Optimization of process Parameters in Incremental Sheet Forming of Al7050 Using Taguchi Analysis

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Abstract— This is the transforming era in which human involvement is going to be eliminate day by day and computer controlled machines have to be performed all the work to remove human idleness and fatigue. Aluminium is essentially used in aircraft industry, mainly in fighter planes and space shuttles because of its high strength and very light weight. The aim of this paper is to explain the Taguchi method to find the best process parameters and improved quality results in incremental sheet forming (ISF). Taguchi technique is used to investigate the variation in number of experiments, parameters and focus on acceptance in improved quality of the workpiece. The optimum possible performance of parameters is obtained by determining the optimum combination of design factors by this technique. The present work was focused on design of experiment by using L 9 Orthogonal Array (OA) on the different steps for optimal values by conducting machining on CNC machining centre. Analysis of variance (ANOVA) is employed to investigate the characteristics and experimental results which will provide the effectiveness of this approach. MINITAB-17 software is used to plot different graphs and tables in this paper. This technology has met the current needs of industry for making prototype and model especially owning to its shorter design cycles and improved the quality of design.

Key words: Step depth, Tool speed, Cone angle, Sheet thickness, Surface Roughness, Forming Time, Dimension Accuracy, Taguchi Analysis

I. INTRODUCTION

The basic principle of incremental sheet metal forming on CNC can be described as follows: the forming tool moves around the outline of the part to be formed along the predefined tool path where sheet metal is fix in the attachment which is mount on the CNC table and a hemispherical tool extrudes the sheet metal incrementally so as that the local plastic deformations are occurred and the sheet metal forming is realized incrementally. It is obvious that the sheet metal forming is realized by the tool extrusion movements around the outline of the part to be formed, so the tool paths that are used for controlling the tool movements have a great effect on the dimensional accuracy, surface quality and forming time. Therefore, how to generate an efficient and reasonable tool path, step depth, tool speed, cone angle, and sheet thickness by fully considering the features of the CNC incremental forming is one of the most important research problems of the CNC incremental forming technology.

The conventional sheet forming process is performed with the help of dies and lathe. Its basic requirement is that the production volume of the product is large; otherwise the cost will be too high. However, the recent market requirements for products tend to vary quickly and to be of small volume, so the conventional sheet forming process with dies is not satisfactory. In order to adapt to the changing requirements of the market, the conventional process must be improved to form a flexible manufacture mode. The CNC incremental sheet forming process is a flexible forming process, in which the NC program is designed according to the forming requirement of the sheet, and then a spherical-head tool forms the sheet step-by-step according to a certain locus by the feed system of the CNC machine, required shape being satisfied. This forming process does not need dedicated forming dies.

It can adjust the forming locus of the spherical-head tool by correcting the NC program to control the shape of production. Thus, its forming period is short and changes in production are fast. It can form a complex surface. This process is very well suited to the small volume, varied, complex production of plate and prototype. The CNC incremental forming process has attracted increasingly more attention recently. In theory, the incremental forming process can control the deformation of any point in the sheet and even the degree of sheet deformation.

Step depth is the feed given to CNC tool in z-direction to the layer being deformed in a single pass from the work piece. Step depth more than specified value may lead shear failure of the sheet metal. It also influence the surface roughness. Higher step depth will cause projection with more crust on sheet surface which reduce the smoothness of sheet metal. Spindle speed may be defined as the rate or speed at which the tool rotates in rpm. In CNC machining center tool mounted on a spindle and spindle speed can be controlled using M-code of CNC. For Fanuc series M03 is prescribed for clockwise rotation of spindle, M04 is prescribed for counterclockwise rotation of tool and M05 is for spindle stop. To run spindle at different speeds we can use these commands in the program of CNC.

Tool speed influence the surface roughness, geometric accuracy and formability of workpiece because of heat generation during forming process and spring back effect.

Cone angle is the angle made by slant length with its top line. As we increase the cone angle slant sheet thickness of sheet metal will decreases. It is very typical to make a product with 90o cone angle with more depth as cone angle decreases it become easier to make a product. Cone angle can easily measure by bevel protector directly. In case of small thickness deformation the upper and lower radius can be measured form dial gauge then we can calculate cone angle by applying Pythagoras on this triangular shape. Sheet thickness is also one of the prominent process parameter. It plays a major role on forming of sheet metal process. Any change in sheet thickness may calculate using sine law. This can also measure directly by using screw gauge or Vernier calliper.

Surface roughness is the major parameter inherently associate with the formability of incremental sheet metal

forming. It measured in microns which gives the average value of crust and trough of any surface. It can easily measure by touching the nose of surf meter to the workpiece. Forming time is time from starting of operation to the end of operation which is measure in minutes. Dimensional accuracy is the variation in dimension of workpiece which is measure in percentage.

A. Material Used:

Work piece material	Aluminium7050 grade
Work piece size	Length= 300 mm, Breadth=300mm, Thickness=0.25, 0.5mm and 1.0mm
Shape	Rectangular

Table 1: Work Piece Specifications

B. Chemical Compostion Of Aluminium Alloy:

ELEMENT	Cu	Mg	Zn	Zr	Fe	Si
% COMPOSITION	2.23	2.25	6.2	0.12	<0.12	<0.15

Table 2: Chemical Composition of Aluminium7050

C. Mechanical Properties:

The different properties of aluminium 7050 are tabulated in Table 3.

Properties	Units
Tensile Strength	515Mpa
Yield Strength	455Mpa
Fatigue Strength	240Mpa
Elastic Strength	70-80Gpa
Poisson's Ratio	0.33

Table 3: Mechanical properties

II. TAGUCHI METHODOLOGY

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance" for the experiment with "optimum settings" of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. [14]

"Orthogonal Arrays (OA)" provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal to Noise ratios, which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

In Taguchi method, optimization means determination of best levels of process parameters. The best parameters are those that minimize the signal to noise ratios. To determine best levels of process parameters, experiments are done based on orthogonal arrays. Orthogonal arrays are minimum number of experiments with balanced combination of process parameters.

The selection of orthogonal arrays is done by satisfying some prerequisite need such as selection of process parameters, interaction between them and their levels. The various reading of response parameters are used to find optimize process parameters means to find best combination of process parameters at which the response characteristics or parameters are optimum. Taguchi design transformed the loss function which is called signal to noise ratio. The sound to noise ratio is log of a quadratic function which is able to identify precise variation from desired response characteristic. The higher sound to noise ratio is indication that the signal is much higher than the undesired effect of noise factors. There are three types of signal to noise ratio i.e. higher the better (HB), nominal is best (NB) and lower the better (LB). If the aim of the investigation is to minimize the response characteristic then lower the better characteristics is used to calculate the S/N ratio. If the aim of the investigation is to maximize the response characteristic then higher the better characteristics is used to calculate the S/N ratio. The S/N ratio used in this study is shown below by following expression.

Lower the better (LB):

$(S/N)LB = -10 \log (MSD)\ LB$

Where $MSDLB = 1/R\sum (y)$

y = value of response characteristic in an experiment j.

R = number of repetition of an experiment.

Analysis of variance (ANOVA) is used to investigate significant factor and percentage distribution in effecting response characteristics [9].

A. Design Of Experiment:

The selection of the process parameters to be investigated depends on the product performance characteristics or response characteristic as the parameters those affect most the response characteristic should be given preference [3]. The three process parameters with their levels and symbols are listed in table 4.

Symbol	Parameters	Level 1	Level 2	Level 3
A	Spindle Speed(rpm)	600	800	1000
B	SheetThickness(mm)	0.25	0.5	1.0
C	Cone Angle (degree)	59.82	44.80	27.02
D	Step Depth(mm)	0.2	0.3	0.4

Table 4: Experiments design

B. Selection of Orthogonal Array:

The selection of orthogonal arrays depends on degree of freedom of selected process parameters. The degree of freedom of selected orthogonal arrays should be greater than or equal to the degree of freedom of selected process parameters. The degree of freedom of selected parameters depends upon number of levels selected for those parameters. Suppose for a parameter number of levels selected are three so the degree of freedom associated with it is two [7]. Taguchi's L9 orthogonal array is selected which is shown below in table 5.

S.NO.	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3

6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 5: Orthogonal array

C. Experiment Results:

Following nine experiments are performed by taking different factor combinations then below three responses are analysed for optimum value of process parameters which are tabulated in Table 6.

Exp.no.	Factors				Response		
	Spindle Speed	Sheet Thickness	Cone Angle	Step Depth	Surface Roughness	Forming Time	Dimensional Accuracy
1	600	0.25	59.82	0.20	2.05	96	98.80
2	600	0.50	44.80	0.30	2.23	72	97.94
3	600	1.00	27.02	0.40	2.90	48	96.04
4	800	0.25	44.80	0.40	2.93	44	98.29
5	800	0.50	27.02	0.20	2.17	92	97.43
6	800	1.00	59.82	0.30	2.32	68	95.53
7	1000	0.25	27.02	0.30	2.37	64	97.74
8	1000	0.50	59.82	0.40	2.80	90	96.88
9	1000	1.00	44.80	0.20	2.25	40	94.98

Table 6: Experimental data

III. Analysis and Discussion of Result

The number of experiment performed to investigate the influence of process parameters (spindle speed, sheet thickness, cone angle, and step depth) on the surface roughness, forming time and dimensional accuracy. The above tables and following graphs indicate the effects of process parameters on the response parameters.

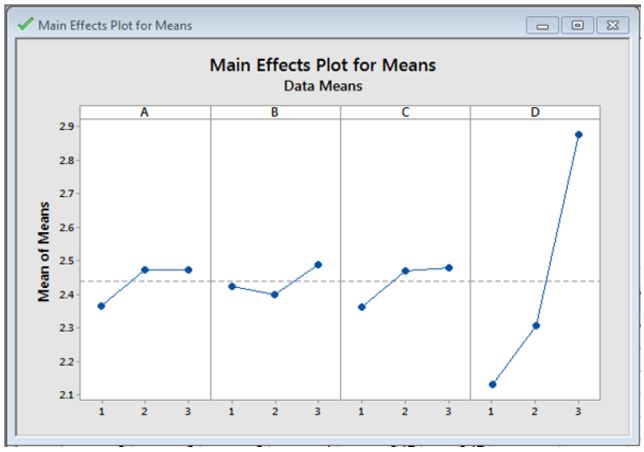

Fig. 1: Effect of process parameters on surface roughness

From the above figure effect of various parameters on surface roughness is analysed.

It is found that roughness increases with increase in spindle speed from level 1st to 2nd but constant between 2nd-3rd levels. It remain almost constant from1st-2nd level but increase little from 2nd-3rd level of experiment. Similarly it increase with cone angle from 1st-2nd level and remain same from 2nd-3rd level. It also increase with increase in step depth for all the levels of experiment.

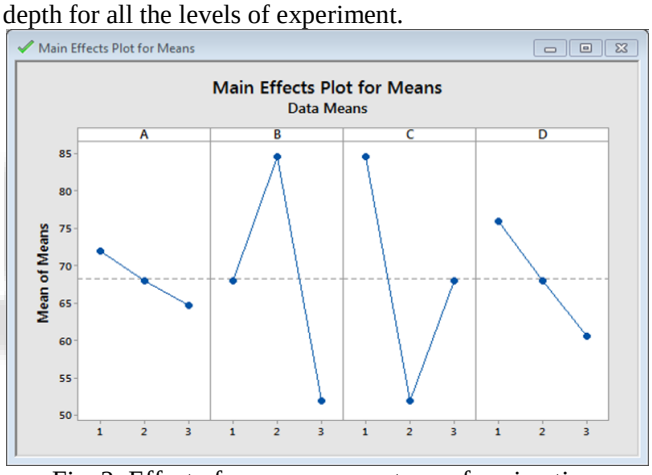

Fig. 2: Effect of process parameter on forming time

In figure 2 the effect different process parameters are analysed by taking forming time as a response parameter. It decreases with increase in spindle speed for all the levels. It gradually increase from 1st-2nd level and decrease from 2nd-3rd level of experiment. For cone angle a vice versa of sheet thickness phenomenon happen. Forming time decreases with increase in step depth for all the levels of experiments.

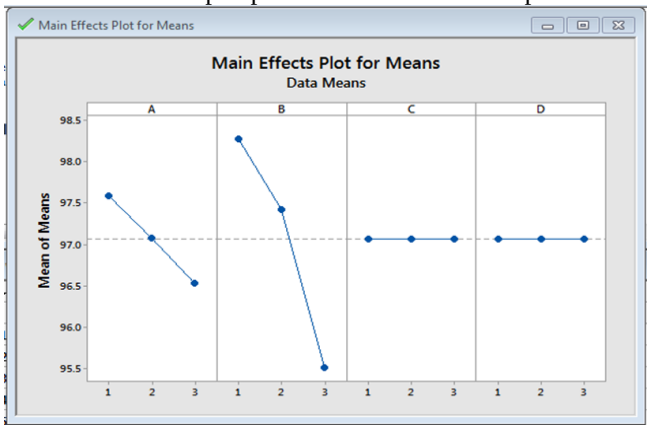

Fig. 3: effect of process parameter on dimension accuracy

In third figure the effect of parameters on dimensional accuracy was analysed. It decreases with increase in spindle speed and sheet thickness. The cone angle and step depth does not affect dimensional accuracy these both have same plots of taguchi analysis.

Source	DF	Adj. SS	Adj. MS	F-VALUE	P-VALUE	% Contribution
A	2	0.05116	0.02558	0.20	0.820	29.38
B	2	0.11832	0.05916	0.46	0.636	22.87
C	2	0.05499	0.02749	0.22	0.808	28.95
D	2	0.16961	0.08480	0.66	0.527	18.88
Error	18	2.29633	0.12757	-	-	-
Total	26	2.69041	-	-	-	-
Order of significance: 1. Step Depth 2. Cone Angle 3. Spindle speed 4. Sheet Thickness						

Table 7: ANOVA result for surface roughness

Source	DF	Adj. SS	Adj. MS	F	P	% contribution
A	2	0.0	0.000	0.00	1.000	26.19
B	2	242.7	121.333	0.20	0.817	21.40
C	2	0.0	0.000	0.00	1.000	26.19
D	2	0.0	0.000	0.00	1.000	26.19
Error	18	10664.0	592.444			
Total	26	10906.7				
Order of significance: 1. Sheet Thickness and Cone Angle 2. Step Depth 3. Spindle speed						

Table 8: ANOVA result for forming time

Source	DF	Adj. SS	Adj. MS	F-Value	P-value	% contribution
A	2	0.0000	0.000	0.00	1.00	30.25
B	2	5.0586	2.5293	1.27	0.305	9.22
C	2	0.000	0.000	0.00	1.00	30.25
D	2	0.000	0.000	0.00	1.00	30.25
Error	18	35.9016	1.99453			
Total	26	40.9602				
Order of significance: 1. Sheet Thickness 2. Spindle speed 3. Cone Angle and Step Depth						

Table 9: ANOVA result for dimensional accuracy

Anova tables are drive from Minitab 17 software which calculate the sum of squares, mean of squares, F-value, and P-value. Anova of response parameters gives us the order of significance along with the percentage contribution of the process parameters which are taken in the experimentation work.

IV. CONCLUSIONS

This is analysed from the taguchi plots and anova tables that the parameters spindle speed, sheet thickness, cone angle and step depth selected in this research paper have almost same influence on the response parameters. Spindle speed have more effect as compare to other three parameters. Response parameter surface roughness have maximum effect of spindle speed. Sheet thickness is least effected parameter because it has least contribution for all response parameters has been explode by anova analysis. The step depth also have little strange effect on surface roughness. It is because of formation of crust and trough. Higher the step depth less number of peaks and valley will form so it results less value of surface roughness or we can say surface will be smoother. The anova analysis reveals the order of significance. As we know it is tougher metal as compare to other grades of aluminium so sheet thickness have more significance.

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