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Prediction of Mean diameter of Aluminum Alloy Tubes in Flow Forming Process

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Abstract: Flow-forming is eco-friendly, chip less, innovative metal forming process employed for the production of thin walled seamless tubes. Experiments were conducted to flow form AA6082 pre-forms on flow forming machine with a single roller. The main flow-forming parameters selected for the present investigation are axial feed of the roller, speed of the mandrel, and radius of the roller. The effects of these input parameters on the mean diameter of flow formed tube have been critically analyzed by Taguchi method. It has been found that the axial feed is the most significant process parameter influencing the mean diameter of flow formed tube followed by radius of the roller. The tubes with desired nominal mean diameter of 43.00 mm are produced by flow forming process when the process parameters were set at their optimum values.

Keywords: Flow-forming, AA6082 alloy, Mean diameter, Taguchi method

I. INTRODUCTION

Flow-forming is an innovative, 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, at cost of reduction in the the wall thickness. 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. Different process parameters namely roller feed, mandrel speed, roller radius, thickness reduction, roller attack angle influence the mean diameter of flow formed tube. Rajan et al. (2002) conducted experiments to know the effect of heat treatment of pre-form on the mechanical properties of flow formed AISI-4130 steel tubes. Duan and Sheppard (2002) studied the effect of rolling parameters on sub-grain size of AA 1100 alloy. Chang et al. (1998) investigated the tube spinnability of AA2024 and 7075 alloys at full-annealed and solution-treated condition. Lee and Lu (2001) investigated the effect of deformation ratio and friction on the drawing force during flow forming of lead cylindrical tubes. Yao Jianguo et al. (2002) studied the effect of roller feed on spinning force, thickness strain and accuracy on spinning of Aluminum tube. Rajanish and Singhal (1995) employed spinning technology to manufacture smaller diameter, thin walled long tubes. They studied effect of roller feed, roller profile, thickness reduction on the surface roughness on forming of AISI-304 steel material. Joseph Davidson et al. (2008) conducted experiments on AA 6061 alloy pre-forms to find out effect of process parameters on quality issues of flow formed tubes. Lakshman Rao et al. (2009) studied the influence of roller attack angle on the surface finish and ovality of Copper tubes by flow forming process. But, no work has been reported on flow forming of AA6082 tubes. AA6082 flow formed tubes having mean diameter with close tolerances are required in the field of defense, aero space and missile applications. Taguchi approach is a standardized version of design of experiments proposed by Dr. Genechi Taguchi of Japan. It is one of the most attractive quality building tool can be used by engineers and researchers in the manufacturing industry. It is a powerful statistical technique used for systematic analysis of results to arrive at meaningful conclusions with minimum experimentation Dhavlikar et al. (2003) applied Taguchi and dual response methods to determine optimal combination of parameters to minimize the roundness error in centerless grinding process.

Nalbant et al. (2006) used taguchi method to establish cutting parameters for surface roughness in turning of AISI 1030 steel. Omer Savas and Ramazan Kayikci (2006) applied Taguchi's method to investigate the effect of casting parameters on micro porosity formation in aluminum alloy. Vijian et al. (2006) employed Taguchi's method to opitmise process parameters in squeeze casting process for LM6 aluminum alloy. Yang and Tarng (1998) optimized cutting parameters for turning S45C steel bars with tungsten carbide tools employing Taguchi method. Seon Jim Kim et al. (2003) optimized manufacturing parameters for brake lining material by Taguchi method. Padmanabhan et al. (2007) studied the influence of input process parameters on the deep drawing of stainless steel. Zhang Xueping et al. (2009) used Taguchi method to optimize process parameters of residual stresses in hard turning. George et al. (2004) arrived the optimal combination of process parameters in electro discharge machining of carbon- carbon composite using Taguchi's approach. Joseph Davidson et al. (2008) employed Taguchi's approach to determine optimal combination of process parameters for elongation on flow forming of AA 6061 alloy. Srinivasulu et al. (2011) investigated the influence of process parameters on surface roughness of AA 6082 flow formed tubes by Taguchi method. But very few works have been reported on optimization of flow forming process. The aim of present research is to establish optimum process parameters to produce precise mean diameter in flow forming of AA6082 tubes with minimum cost of experimentation by Taguchi's method.

II. Experiment Work

2.1 Material

The material chosen for the present study is AA6082 alloy. The composition of AA6082 alloy is given in Table 1. It has medium strength, good machinability and weldability with excellent corrosion resistance. Addition of Manganese controls the grain structure, which results in superior strength. The alloy age hardens by formation of Mg_2Si precipitates. This alloy has an ultimate tensile strength of 340 MPa, yield strength of 310 MPa and hardness of 95 BHN. AA6082 alloy used in automobiles, truck frames, ship building, motor boats, pylons, towers, aero space and missile applications.

Table 1 Composition of AA6082 alloy

Element	Al	Mg	Mn	Si	Fe	Cr	Cu
%	95.6	1.2	1.0	1.3	0.5	0.25	0.1

2.2 Equipment

The present investigation is carried out on a CNC flow-forming machine with a single roller. The mandrel rotates at a speed, S rpm. The roller moves 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 aimed to produce seamless tubes with precise mean diameter and good strength.

2.3 Pre-form Design

The design of pre-form was 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. The pre-form was then annealed at a temperature of 550^0C for two hours to take the precipitation into solution and quenched in water to retain solute in solution. The flow-forming mandrel is made up of tool steel and hardened to 63HRC. A thin film of lubricant is applied on mandrel to avoid sticking of flow formed tube. Slight taper is given in the mandrel for easy ejection of the tube. The machined pre-form is shown in Figure 1.

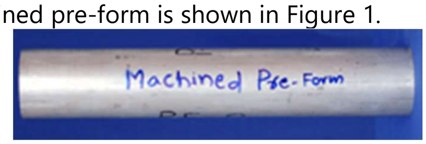

Figure 1 Machined Pre-form

III. Plan of experiments

3.1 Methodology

Taguchi method, a powerful tool for design of experiments is used in the present investigation. This method provides a simple, efficient, cost effective and systematic approach to determine optimum combination of input process 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 the effect of all the factors involved in the process and to determine their main effects (i.e., the individual effects) in a single experimental run. Taguchi technique overcomes all these drawbacks and provides meaningful conclusions with minimum experimentation. Taguchi method is used for optimizing process parameters and identifying the optimal combination of factors for the desired responses. The steps involved in Taguchi's method are:

1. Identification of input 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. Performing confirmation test to verify the optimal process parameters.

3.2 Selection of input process parameters

Trial experiments are conducted preliminarily to know the effect of different process parameters on the mean diameter of flow formed tube. The input parameters selected for the present investigation are (a) Axial feed of the roller, F (mm/min) (b) Speed of the mandrel, S (rpm) and (c) Roller radius (mm). The input parameters and their levels are given in Table 2. It is desired to produce flow formed tubes having a nominal value of 43.00 +/- 0.25 mm. The response parameter selected for the present research is mean diameter of flow formed tube having nominal value of 43.00 mm.

Table 2 Input parameters and their levels

Parameters	Unit	Level 1	Level 2	Level 3
Axial feed	mm/min	50	75	100
Mandrel speed	rpm	150	200	250
Roller radius	mm	4	8	12

3.3 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 factor, L9 (3^3) orthogonal array, with three columns and nine rows, which can handle 3-level factors is selected to study and optimize the flow forming process. The L9 Orthogonal array requires only 9 experiments to formulate the entire process whereas in classical method, full factorial requires 27 ($=3^3$) experiments. The experimental layout using L9 OA with actual values of parameters is given in Table 3.

IV. Experimentation

Experiments were conducted as per the different combination of process parameters given in Table 2 and mean diameter is measured for each experiment. The response parameter, mean diameter obtained in each experimental run is measured by bore dial gauge. The accuracy of bore dial gauge is 0.001 mm. Each experimental trial combination is replicated twice to minimize the effect of noise factors. The flow formed tube is shown in Figure 2.

Figure 2 Flow formed tube.

In Taguchi method, a loss function is defined to calculate the deviation of experimental value from the target value. Further, the loss function is converted in to Signal-to-Noise (S/N) ratio. The S/N ratio for response characteristic, in which nominal-is-the better can be calculated by the equation,

$$S/N\ Ratio = -10 \log (MSD) = -10 \log (1/r \sum y_i^{2})$$

Where "MSD" is mean square deviation, "y" is the observed value and "r" is the number of observations. The experimental results and calculated corresponding S/N Ratios are given in Table 3.

Table 3 Experimental layout using L9 OA

Run No.	Parameters			Mean diameter, D (mm)		S/N Ratio
	Feed (F)	Speed (S)	Radius (.R)	Trial-1	Trial-2	
1	50	150	4	43.65	43.63	3.875
2	50	200	8	43.98	43.97	0.219
3	50	250	12	44.15	44.16	-1.252
4	75	150	8	43.41	43.42	7.638
5	75	200	12	43.56	43.55	5.113
6	75	250	4	43.30	43.31	10.312
7	100	150	12	44.61	44.64	-4.218
8	100	200	4	44.29	44.28	-2.179
9	100	250	8	44.45	44.46	-3.258

Table 4 Main effects and their differences on mean diameter

Factors	Level 1 (L_1)	Level 2 (L_2)	Level 3 (L_3)	Differences between levels		
				L_2-L_1	L_3-L_2	L_3-L_1
F	0.94	7.68	-3.21	6.74	-10.8	-4.15
S	2.43	1.05	1.93	-1.38	0.88	-0.50
R	4.00	1.53	-0.19	-2.47	-1.72	-4.19

V. Results and Discussions

5.1 Main effects

The main effects of process parameters are used to determine their influence on the response function. The factor main effects and their differences are analyzed by calculating the average value of S/N ratios of observations of the experiment. The main effects and their differences on the mean diameter are given in Table 4. The main effects plot for mean diameter is shown in Figure 3.

The change of roller feed from 50 to 75 mm/min, increases the main effect S/N value by 6.74 and raise of roller feed from 75 to 100 mm/min decreases the main effect S/N value by 10.89. i.e., the process produces tubes with minimum variation in mean diameter when the feed is at level 2, where the S/N ratio is maximum. Lower value of roller feed rate (50 mm/min) produces, non-uniform plastic deformation as the roller passes slowly over the pre-form. This uneven plastic deformation leads to variation in mean diameter. When the roller feed reaches to 75 mm/min, it becomes optimum and produces localized uniform plastic deformation which results in lower variation. And the feed rate increases further to 75mm/min, the forming forces becomes higher, this leads to larger variation in mean diameter from level 2 to level 3.

The increase of mandrel speed from 150 to 200 rpm decreases the main effect S/N value by 1.38 and from 200 to 250 rpm increases the main effect S/N value by 0.88. .i.e., the process produces flow formed tubes with minimum variation in mean diameter when the speed is at level 1. At the lower mandrel speed, lower forming forces produce the tubes with smaller variation in mean diameter. As the speed of the mandrel increases to level 3, the optimized plastic deformation produces the tubes with minimum variation in mean diameter.

The change of roller radius from 4 to 8 mm results the decrease in the main effect S/N value by 2.47, and the change of roller radius from 8 to 12 mm further decreases the main effect S/N value by 1.72. i.e., the process produces tubes with nominal mean diameter when the roller radius is at level 1. As the roller radius increases, the forming forces become high, results in diametric growth and produce the tubes with larger mean diameter.

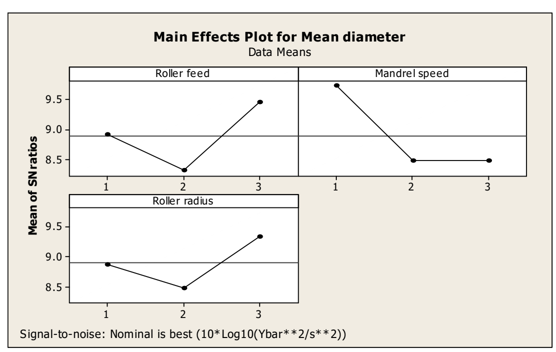

Figure 3 Main effects plot for mean diameter.

The relative slopes of linear graphs in Figure 3 indicate the significance of parameters. In the present study, it is clear that, the slope of line indicating the roller feed is more as compared to slopes of roller radius and mandrel speed. From the main effects and graphs of parameters, it is evident that the roller feed is having significant influence on the mean diameter of flow formed tube, followed by roller radius and mandrel speed.

5.2 ANOVA

Statistical analysis of variance (ANOVA) is performed to find out the significance of the process parameters on the flow forming process which produce tubes with minimum variation in mean diameter. It gives optimal combination of process parameters. The results of ANOVA performed for the mean diameter is given in Table 5. For a process parameter to be significant, the calculated F-ratio should be more than the F-ratio from tables. The F-ratio from the tables, at F (2, 2) is 18. ANOVA Table indicates that the roller feed is the most significant process parameter influencing the mean diameter of flow formed tube followed by roller radius. Mandrel speed is insignificant parameter. This also confirms in the graph shown in Figure 3.

Table 5 ANOVA Table for mean diameter

Fac-tor	DOF (f)	Sum of Sqrs (S)	Varia-nce (V)	F-Ratio (F)	Pure sum (S′)	Percent (P)(%)
F	2	181.7	90.8	230	181	85.64
S	2	2.93	1.46	3.71	2.14	1.02
R	2	25.81	12.9	32.7	25.0	11.85
	2	0.78	0.39			1.49
	8	211.2				100

5.3 Contour Plots

The contour plots of input parameters on the mean diameter are shown in Figures 4-6. The contour plot of roller feed and mandrel speed on mean diameter of flow formed tube is shown in Figure 4. The flow formed tube with nominal value of mean diameter can be produced when feed at level 2 combined with lower (level 1) and higher levels (level 2) of mandrel speed. The lower and higher levels of roller feed are undesirable.

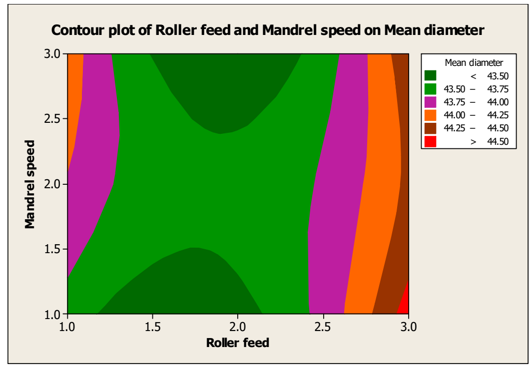

Figure 4. Contour plot of roller feed and mandrel speed on mean diameter.

The contour plot of roller feed and roller radius on mean diameter is shown in Figure 5. It is clear that, middle level of roller radius combined with middle level of feed produces the tubes with required nominal mean diameter. The increased levels of roller radius produce undesirable effect.

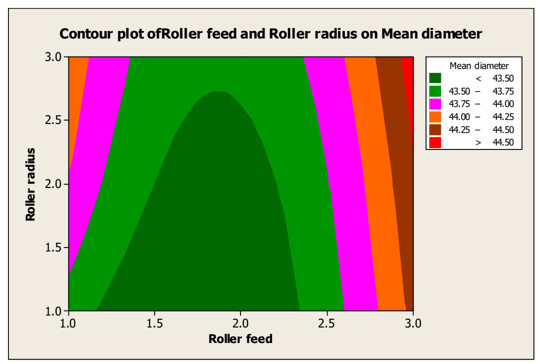

Figure 5 Contour plot of roller feed and roller radius on mean diameter.

VI. Optimum Conditions

The optimum condition for nominal mean diameter of flow formed tube is given in Table 6. It reveals that the roller feed should be at level 2 (75 mm/min), the mandrel speed should be at level 3 (250 rpm) and the roller radius should be at level 1(4mm) for production of flow formed tube with required

nominal mean diameter. The model predicts an optimum value of 43.00 +/- 0.298 mm for mean diameter. The developed model produces tubes having mean diameter within the range of 432.702 to 43.298 mm.

Table 6 Optimum conditions for nominal mean diameter

VII Confirmation Test

In Taguchi method a confirmation test is required to verify the optimum conditions and to compare the results with expected conditions. Confirmation runs were performed by selecting the input parameters at their optimum conditions. The percentage of error was determined from the experimental value and predicted value. The maximum error is found to be 1%, which is within the allowable limits.

VIII. Conclusion

In the present research, Taguchi method is applied to investigate the effects of process parameters on the mean diameter of AA6082 flow formed tube. The influences of parameters on the mean diameter are shown in Figure 7. It is found that the roller feed having most significant influence on the mean diameter of flow formed tube and contributing to 85.64%. The roller radius is also having significant influence limited to 11.85%. The mandrel speed not having any significant influence and contributes 1.02% only. The optimum conditions to produce the tubes with nominal value of mean diameter (43.00 mm) by flow forming are roller feed at 75 mm/min, mandrel speed at 250 rpm and roller radius at 4 mm. It has been proved from the confirmation test that, the improvement of response function is significant, when the process parameters set at their optimal values.

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