force. Finally, optimization of various selected process parameters is done to choose the combination from the selected process parameters for minimizing the forming force. The results show, tool feed rate here is the major influential parameter, followed by Spindle speed for the forming force. The optimized process parameters for incremental forming are found and can be used for incremental forming for minimum forming force.

Keywords: SP Incremental Forming · CNC Machine · ANOVA

1 Introduction

The Incremental Forming is a flexible process most suitable for producing components for mass customization. In Conventional forming process, a die is required for the forming. The design and manufacturing of a die involve high costs, and also the die is unique for every individual component. During mass production, the high cost involved for making dies and punches which are balanced by manufacturing more number of components. But for low-volume production, manufacturing of the components using a die is not economical. Hence, the Incremental forming without die is introduced and has been

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under research and development is going on for the past twenty years. This process needs further improvement in accepts of formability, accuracy and quality. The incremental Sheet Forming process needs a simple ball nose tool, a fixture which holds the sheet material firmly and any Computer Controlled Machine (CNC) machine. The tool can also be moved by using a robotic end effector arm in place of a CNC machine.

2 Literature Survey

C. Veera Ajay (2021) [1] have performed Incremental sheet forming (ISF) process without using a die using a NC machine with a part program. The effect of three process parameters are examined to find its effects on incremental forming force. The Experiments are done on a CNC Machine using a ball nose tool and a required fixture. The three parameters selected were Tool Speed, Feed rate and depth of increment. The Response Surface Methodology and ANOVA was done on the obtained results. It was concluded that Incremental depth is an important parameter effecting the forming force.

Cheng Z et al. [2] used Ultrasonic vibration in the proposed incremental sheet forming process. They could increase the formability and reduce generated forming force by using SPIF assisted by ultrasonic. A model combining dislocation and thermal activation is calibrated and used for the experiments. A FEA model was also used for the Experiments in which a user-defined subroutine and the hybrid model were used to find out the result of ultrasonics and simulation of high-frequency vibration. Comparing Experimental results with that of simulation, the errors were less than 10% for the forming force.

Joost R. Duflou et al. [3] measured Three different components of force during the forming process using a force dynamometer with a fixture for incremental forming positioned on top. The described experimental test programme concentrated on how four different selected process parameters, the step size in vertical between subsequent contours, diameter of tool used and the steepness of the part's wall and sheet thickness effected the forming forces.

Ajay Kumar et al. [4] has investigated the various effects of process parameters during incremental forming on the axial peak forces. The material used was AA2024. It was observed that the axial forces would be high for higher tool diameter and high wall angle. Using a larger diameter of tool and larger thickness of sheet will produce maximum peak force. It was also found that larger sheet thickness will affect in the increase of formability of the material but requires larger forming forces.

Bagudanch et al. [5] measured the forming forces during incremental forming and it was found that the forming force increases with increase in tool diameter and step size mean while the forming force decreases with larger tool speeds.

Aerens et al. [6] have predicted the three force components for five different materials using Experimental and FEM methods.

Durante et al. [7] have evaluated the effect of tool speed on surface finish in SPIF and not much significant effect was seen.

Perez-Santiago et al. [8] formed an equation to predict forming force for different geometries which can be used to predict the forming force of other geometries using computational intelligence. This is useful in predicting forming force online. The in-process inspection done on CNC machine [9] can be used for SPIF as well.

Table 1. Selected Process parameters along with their levels for Experimentation

Process parameters	Level 1	Level 2	Level 3
Sheet thickness (mm)	0.8	1	1.2
Spindle Speed (rpm)	1000	1200	1400
Feed rate (mm/min)	600	800	1000

Y. Li et al. [10] proposed an analytical model for force prediction and validated experimentally.

Zeradam et al. [11] have generated tool path for SPIF numerical simulations using Microsoft excel. Further the tool path strategies on the formability is investigated [12] using experimental and numerical methods. The simulations are also used to predict the thinning of DDQ steel during incremental forming [13].

B. Saidi et al. [14] have done the optimization of process parameters for minimizing the forming force during SPIF.

3 Experimental Setup and Procedure

3.1 Selecting Process Parameters

In the present experimental work, the effects of different input selected parameters on the axial force during the SPIF process is investigated. As per Literature, the most important and main process parameters are spindle speed, sheet thickness, feed rate, and tool diameter. The experiments are done on a CNC machine using a partial die with a ball nose tool of 10mm diameter. The experiments are done as designed by Taguchi's design of Experiments. The selected process parameters for the experimentation are sheet thickness, tool feed rate and Tool spindle speed where tool is fixed. The experiments are done by varying levels of the process parameters at three levels. Table 1 shows the selected process parameters along with their levels selected.

3.2 Design of Experiments

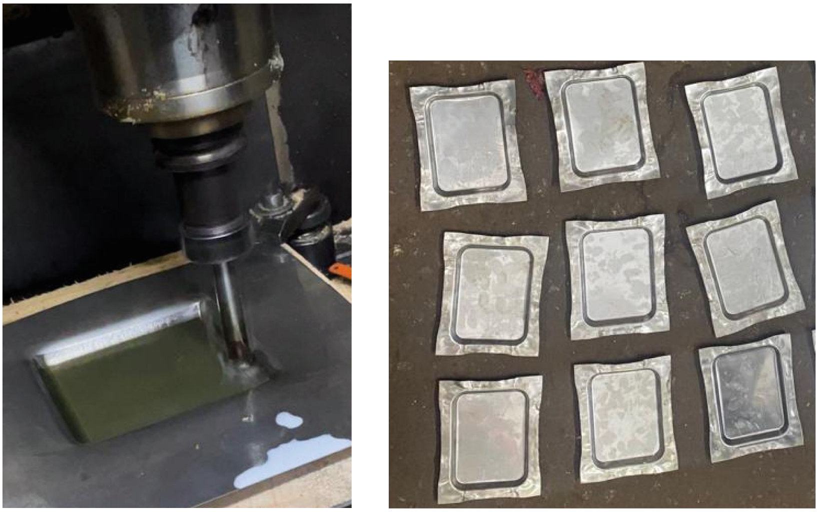
After selecting the three parameters along with their levels, the experiments are done as per Taguchi's design of experiments. In the present experimental work, Taguchi's L9 orthogonal array is selected. The incremental forming is done for each trial and the axial forming force during SPIF is recorded. The run order of the experiments is shown in Table 2.

3.3 Experimentation

The experiments are conducted on a 3 Axis milling machine by using a ball nose tool of 10mm diameter. The tool is fixed for all the experiments. The tool path required for incremental forming is generated, and the required process parameters are set for each experimentation. The sheet is fixed onto the CNC table, and a partial die for forming is used at the end of the formed sheet. The axial force during the forming process is recorded. The experimental set-up and machine used is shown in Fig. 1.

Table 2. Process parameters with their levels selected for Experimentation

S. No	Sheet thickness (mm)	Tool Speed (rpm)	Feed rate (mm/min)
1	0.8	1000	600
2	0.8	1200	800
3	0.8	1400	1000
4	1	1000	800
5	1	1200	1000
6	1	1400	600
7	1.2	1000	1000
8	1.2	1200	600
9	1.2	1400	800



a b

Fig. 1. a) Experimental set up of incremental forming b) Components formed

4 Results and Discussions

The experiments which are done based on the L9 orthogonal array. The effects of Tool speed, Tool feed rate and sheet size on the axial force developed on the sheet are recorded. The recorded output values are shown in Table 3.

After performing the experimentations, the obtained results are used for optimizing the set input parameters that can be used for SPIF to reduce and minimize the forming force. The main effect plots are drawn for the experiments. The Analysis of variance is done to see the importance of each selected input parameters on the resulted forming

Table 3. Selected Process parameters and their levels

S. No	Sheet thickness (mm)	Spindle Speed (rpm)	Feed rate (mm/min)	Maximum Axial force (N)
1	0.8	1000	600	657.24
2	0.8	1200	800	674.27
3	0.8	1400	1000	712.87
4	1	1000	800	756.85
5	1	1200	1000	785.36
6	1	1400	600	616.19
7	1.2	1000	1000	843.86
8	1.2	1200	600	682.45
9	1.2	1400	800	728.32

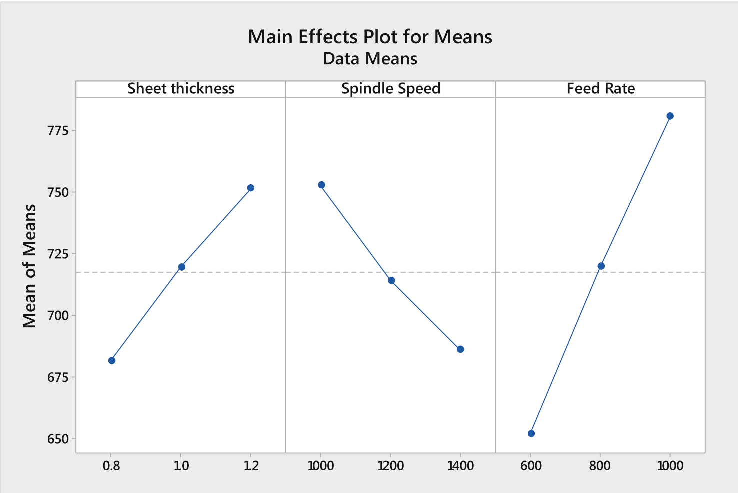


Fig. 2. Main Effects plot for selected process parameters

force. Figures 2 and 3 shows the main effect plots and interaction plots and finally ANOVA results are shown in Table 4.

5 Conclusions

The effects of several selected process parameters like Sheet thickness, Tool Spindle speed and Tool Feed rate on the resulted forming force have been analyzed Experimentally, and these process parameters were optimized to minimize the forming force. It has been observed that an increase in the Spindle speed and feed rate will decrease the forming force. There is an irregularity in the axial force w.r.t sheet thickness, spindle

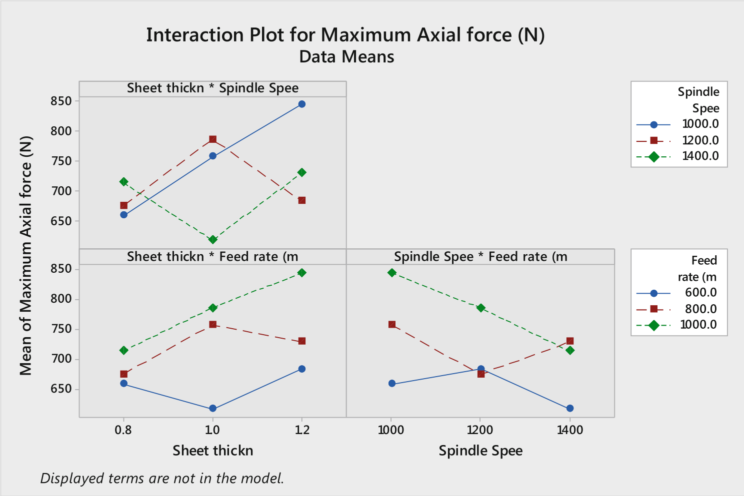


Fig. 3. Interaction plots of selected process parameters for maximum Axial force

Table 4. ANOVA for the Process parameters

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sheet thickness	2	7385.1	3692.5	33.07	0.029
Spindle Speed	2	6758.7	3379.3	30.27	0.032
Feed Rate	2	24884.0	12442.0	111.43	0.009
Error	2	223.3	111.7		
Total	8	39251.1			

speed and feed rate which may be because of using a partial die. The Excessive forming force may lead to fracture in the sheet material; thus, optimization is done to keep the forming force minimum. The main effect plots as well as interaction plots for the results are generated. The results from the ANOVA test shows that the tool feed rate here is the major influential parameter, followed by Spindle speed for the forming force. The optimized process parameters for incremental forming are 0.8mm Sheet thickness, 1380 rpm Tool speed and 715mm/min of Feed rate. The optimized results can be used for incremental forming for minimum forming force. The further investigation can be done to reduce the failures.

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