

Parametric Optimisation of AA6082 Flow-Formed Tubes for Good Surface Finish

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Abstract:

Flow-forming is an eco friendly, chip less metal forming process. A single roller flow forming machine has been used to manufacture the thin walled tubes of AA6082 alloy. The effect of process parameters on the surface finish of flow formed tubes have been studied by Taguchi method. The main flow-forming parameters selected for the present investigation are axial feed of the roller, speed of the mandrel, and thickness reduction. The effects of these input parameters on the response, surface roughness (R_a) have been critically analyzed. It has been found that the axial feed of the roller and speed of the mandrel are the most important process parameters influencing the surface roughness of flow formed tube. A finish of $1.10 \mu\text{m}$ is produced by flow forming process when the process parameters were set at their optimum values.

Key Words: Flow-forming, AA6082 alloy, DOE, Surface finish.

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I. Introduction

Flow-forming is an advanced, chip less metal forming process which employs an incremental rotary point deformation technique. In flow-forming, the pre-form is elongated on a rotating mandrel without changing the internal diameter, which reduces the wall thickness of a tube. Flow-forming employed in the production of cylinders, flanged components, axi-symmetric sheet metal parts, seamless tubes for high strength aerospace and missile applications etc. Flow-forming is the capable technology for forming thin walled seamless tubes. AA6082 tubes are used in the field of defense, aero space and missile applications.

However, very little work has been done on the flow-forming of AA6082 tubes. The surface finish is one of the important characteristic of flow formed tube for defense applications.

Taguchi approach is a standardized version of design of experiments (DOE) proposed by Dr. Genechi Taguchi of Japan. Taguchi technique reduces cost of experimentation. It gives meaningful conclusions with minimum experimental runs. The aim of the present investigation is to study the effect of important process parameters such as roller feed, mandrel speed and thickness reduction on the surface finish of AA6082 flow formed tubes and to select the optimal combination of these parameters to produce good surface finish using Taguchi's approach.

Ram Mohan and Mishra (1) studied the various aspects, defects pertaining to the tubes produced in spinning. Chang SC et al. (2) conducted experiments on AA2024 and AA7075 Aluminum alloys and reported their spinnability. Wong CC et al. (3) carried out studies on cylindrical components using flow forming principles. Lee K S et al. (4) has conducted research work on flow forming of cylindrical tubes. Research works (5-12) have used different Techniques like Taguchi Technique, Response Surface Methodology and ANN etc to optimise the process parameters of different manufacturing processes. Research studies (13-16) are done on optimisation of surface roughness in various manufacturing processes. Flow forming is non-linear process and very few studies are available on optimisation of process parameters(17-20).

The literature [17-20] reveals that Taguchi Technique can be applied successfully to predict the process parameters of flow forming process for different materials. The present investigation is carried out to optimize the process parameters during the flow forming of AA6082 pre-forms to obtain good surface finish.

II. Experimental Work

The present investigation is carried out on a single roller CNC flow-forming machine. The mandrel rotates at a speed, S rpm. The roller travels parallel to the axis of the mandrel with a feed rate, F mm/min and decreases the wall thickness of pre-form when a thickness reduction t (%) is given by radial feed. The thickness reduction is effected by maintaining gap between the mandrel and the roller less than the thickness of pre-form. The axial and radial feeds are maintained by hydraulic power pack through servo motors. The pre-form is reduced

to a final wall thickness by elongating it without change in the inside diameter of the tube. Due to volume constancy, this reduction in thickness of the pre-form leads to an increase in length of the tube. It is desired to produce seamless tubes with good surface finish.

Material: The material used for the present investigation is AA6082 alloy. The major alloying elements are Al-1.2Mg-1.0Mn-0.13Si-0.50Fe-0.25Cr-0.1Cu. AA6082 has medium strength alloy with excellent corrosion resistance. Addition of Manganese controls the grain structure, which results in superior strength. The alloy age hardens by formation of Mg₂Si precipitates.

Pre-form Design: The pre-form was designed based on two factors namely maximum possible deformation and constant volume principle. These pre-forms were manufactured by hot forging. Generally 15% allowance is provided on the diameter for machining and other allowances including extra material required for test specimens. The pre-form was then annealed at a temperature of 510-540 °C for two hours and quenched in water. The flow-forming mandrel is made of tool steel. A slight taper is given in the mandrel for easy ejection of the product. The machined pre-form is shown in fig. 1.

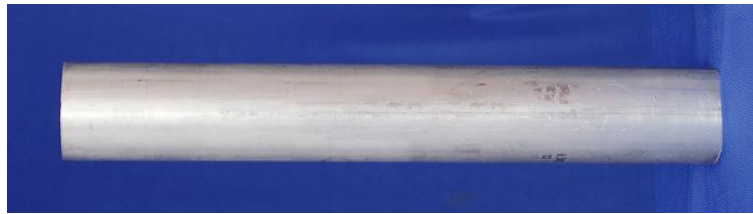


Fig. 1: Machined pre-form

III. Plan of Experiments

Taguchi method, a powerful design of experiments tool is used in the present investigation. This method provides a simple, efficient and systematic approach to determine optimal machining parameters. Conventional experimental design methods are too complex and expensive, as large numbers of experiments have to be carried out to study the process. Taguchi method uses an orthogonal array to study the entire process with only fewer experimental runs. Moreover, traditional experimentation involves one-factor-at-a-time experiments, wherein one variable is changed while the rest are held constant. It is also not possible to study all the factors involved in the process and to determine their main effects (i.e., the individual effects) in a single experiment. Taguchi technique overcomes all these drawbacks. Taguchi method is used for optimizing process parameters and identifying the optimal combination of factors for the desired responses. The steps involved are:

1. Identification of process parameters and their levels.
2. Identification of response function and its quality characteristic.
3. Selection of the appropriate orthogonal array.
4. Performing the experiments as per the conditions specified in orthogonal array.
5. Analysis of results through ANOVA and selection of the optimum level of process parameters.
6. Confirmation test to verify the optimal process parameters.

The input parameters chosen for the experiments are: (a) Axial Feed, F (mm/min) (b) Speed of the mandrel, S (rpm) and (c) Thickness reduction (%) while the response function selected is the surface roughness R_a (µm) of flow formed tube. The input parameters and their levels are given in Table-1.

Table 1: Parameters and their levels

Symbol	Parameters	Level 1	Level 2	Level 3
F	Axial feed, mm/min	50	75	100
S	Mandrel speed, rpm	150	200	250
t	Thickness reduction, %	25	50	75

Selection of Orthogonal Array:

The flow forming process involves material non-linearity, which can be effectively studied by 3-level or 4-level variables. However by considering the cost factors, L9 (3³) orthogonal array, with three columns and nine rows, which can handle 3-level factors is selected to study the optimize the flow forming process.

Table 2: Experimental layout using L9 array

Experiment Number	Parameter Level			Experimental result for R_a
	F	S	t	
1	1	1	1	3.6
2	1	2	2	2.9
3	1	3	3	2.4
4	2	1	2	4.8
5	2	2	3	5.4
6	2	3	1	3.8
7	3	1	3	8.2
8	3	2	1	7.5
9	3	3	2	4.5

The L9 OA requires only nine experiments to formulate the entire process whereas in classical method, full factorial requires, $3^3 = 27$ experiments. The experimental layout using L9 OA is shown in table 2. The coded values of 1, 2 and 3 represent level 1, level 2 and level 3 of parameters respectively.

Statistical analysis of variance (ANOVA) is performed to find out the signification of the process parameters on the flow forming process which produce tubes with smaller ovality. Optimal combination of process parameters is predicted by ANOVA.

IV. Analysis of Experiments

Main Effects: In the present investigation only single run is performed for each of nine experiments by considering the cost and time factor. The Taguchi analysis is performed based on the average of valued methodology. The experimental results are analyzed by considering the main effects and their differences between the level 1, level 2, and level 2 and level 3 of the factors.

The factor main effects and their differences are analyzed by calculating the mean value of observations of the experiment. The overall mean value of ovality is calculated from the following equation.

$$\text{Mean } (R_a) = [\sum_{i=1-9}(R_a)] / 9 = 4.78 \quad \text{----- (1)}$$

The main effect of a parameter level, for example, feed, F at low level 1 (i.e. F=50 mm/min), on R_a is given by Eq (2) [21].

$$\text{Mean } [(R_a)]_{F=50 \text{ mm/min}} = (R_{a1} + R_{a2} + R_{a3}) / 3 = 2.96 \quad \text{----- (2)}$$

The main effects and their differences for the surface roughness are given in table-3.

Table 3: Main effects and their difference on the percentage elongation

Factors	Level 1 (L ₁)	Level 2 (L ₂)	Level 3 (L ₃)	Difference between levels		
				L ₂ -L ₁	L ₃ -L ₁	L ₃ -L ₂
F, mm/min	2.96	4.66	6.73	1.70	3.77	2.07
S, rpm	5.53	5.26	3.57	-0.27	-1.96	-1.69
t, %	4.96	4.06	5.33	-0.90	0.37	1.27

The change of Roller feed from 25 to 50 mm/min and from 50 to 75 mm/min increases the main effect increases by 1.70 and 3.77. The raise of main effect is maximum when the feed changes from level 2 to level 3. As the feed increases the height of micro irregularity increases and produces higher surface roughness.

The change of mandrel speed from 150 to 200 rpm decreases the average value of response function 5.26 to 5.53, and also the increase in speed from 200 to 250 rpm further reduces the main effects from 5.53 to 3.57. At the lower mandrel speed, the sticking of roller to the surface of tube results in higher surface roughness. i.e., poor finish. The increase in the speed of mandrel unifies surface defects and produces good surface finish.

The change of thickness reduction from 25 to 50 % results the decrease in the main effects by 0.90. However the change of thickness reduction from 50 to 75 % increases the main effects by 1.27.

A low thickness reduction ratio results in non uniform deformation of pre form and produces tubes with higher roughness. The thickness reduction reaches to uniform plastic zone (Level 2), the process produces tubes with minimum surface roughness. When the thickness reduction reaches to level 3, which is beyond the uniform plastic zone, again a lead to non-uniform plastic deformation and results in higher surface roughness.

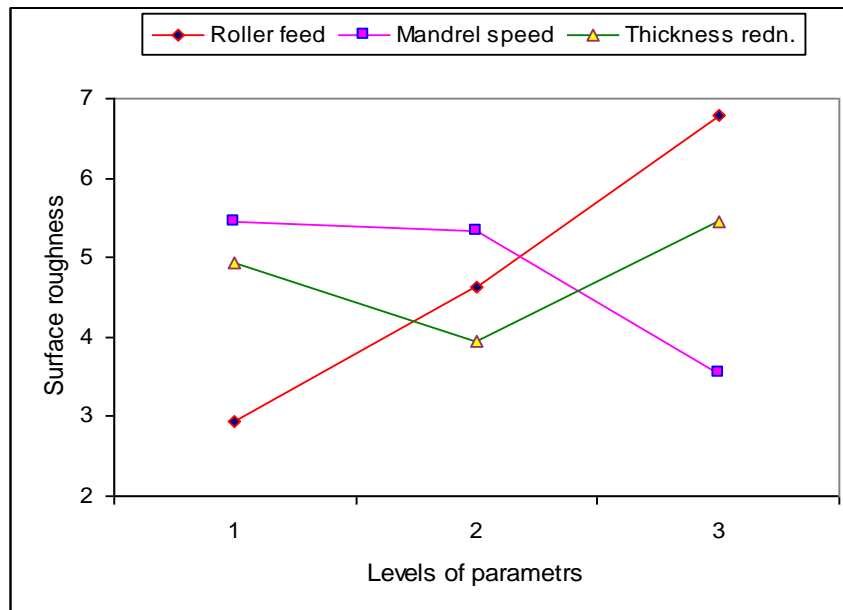


Fig 2 Main Effects of process parameters on surface roughness

Fig. (2), shows the main effects and their differences between the levels of parameters on the surface roughness. The relative slope of linear graph indicates the significance parameters. In the present investigation, it is clear that, the slope of line indicating the roller feed is more as compared to slopes of other parameters. From the main effects and graphs of factor parameters, it is evident that the roller feed is having significant influence on the surface roughness of flow formed tube, followed by mandrel speed and thickness reduction.

ANOVA: The results of ANOVA performed for the response parameter are shown in table- 4. For a process parameter to be significant, the calculated F-ratio should be more than the F-ratio from tables.

Table 4 - ANOVA Table

Factor	Symbol	D.O.F	Sum of squares, S	Variance, V	F-Ratio, F	Pure Sum, S''	Percent, (%)
Feed	F, mm	2	22.54	11.27	76.25	22.23	67.30
Speed	S, rpm	2	6.75	3.37	22.83	6.45	19.53
Thick. redn	t, mm	2	3.46	1.73	11.73	3.17	9.61
Others/Error		2	0.29	0.14			3.56
Total		8	33.04				100.0

The F-ratio from the tables, F (2, 2) is 18. ANOVA table indicates that the roller feed is the most significant process parameter influencing the surface roughness of flow formed total followed by mandrel speed. Thickness reduction is least significant parameter. This also confirms in the graph shown in fig. 2. One of the flow formed tube is shown in Fig. 3.

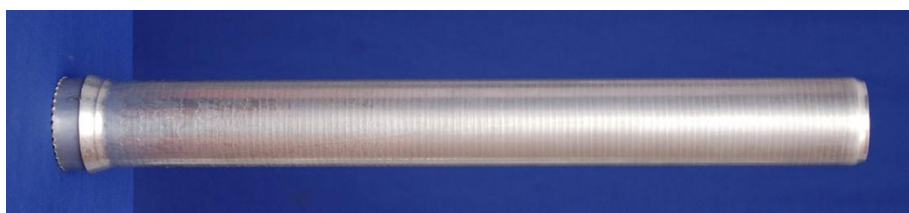


Fig. 3-Flow formed tube

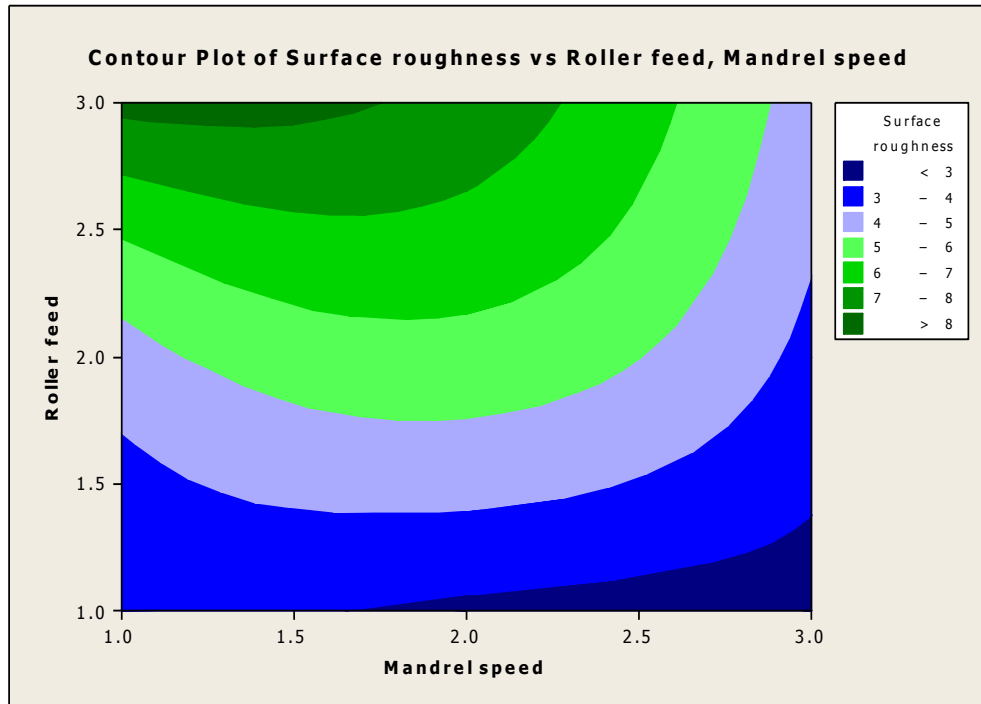


Fig. 4- Contour plot of roller feed and mandrel speed on surface roughness

Effect of roller feed and mandrel speed: The contour plot of roller feed and mandrel speed on surface roughness is shown in Fig. 4. The lower surface roughness can be produced when lower feed is combined with higher speed of mandrel. Also mid roller speed and mid value of mandrel speed results in average value of surface roughness. Lower mandrel speed combined with higher roller feed produces bad surface finish. This is because of uniform plasticization of work material at higher speed of mandrel to mid range and uneven plasticization at lower mandrel speed and also at higher roller feed.

Effect of roller feed and thickness reduction: The contour plot of roller feed and thickness reduction on surface roughness is shown in Fig. 5. Lower value of roller feed is required to produce the tubes with good surface finish. Lower values of thickness reduction combined with lower to medium range of roller feed results in lower value of surface roughness. This is due to the fact that, uniform plasticization takes place at lower values of roller feed combined with lower to medium values of thickness reduction. Lower and higher roller feed results in bad finish.

Effect of roller feed and thickness: The contour plot of mandrel speed and thickness reduction on surface roughness is shown in Fig. 6. The lower surface roughness can be obtained when the mandrel speed and thickness reduction are set at their mid-level (i.e., Level-2). This is due to the fact that, even plasticization of work material at the mid range values of roller feed and thickness reduction. It is also noticed that, the effect of mandrel speed is very small compared thickness reduction.

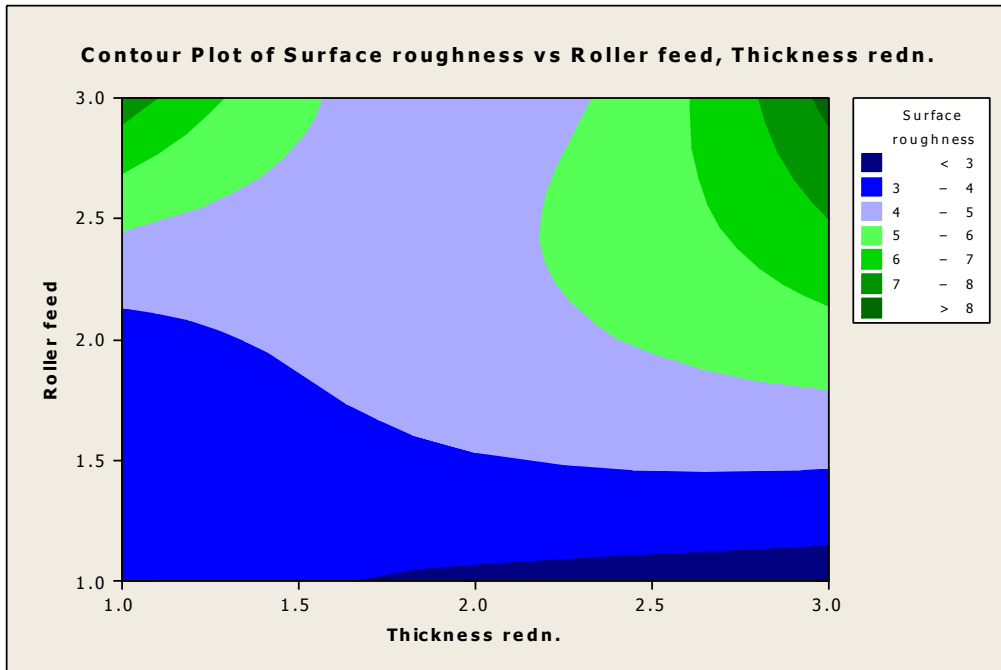


Fig. 5: Contour plot of roller feed and thickness reduction on surface roughness

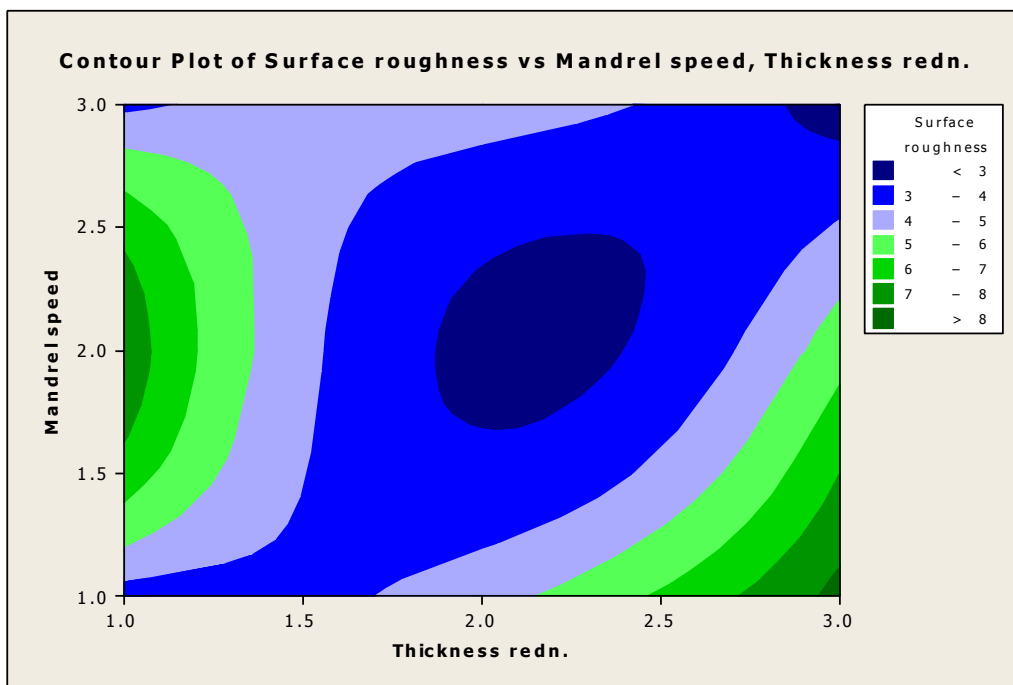


Fig. 6: Contour plot of mandrel speed and thickness reduction on surface roughness

Table 5: Optimum Conditions and performance for minimum surface roughness

Factors	Level Description	Level	Contribution
F, mm/min	50	1	-1.86
S, rpm	250	3	-1.23
t,%	50	2	-0.81

Total Contribution from all factors ... -3.90
 Current Grand average of performance ... 4.78
 Expected Result at Optimum condition ... 0.92

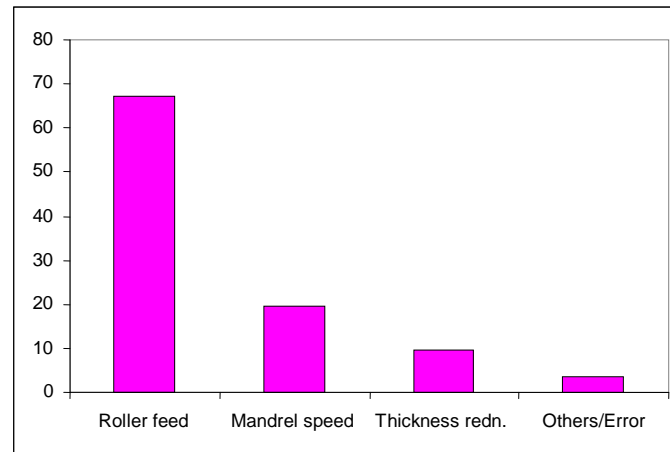


Fig. 7. Influences of Input Parameters on surface roughness

V. Confirmation Test:

In Taguchi method a confirmation test is required to verify the optimum conditions and to compare the results with expected conditions. The optimum condition for smaller surface roughness is shown in table-5. It reveals that the roller feed should be at level 1, the thickness reduction should be at level 2 and the mandrel speed should be at level 3 for production of flow formed tube with good surface finish. i.e., with smaller surface roughness. The model predicts an optimum value of 0.95 μm for surface roughness. A confirmation test is conducted by setting the parameters at their optimum values and response parameter obtained is 1.10 μm , which is within the range of predicted value.

VI. Conclusions:

In the present investigation, the effects of process parameters on the surface roughness of AA6082 flow formed tube have been studied using Taguchi method. The influences of parameters on the surface roughness are shown in Fig.-7. It is concluded that the parameters that have relative significant influence on surface roughness are roller feed (67.80%), mandrel speed (19.65%), and thickness reduction (9.54%) respectively. The optimum conditions for smaller surface roughness are roller feed at 50 mm/min, mandrel speed at 250 rpm and thickness reduction at 50%. It has been proved that the improvement of response function is significant, when the process parameters set at their optimal values.

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