# OPTIMIZATION OF FORMABILITY PARAMETERS IN INCREMENTAL SHEET METAL FORMING PROCESS

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**Abstract-**The Conventional forming process, without die and punch press, cannot be completed for desired product output and it leads to higher cost of setup forming process in industries, especially in automotive and sheet metal industries. To come over this cost factor, there is need of unique process for forming of sheet metal which eliminates higher setup cost of die and punch press. Considering lead time for process starting, it also takes higher lead time in conventional process which also effects on ultimate manufacturing cost. Surface quality and wall thickness mainly depends on the input parameters during forming process. This study aims to optimize surface roughness and wall thickness through incremental forming on AA6063 Aluminium alloy at room temperature by controlling the effects of forming parameters. To conclude the optimum process parameters in ISF, Taguchi method of DOE with L9 orthogonal array was developed for different process parameter factors such as feed rate, speed of spindle, wall angle, and step depth increment.

**Keywords:** Incremental forming, Optimization, Surface roughness, Wall thickness, Taguchi grey relation analysis

## 1. Introduction

Incremental forming (IF) is one of the most promising techniques due to its various applications. Single Point Incremental Forming (SPIF) is a process for producing complex external shapes and profiles in a sheet metal using a hemispherical shaped tool controlled by means of a CNC milling machine. Since it does not require dies and punch to form a complex shape, it is very appropriate for rapid prototyping. The tool travels in the programmed path and deforms the sheet into desired shape. Some of the outstanding features, such as flexibility, low cost tooling, makes it suitable for various applications. It is capable to manufacture various irregular complex components and highly customized medical components [1-3]. Many researchers studied the metal forming parameters like spindle speed, tool feed and step size. In this study, an attempt has been made to optimize the metal forming parameters such as surface roughness and sheet thickness after forming [4-7]. The aim in this study is to obtain minimum surface roughness and maximum wall thickness in incremental forming. Response surface methodology has been used to develop mathematical relations between the forming parameters (spindle speed (V), tool feed (F) and step size(S) and response parameters (surface roughness (Ra) and wall thickness (t) by using the experimental data obtained through experimentation [8-10]. A five level full central composite factorial design was chosen with quadratic model to optimize the forming parameters. Analysis of variance test has been done to test the adequacy of the developed mathematical model.

## 2. Material and Methods

AA6063 Aluminium alloy sheet metal of thickness 1 mm in cold rolled condition was used for experimentation. The blank with size 150 mm x 150 mm was held in a fixture shown in figure 2(a). The fixture along with the sheet metal is mounted on the table of the CNC machine is shown in figure 2(b). A frustum of a cone with 100 mm as maximum diameter, 50 mm as minimum diameter and 50 mm depth was formed incrementally in AA6063 Aluminum sheet (figure 3)

**Fig.1 CNC Machine for metal forming process**

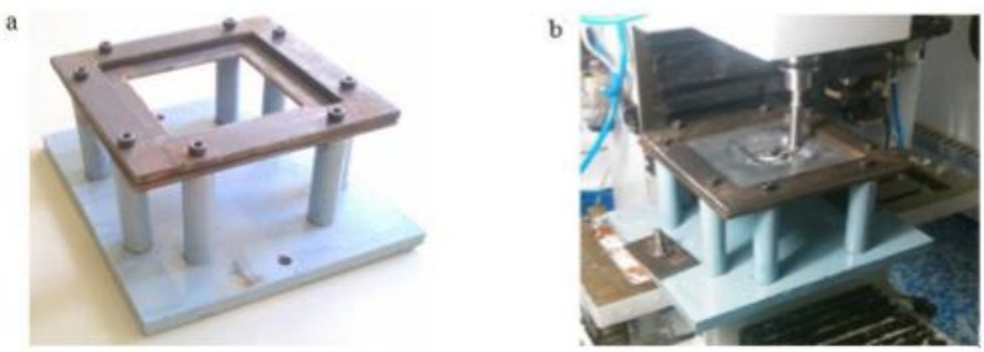


**Fig.2 (a) Fixture to hold sheet metal and (b) fixture with sheet metal mounted on CNC machine**

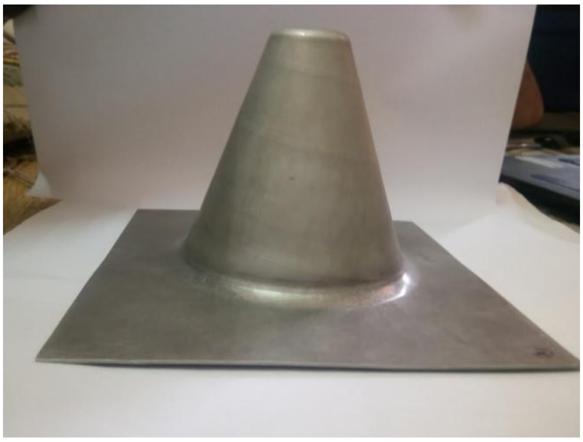

**Fig.3 Cone formed by increment forming process**

### 2.1 Surface Roughness Test

Surface roughness often shortened to roughness, is a component of surface. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. Roughness is typically considered to be the high-frequency, short-wavelength component of a measured surface. However, in practice it is often necessary to know both the amplitude and frequency to ensure that a surface is fit for a purpose.

**Fig.4 Surface roughness tester taking trace of Ra value**

### 2.2 Dial Gauge

A dial indicator is any of various instruments used to accurately measure the small distances and angles, and amplify them to make them more obvious. Many indicators have a dial display, in which a needle point to graduation in a circular array around the dial. Indicators may be used to check the variation in tolerance during the inspection. In this study, during optimization of the process parameters, thickness distribution is to be measured. Thickness distribution is one of the output responses of the optimization.

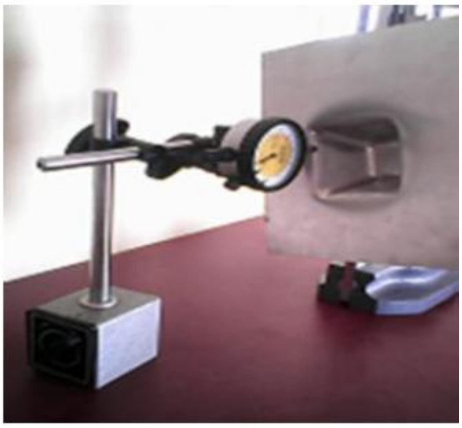

**Fig.5 Thinning measurement using Dial**

## 3.Design of Experiment

Taguchi method is adopted for optimizing process variables as it is simple and easy. The method is popularly known as the factorial design of experiments. This method uses a special set of arrays called orthogonal arrays. The orthogonal arrays method lies in choosing the level combinations of the input design variables for each experiment. The L9 orthogonal array is meant for understanding the effect of 4 independent factors each having 3 factor level values. Design of experiments (DOE) is a systematic method to determine the relationship between factors affecting a process and the output of that process. In other words, it is used to find cause-and-effect relationships. This information is needed to manage process inputs in order to optimize the output.

**Table 1 level of factor**

| S.NO | FACTORS | LEVEL1 | LEVEL 2 | LEVEL 3 | UNITS |
|---|---|---|---|---|---|
| 1 | FEED RATE | 400 | 600 | 800 | **mm/min** |
| 2 | SPINDLE SPEED | 1500 | 2000 | 2500 | **Rpm** |
| 3 | VERTICAL STEP DEPTH | 0.25 | 0.5 | 0.75 | **mm** |
| 4 | WALL ANGLE | 60 | 63 | 66 | **degree** |

### 3.1 Experimental Input Parameter

The input parameter chosen for the optimization process are given below. In L9 orthogonal array we can take maximum four input parameter with maximum three level of factor. The table given below shows the L9 orthogonal array with the input parameter.

**Table 2 Experiment layout**

| EX.NO | FEED RATE | SPEED | VERTICAL STEP | WALL ANGLE |
|---|---|---|---|---|
| 1 | 400 | 1500 | 0.25 | 60 |
| 2 | 400 | 2000 | 0.50 | 63 |
| 3 | 400 | 2500 | 0.75 | 66 |
| 4 | 600 | 1500 | 0.50 | 66 |
| 5 | 600 | 2000 | 0.75 | 60 |
| 6 | 600 | 2500 | 0.25 | 63 |
| 7 | 800 | 1500 | 0.75 | 63 |
| 8 | 800 | 2000 | 0.25 | 66 |
| 9 | 800 | 2500 | 0.50 | 60 |

### 3.2 Response Parameter

The response parameters are the output or expected parameter to be optimized. The chosen parameters are wall thickness and surface roughness. The mean value of the response.

**Table 3 Observed Response**

| EX.NO | FEED RATE | SPEED | VERTICAL STEP | WALL ANGLE | SURFACE ROUGHNESS | WALL THICKNESS |
|---|---|---|---|---|---|---|
| 1 | 400 | 1500 | 0.25 | 60 | 2.127 | 0.75 |
| 2 | 400 | 2000 | 0.50 | 63 | 3.691 | 0.67 |
| 3 | 400 | 2500 | 0.75 | 66 | 4.481 | 0.56 |
| 4 | 600 | 1500 | 0.50 | 66 | 3.573 | 0.55 |
| 5 | 600 | 2000 | 0.75 | 60 | 4.292 | 0.74 |
| 6 | 600 | 2500 | 0.25 | 63 | 2.017 | 0.65 |
| 7 | 800 | 1500 | 0.75 | 63 | 4.072 | 0.64 |
| 8 | 800 | 2000 | 0.25 | 66 | 1.947 | 0.54 |
| 9 | 800 | 2500 | 0.50 | 60 | 3.241 | 0.72 |

**Table 4 S/N ratio for experimental result**

| EX.NO | S/N RTIO SURFACE ROUHNESS | S/N RATIO FOR WALL THICKNES |
|---|---|---|
| 1 | -6.55535 | -2.50032 |
| 2 | -11.2091 | -3.43603 |
| 3 | -13.0333 | -5.03901 |
| 4 | -11.0575 | -5.20424 |
| 5 | -12.6539 | -2.65835 |
| 6 | -6.09844 | -3.84055 |
| 7 | -12.1976 | -3.83197 |
| 8 | -5.79201 | -5.3551 |
| 9 | -10.2279 | -2.81707 |

**Table 5 normalized response value**

| EX.NO | SURFACE ROUGHNESS | WALL THICKNESS |
|---|---|---|
| 1 | 0.111243 | 1 |
| 2 | 0.789446 | 0.67223 |
| 3 | 1.055291 | 0.110723 |
| 4 | 0.767353 | 0.052845 |
| 5 | 1 | 0.944644 |
| 6 | 0.044657 | 0.530531 |
| 7 | 0.933502 | 0.533537 |
| 8 | 0 | 0 |
| 9 | 0.646453 | 0.889046 |

**Table 6 calculation of grey relation coefficient and grey relation grade**

| EX.NO | SURFACE ROUGHNESS | WALL THICKNESS | GREY GRADE VALUE |
|---|---|---|---|
| **1** | 0.18370 | 1.00000 | 0.591848 |
| **2** | 0.48715 | 0.37895 | 0.433050 |
| **3** | 1.38208 | 0.18361 | 0.782846 |
| **4** | 0.46227 | 0.17434 | 0.318307 |
| **5** | 1.00000 | 0.78322 | 0.891610 |
| **6** | 0.17311 | 0.29874 | 0.235927 |
| **7** | 0.75048 | 0.30009 | 0.525284 |
| **8** | 0.16667 | 0.16667 | 0.166667 |
| **9** | 0.36131 | 0.64318 | 0.502244 |

The average grey relation grades are calculated for each level of each factor and are shown below.

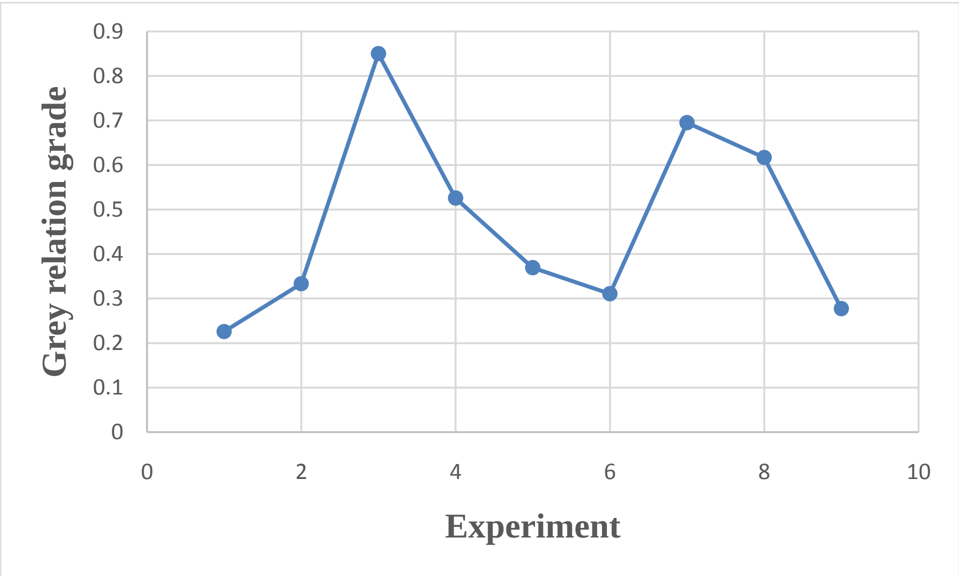


**Fig.6 Grey relation grade for each experiment**

## 4. Determination of Optimal Conditions After Multi-response Optimization

Optimal process parameters are determined from the average grey relation grade table. The levels of factors corresponding to highest value of average grey relation grades are taken as the optimized process parameters. The optimal process Parameters are shown in the table below.

**Table 7 Grey grade value**

| LEVEL | FEED | SPEED | STEP | WALL ANGLE |
|---|---|---|---|---|
| 1 | **0.6026** | 0.4785 | **0.3315** | **0.6619** |
| 2 | 0.4819 | 0.4971 | 0.4179 | 0.3981 |
| 3 | 0.3981 | **0.5070** | 0.7332 | 0.4226 |

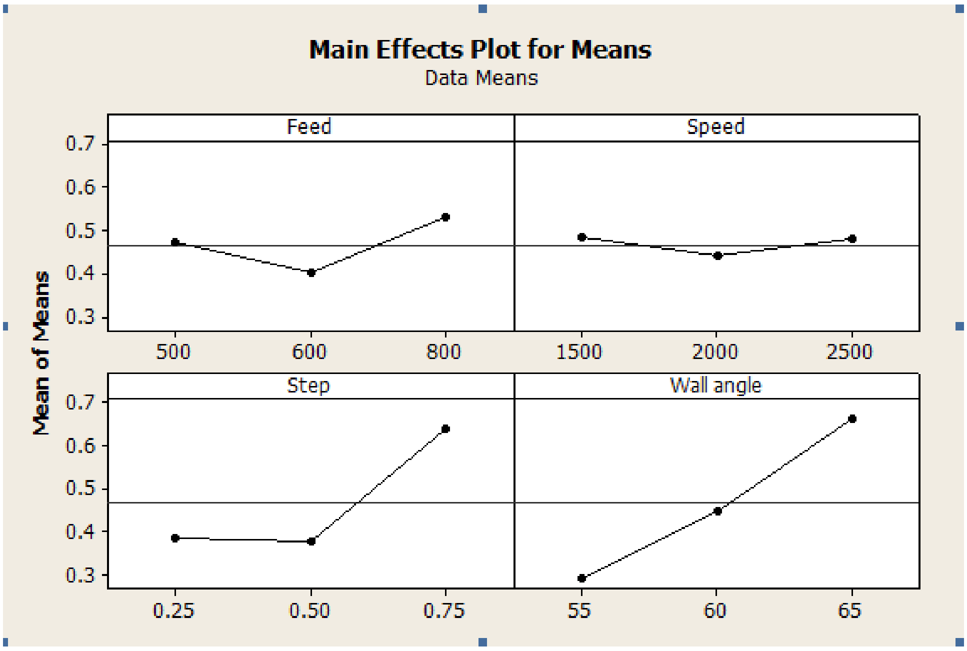


**Fig.7 Main effect plot of the grey grade value**

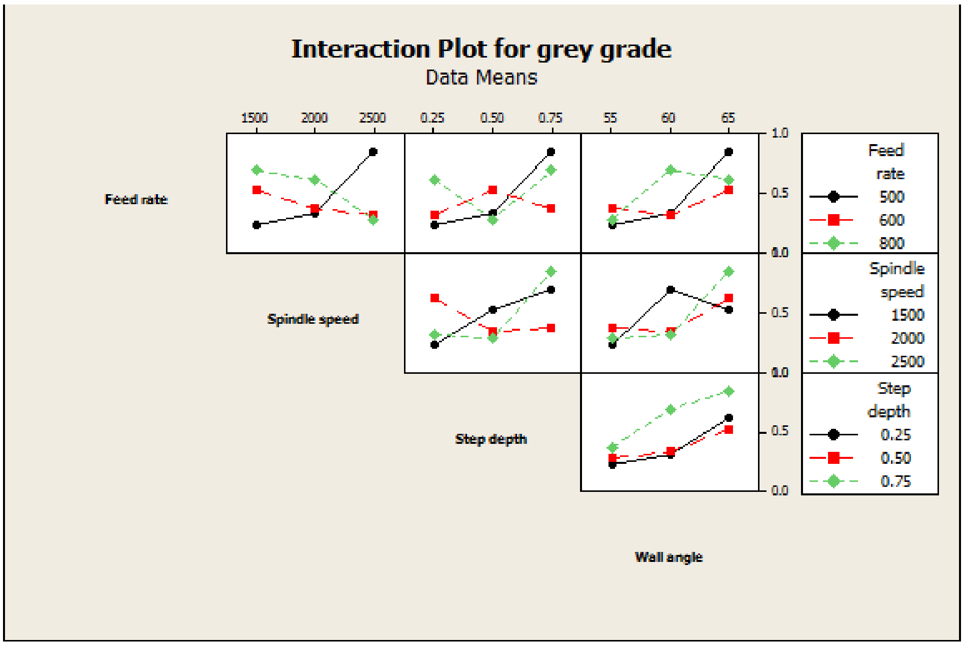


**Fig.8 Interaction plot of the grey grade value**

## 4.1 Fesm Test

Field emission scanning electron microscopy (FESEM) provides topographical and elemental information at magnifications of 10x to 300,000x, with virtually unlimited depth of field. Compared with convention scanning electron microscopy (SEM), field emission SEM (FESEM) produces clearer, less electrostatically distorted images with spatial resolution down to 1 1/2 nanometers – three to six times better.

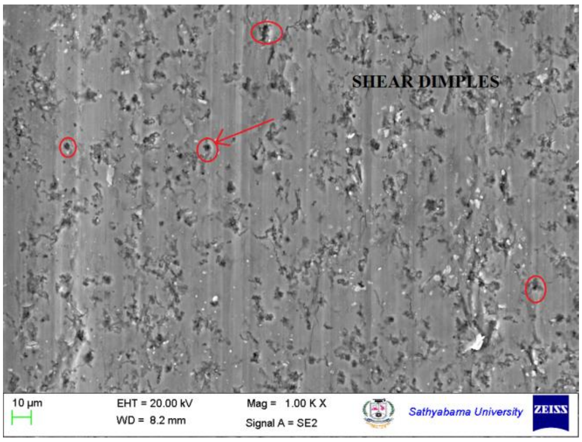


**Fig.9 shear dimple in FESEM**

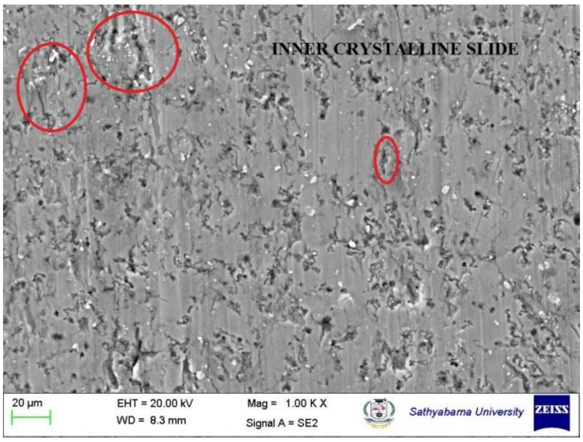


**Fig.10 inter crystalline slide in FESEM**

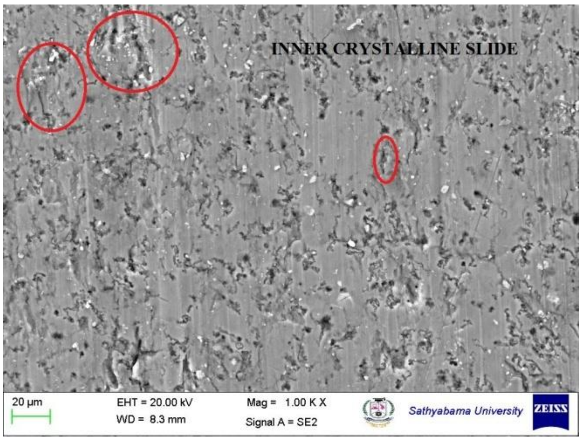


**Fig.11 Inter crystalline slide at the surface**

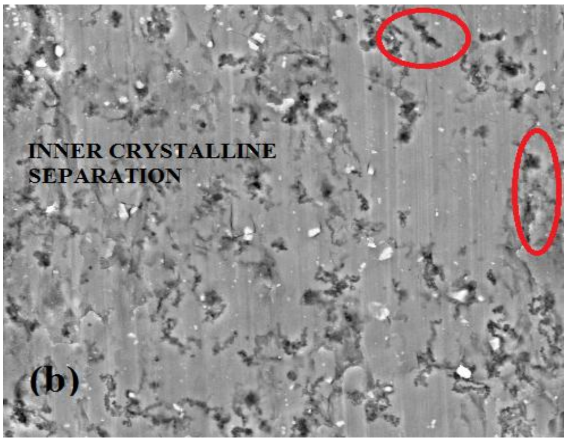


**Fig.12 Inner crystalline separation**

## 5. Conclusion

The incremental sheet metal forming process and the effect of the various process parameters were analysed by Taguchi methods. Grey relation analysis was done for multi objective optimization. The following conclusions were arrived from the research. The hierarchy of process variables affecting Surface Roughness and wall thickness were established, and optimal conditions for obtaining a better output with the desired minimum Surface Roughness and better wall thickness were determined. The Grey relation analysis done on the observed measurement values predicts that speed of 2500 rpm, feed rate 800 mm/min and 60 degree wall angle are the optimal process parameter setting to achieve minimum surface roughness, and wall thickness. From the experimental layout and result it is observed that, step depth and feed rate has the greater influence in surface roughness. Lowering the step depth and in combination with larger feed rate, the observed surface finish is small. Spindle speed has no impact towards Surface roughness and wall thickness.
Better response wall thickness is observed when wall angle is minimum, this shows that feed rate and depth of cut has no greater impact towards wall thickness. Wall thickness is purely depend on wall angle

- The optimal control settings of 2500 rpm, 800 mm/rev, 0.25mm, 60degree were found to yield the highest S/N ratios and low surface roughness.
- The optimal control settings of 2500 rpm, 8000 mm/rev, 0.25mm, 60 degree were found to yield the highest S/N ratios and wall thickness.

The Grey relation analysis done on the observed measurement values predicts that speed of 2500 rpm, feed rate of 800 mm/min and 0.25 step depth and 60 degree wall angle are the optimal process parameter setting to achieve minimum Surface Roughness and wall thickness. The main effect plot of S/N ratio and Interaction plot shows the impact of combination of parameter and its shows same as the rest obtained.

### 6. Scope for Future Work

From the above work on investigating the sheet metal forming using incremental forming operation, the real time respond variable has been monitored during the experimentation. By similar way, with the same machining parameters, machining condition, Tool geometry and work piece characteristic, “**Finite element analysis”** will be carried out to compare the results with the actual responds to that of the Simulated respond results. Which will reveal the actual online condition monitoring to obtain any aspect level of data during the incremental sheet metal forming operation and to optimize much more reliable machining conditions for higher yield respond variable is possible.

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