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Optimization of Incremental Sheet Forming (ISF) process for AA6063 - 'O' by using Grey Relational Grade

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Abstract

The unconventional technique of sheet forming from ductile material is incremental sheet forming. The best materials are bronze, copper, and aluminium. The sheet is held in holding devices and a rotating tool during incremental sheet forming (ISF) in order to create a localized deformation of the sheet and produce the required component. The ISF technique was used to create a circle with a diameter of 100 mm and a depth of 30 mm with a spiral tool path as the single path approach. on a 6063-'O' Al sheet with a commercial thickness of 1.5 mm. All components had a maximum forming depth of 28.5 mm. 0.1 % to 1% spring back of the inner circle was seen in all components. The maximum and minimum sheet thinning at wall angles are 34.667% and 20%, respectively. Due to its various application across a variety of industries, an experimental study has been conducted on 6063 - "O" aluminium, which offers high formability and less hardness than many other materials.

Keywords: incremental sheet forming, spring back, sheet thinning, Al 6063 -'O'.

1. INTRODUCTION

One of the unconventional sheet metal forming techniques is incremental forming, commonly referred to as a die-less forming method. Rapid prototyping is a technique that is frequently employed in the automotive, aerospace and biomedical sectors. A spherical tool that rotates at a steady rpm and follows a predetermined route on a CNC vertical milling machine produces the end product in the desired size and form. By adjusting process variables such as step size, tool speed, and tool feed, the component's maximum wall angle and depth may be achieved. [1, 2]

The thought of using an automated technique for tasks carried out on formed products surfaced. Anything better than computer numeric controlled (CNC) machinery. With any typical milling machine with at least a 3-axis CNC control technique, incremental sheet formation is possible. The material to be formed, a blank holder that clamps the blank, a very basic, all-purpose forming tool, and a forming machine with CNC control are therefore likely the fundamental components of incremental forming processes. Making ISF the very procedure that aids in small batch mass manufacturing and lowers its total cost has been the aim behind it. As this technique can be performed on any 3-axis CNC machine, its components may be created immediately in CAD data file applications such (as CREO, Solid works, ANSYS).

The nature and thickness of the sheet have a significant impact on the process variables. For example, as sheet thickness grows, more force is needed to create the sheet and vice versa. In order to achieve acceptable sheet-surface finishing qualities and prevent any stress creation during the whole forming procedure, a seemly lubrication is required. The force that must be supplied is determined by the contact between the tool and the sheet to be handled. The ability to use the method for various materials is one strategy that gave ISF a flexible performance.

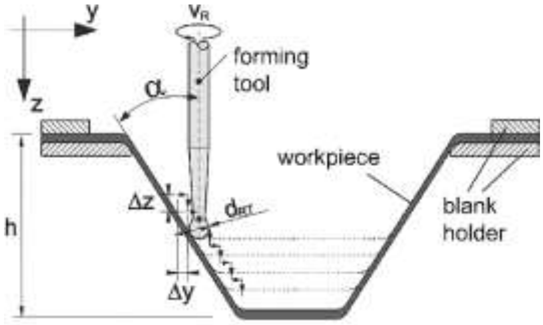

Figure 1.1 ISF schematic diagram [2]

2. EXPERIMENT PROCEDURE

2.1. Sheet Material and Tool:

Aluminium alloy 6063'O' (soft) of 200*200*1.5mm plate is utilised in this single-stage incremental technique to create a spiral-shaped component. The chemical composition and significant mechanical characteristics of AL6063'O' are shown in Tables 2.1 and 2.2, respectively.

Table 2.1. Chemical Composition of AL6063'O'

Element	Al	Mg	Si	Fe	Cr	Cu	Mn	Ti	Zn	other
Minimum (% by weight)	97.5	0.45	0.20	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Maximum (% by weight)	99.35	0.90	0.60	0.35	0.10	0.10	0.10	0.10	0.10	0.015 total (0.05 each)

Table 2.2. Mechanical properties of AL6063'O'

Property	Observed Value
Young's modules (GPa)	68
Ultimate tensile strength (MPa)	185
Elongation at break (%)	32.95
Poission ratio	0.28
Yield strength (MPa)	213.5

The incremental forming tool with a spherical end of 12 mm in diameter and an overall length of 110 mm is fabricated of WPS stainless steel.

2.2 Machine and Process parameters:

The experiment was carried out using a CNC milling machine called the ACE/MCV 350, which has a 5.0 kW spindle motor and an 8000rpm spindle speed. Models are created using the Siemens NX programme, and G-code and tool path are produced from the models. The aluminium sheet was fastened in a fixture with a 100 mm-diameter circular. The oil used was Harlube GPL 60, which contains a lubricant.

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CNC Milling Machine ACE/MCV 350		
Machine Specifications		
X Axis	MM	[illegible]
[illegible]	MM	[illegible]
[illegible]	MM	[illegible]
Maximum Lod on Table	KG	[illegible]
Positioning of Axis(Accuracy)	MM	[illegible]
Maximum Tool Length	MM	[illegible]
Taper		[illegible]
Maximum Speed	RPM	[illegible]
Magazine Capacity	NOS	[illegible]
Maximum Lod on Table	KG	[illegible]
Spindle Motor		AC Servo
Maximum Tool Diameter	MM	[illegible]
Maximum Tool Weight	KG	[illegible]
Spindle Motor Capacity	KG	[illegible]

Figure 2.1 MCV350 Table

Figure 2.2 Incremental forming tool

Figure 2.3 Fixture used to fix a sheet

Figure 2.4 MCV350 Machine

2.3 Experiment design using Taguchi design for the process parameter:

Each process starts with a design of experiment (DoE) that is appropriate for the process parameters. The step size, spindle speed, and feed rate were chosen as the test's input parameters. Step size (0.2, 0.25, 0.3) parameters, spindle speed (900, 950, 1000 rpm), and feed rate (900, 950, 1000 mm/min) parameters were all used as input values. There are nine various states that should be carried out in this procedure, according to the Taguchi design (Table 2.3).

Table 2.3. L9 Orthogonal Array

Experiment No.	Step size (mm)	Spindle speed (rpm)	Feed rate (mm/min)
1	0.2	900	900
2	0.2	950	950
3	0.2	1000	1000
4	0.25	900	950
5	0.25	950	1000
6	0.25	1000	900
7	0.3	900	1000
8	0.3	950	900
9	0.3	1000	950

3. PERFORMING TESTS AND MEASURING THE OUTPUT PARAMETERS

1. In this work, tests were carried out to determine how input factors affected the output parameters of spring back and sheet thinning. The results of experiments to find the lowest sheet thinning and least spring back were given.

Figure 3.1. Forming tool

Figure 3.2. Forming process

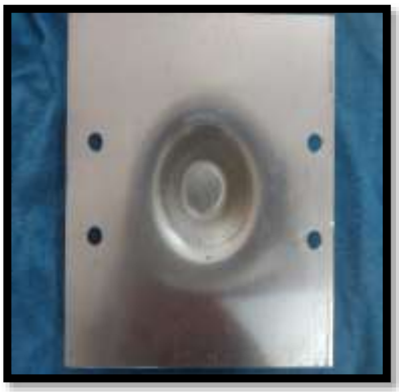

Figure 3.3 Formed sheet

2. The following output parameters were chosen to represent the outcomes and analysis of this experiment:

1. Sheet thinning: a) side 1 and b) side 2
2. Spring back of the inner circle
3. Spring back of the depth

The following are the output values obtained with respect to the design of experiment in terms of percentage as stated in the previous chapter.

Sheet thinning side 1 (%)	Sheet thinning side 2 (%)	Spring back of the inner circle (%)	Spring back of the depth (%)
34.667	33.333	0.12	5.2631
26.667	25.333	0.087	5.2631
26.667	26.667	0.28315	5.0877
33.333	32	0.415	10.5263
24	23	0.36	7.0175
22	26.667	0.00663	12.2807
26.667	26.667	0.1329	7.0175
20	20	0.116	3.5087
26.667	26	0.1389	2.4561

4. RESULTS AND DISCUSSION

The analytical data that were collected after successfully completing this analysis are as follows;

4.1. Derive SN ratios:

Signal to noise ratio is measured in decibels and compares the strength of the signal to the strength of the noise. The solution "smaller is better" was chosen using the Taguchi approach for optimization.

4.1.1 Taguchi Analysis: sheet thinning side 1 versus step size, spindle speed, feed rate:

Table 4.1 Response Table for Signal-to-Noise Ratios

Smaller is better

Industrial Engineering Journal
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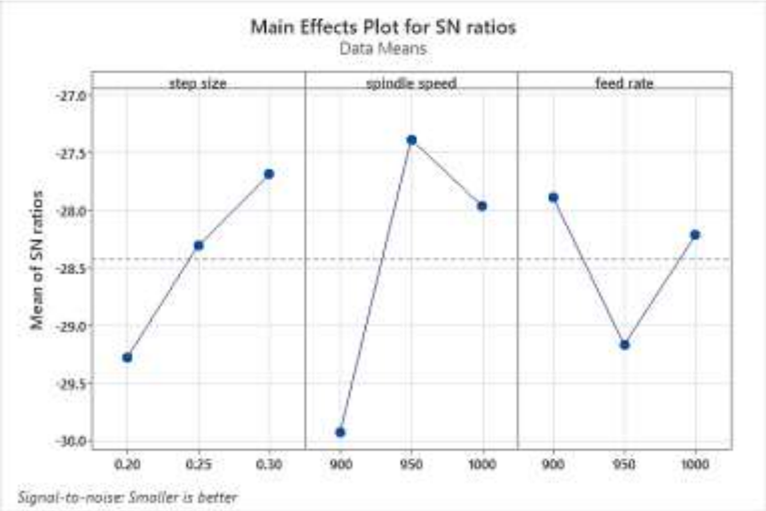
Level	step size	spindle speed	feed rate
1	-29.28	-29.93	-27.89
2	-28.30	-27.38	-29.17
3	-27.69	-27.96	-28.21
Delta	1.59	2.54	1.28
Rank	2	1	3

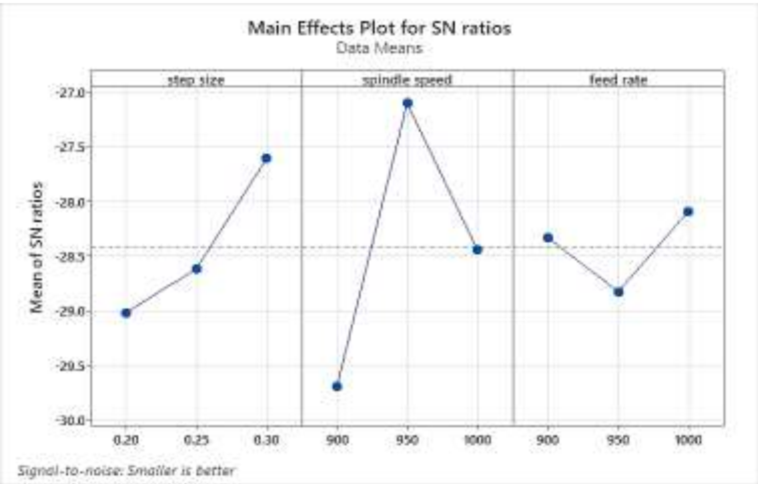


4.1.2 Taguchi Analysis: sheet thinning side 2 versus step size, spindle speed, feed rate:

Table 4.2 Response Table for Signal-to-Noise Ratios

Smaller is better

Level	step size	spindle speed	feed rate
1	-29.02	-29.69	-28.33
2	-28.62	-27.11	-28.83
3	-27.61	-28.45	-28.09
Delta	1.40	2.58	0.73
Rank	2	1	3



4.1.3 Taguchi Analysis: inner circle versus step size, spindle speed, feed rate:

Table 4.3 Response Table for Signal-to-Noise Ratios

Smaller is better

Industrial Engineering Journal
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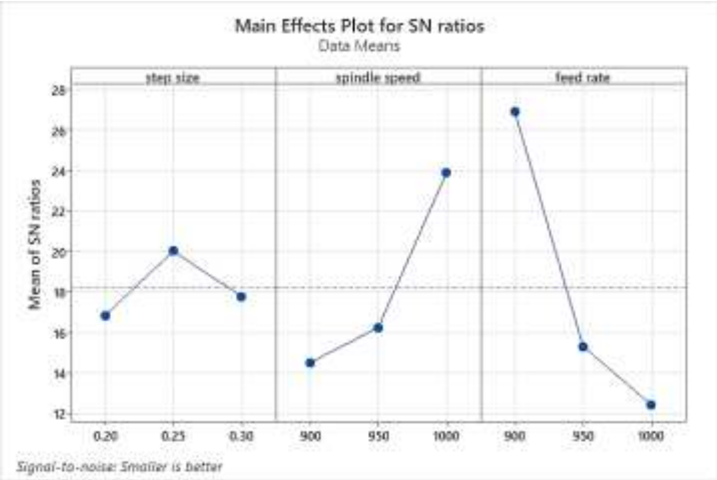
Level	step size	spindle speed	feed rate
1	16.86	14.53	26.90
2	20.03	16.26	15.33
3	17.80	23.89	12.45
Delta	3.17	9.36	14.44
Rank	3	2	1



4.1.4 Taguchi Analysis: depth versus step size, spindle speed, feed rate:

Table 4.4. Response Table for Signal-to-Noise Ratios

Smaller is better

Level	step size	spindle speed	feed rate
1	-14.33	-17.26	-15.70
2	-19.72	-14.08	-14.23
3	-11.88	-14.57	-15.99
Delta	7.84	3.18	1.77
Rank	1	2	3

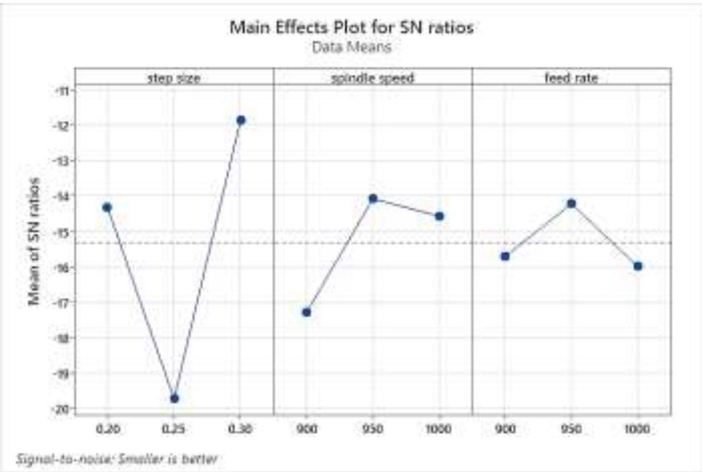


Table 4.1.5 The SN values of the output parameters

SNRA1	SNRA2	SNRA3	SNRA4

-30.7983	-30.4575	18.41638	-14.4248
-28.5195	-28.0737	21.20961	-14.4248
-28.5195	-28.5195	10.95967	-14.1304
-30.4575	-30.103	7.639038	-20.4455
-27.6042	-27.2346	8.87395	-16.9236
-26.8485	-28.5195	43.56973	-21.7845
-28.5195	-28.5195	17.5295	-16.9236
-26.0206	-26.0206	18.71084	-10.9029
-28.5195	-28.2995	17.14596	-7.80492

4.2. Normalization of SN ratios:

Signal to Noise ratio is standardized and optimized in MS Excel with respect to each output parameter, with the goal of achieving a value that is generally optimized for better calculation. If the Signal to Noise ratio is greater than 1, this indicates that the noise power is greater than the signal power.

Table 4.2.1 The Normalized SN ratio values

Normalized SNRA1	**Normalized SNRA2**	**Normalized SNRA3**	**Normalized SNRA4**
0.0000	0.0000	0.2999	0.5265
0.4770	0.5373	0.3777	0.5265
0.4770	0.4368	0.0924	0.5475
0.0713	0.0799	0.0000	0.0958
0.6685	0.7264	0.0344	0.3477
0.8267	0.4368	1.0000	0.0000
0.4770	0.4368	0.2753	0.3477
1.0000	1.0000	0.3081	0.7784
0.4770	0.4864	0.2646	1.0000

4.3. Deviation of SN ratios:

Table 4.3.1 The deviation SN ratio values

Deviation SNRA1	**Deviation SNRA2**	**Deviation SNRA3**	**Deviation SNRA4**
1.0000	1.0000	0.7001	0.4735
0.5230	0.4627	0.6223	0.4735
0.5230	0.5632	0.9076	0.4525
0.9287	0.9201	1.0000	0.9042

0.3315	0.2736	0.9656	0.6523
0.1733	0.5632	0.0000	1.0000
0.5230	0.5632	0.7247	0.6523
0.0000	0.0000	0.6919	0.2216
0.5230	0.5136	0.7354	0.0000

4.4. Obtain Grey Relation Co-relation grade:

The approach of computing multi-factor optimization for each process and obtaining a grade for each individual process is known as grey relation co-relation.

$$GRC = [\Delta_{minimum} + (0.5*\Delta_{maximum})] / [(value) + (0.5*\Delta_{maximum})]$$

Table 4.4.1. The GRC for each of the output parameters

GRC SNRA1	GRC SNRA2	GRC SNRA3	GRC SNRA4
0.3333	0.3333	0.4166	0.5136
0.4887	0.5193	0.4455	0.5136
0.4887	0.4703	0.3552	0.5249
0.3500	0.3521	0.3333	0.3561
0.6014	0.6463	0.3412	0.4339
0.7426	0.4703	1.0000	0.3333
0.4887	0.4703	0.4083	0.4339
1.0000	1.0000	0.4195	0.6929
0.4887	0.4933	0.4047	1.0000

The measured GRC values are then standardized and a solo GRC factor is generated by taking the average of all the three GRC values found in the table above and the average value calculated.

Table 4.4.2

GRC	Rank
0.3992	8
0.4918	5
0.4598	6
0.3479	9
0.5057	4
0.6366	2
0.4503	7
0.7781	1
0.5967	3

The Grey's relation co-relation grade (GRG) provides the best and more optimal process parameters for the whole L9 DOE of ISF on AA 6063'O' sheets after completing the Taguchi analysis as previously mentioned.

Table 4.4.3 Optimized Results from Taguchi Analysis

Rank	Tool geometry	Step size	Spindle speed (rpm)	Feed rate (mm/min)
1	Spherical tool	0.3	950	900
2	Spherical tool	0.25	1000	900

5. CONCLUSION

- In this research, it has been determined step size, feed rate, and spindle speed affect sheet thinning and spring back during the ISF. Taguchi Method help to solve the ISF problem which is proposed in research.
- From experiment the sheet thinning has maximum and minimum percentage of error is 34.667% and 20%.because from SN ratio it seen that the more influence factor is spindle speed as compare to feed rate and step size.
- For spring back of inner circle the less influence factor is spindle speed and step size and for depth the maximum depth is occur is 27.80mm and the taken depth for experiment was 30mm . the most influence factor is step size with respective to other parameter.
- By using grey relational grade experiment 8 (Rank 1) and experiment 6 (Rank 2) are the best results out of other experiment

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