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(RESEARCH ARTICLE)

Experimental Investigations on Thickness Variation of AA 6082 Flow-Formed Tubes: A Taguchi's Approach

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Abstract

Flow-forming is 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 Thickness variation of flow formed tubes have been studied by employing 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, Thickness variation (t_r) have been critically studied. It has been found that the axial feed of the roller and speed of the mandrel are the most important process parameters influencing the thickness variation of flow formed tube. The tubes with Thickness variation of 0.04 mm produced by flow forming process when the process parameters were set at their optimum values.

Keywords: Flow-Forming; AA6082 Alloy; Taguchi Method; Thickness Variation

1. Introduction

Flow forming is advanced, eco-friendly, chip less metal forming process for the manufacture of precision, seamless tubes. Flow forming employs rotary point deformation technique. Flow-forming employed in the production of flanged components, cylinders, automobile parts, axi-symmetric sheet metal parts, seamless tubes for high strength aerospace and missile applications etc. AA6082 thin-walled tubes are used in the field of defense, aerospace and missile applications.

Ram Mohan and Mishra [1] analysed power spinning of tubes and Forces are evaluated on the basis of the work of plastic deformation method. Rajanish and prakash [2] developed the shear spinning technology for the manufacture of long thin wall tubes of smaller diameter and reported the effect of power consumption roller profile, feed, percentage reduction on the surface finish of AISI-304 tubes. Chang and others [3] investigated tube spinnability of AA 2024 and 7075 Aluminum alloys and found that the spinnability of solution-treated 2024 and 7075 tubes is lower than that of full-annealed conditions. Rajan et al. [4] studied effect of heat treatment of perform on the mechanical properties of flow formed AISI 4130 steel tubes. Lakshman Rao et al. [5] performed experiments to study the influence of flow forming parameters of maraging steel tubes. Srinivasulu M, Krishna Prasada Rao CS, Komaraiah M [6] employed the Response Surface Methodology to predict the Ovality of AA 6082 flow formed tubes. Bikramjit Poddar et al. [7] conducted experiments on flow forming and found that axi-symmetric, components with complex geometry are produced by flow forming and also elevated the current state of art of flow forming process. Lai and Lee [8] investigated on fracture and creep properties of flow formed components and revealed that fracture toughness is recorded high value at 50% of thickness reduction. Taguchi method can be applied successfully to optimize the process parameters of any machining process.

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Taguchi method can be applied successfully to optimize the process parameters of any machining process. Joseph Davidson et al. [9] used Taguchi approach to study the influence of different process parameters to get maximum elongation on flow forming of Aluminum Alloy (AA6061) with a single roller flow forming machine. Amin Abedini and Samand Rash Ahmadi [10] used Taguchi method to optimize surface roughness of flow formed tubes. But very little work has been reported on the flow forming of AA6082 alloy tubes.

The aim of the present work is to study the effect of important process parameters such as roller feed, mandrel speed and thickness reduction on the thickness variation of AA6082 flow formed tubes and to select the optimum process parameters to produce tubes with minimum thickness variation using Design Of Experiments.

Taguchi approach is a standardized version of design of experiments (DOE) technique, proposed by Dr. Genechi Taguchi of Japan. It is one of the most attractive quality building tool can be used by engineers in the manufacturing industry. Taguchi method significantly reduces the time required for experimental investigations.

2. Experimental setup

2.1. Flow forming process

Flow forming is chip less, an advanced metal forming process used for the production of high precision, seamless tubular and other symmetrical products. In flow forming, the pre-form, is elongated by decreasing its wall thickness. The pre-form is stretched on a rotating mandrel by means of mechanically guided rollers. The flow forming process is classified into two types as forward flow forming and backward (reverse) flow forming process. In forward flow forming, the material flow takes place in the same directions as that of rollers. The forming is done near tail stock and requires tubes with closed ends. In backward flow forming the material flows with opposite direction of roller feed. In this process, tubes longer than mandrel can be formed.

2.2. Equipment

The present work is carried out on a single roller CNC flow-forming machine, Leifield make of West Germany, used in present research work is shown in Figure. 1. 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 affected 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 minimum thickness variation. The thickness variation is one of the important characteristics of flow formed tube for aerospace and defence applications and should be as low as possible.

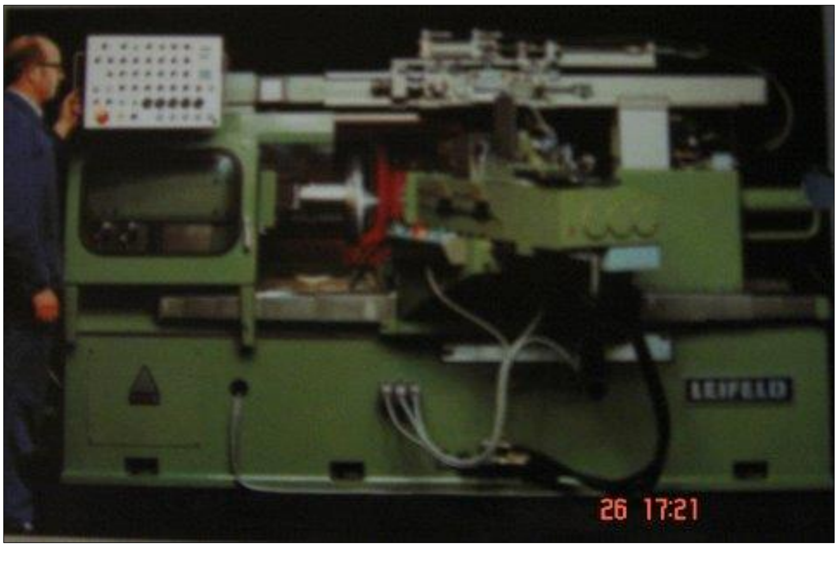

Figure 1 Single roller CNC flow forming machine

2.3. Material

The material used for the present research work is AA6082 alloy. The major alloying elements are Al-1.2Mg-1.0Mn-01.3Si-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 Mg_2Si precipitates.

2.4. Design of Pre-form

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.

Figure 2 Machined pre-form

The pre-form was then annealed at a temperature of 510-540 ^{0}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 Figure.

3. Planning of experiments

The present investigation employs Taguchi Approach, which is a powerful tool for design of experiments (DOE). The Taguchi method provides a simple, efficient and systematic approach to determine the optimal machining parameters. The following steps are involved in the Taguchi method:

- Identification of the input process parameters and response function
- Determination of number of levels for process parameters and possible interaction between them.
- Selection of appropriate orthogonal array.
- Conduction of experiments as per the factors specified in OA.
- Analysis of the results and selection of the optimum process parameters through ANOVA.
- Performing the confirmation test to verify the optimal process parameters.

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

Table 1 Process parameters and their levels

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

The thickness variation of flow formed tube is measured by a micrometre. The resolution of instrument is 0.01mm. Thickness variation can be found by the difference between maximum and minimum thickness of the tube.

3.1. Construction 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 (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 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.

Table 2 Experimental Layout using L9 array

Run No.	Parameter Level			Experimental result for Surface roughness		
	F	S	t	Trial-1	Trial-2	S/N Ratio
1	1	1	1	0.12	0.11	18.77
2	1	2	2	0.03	0.04	29.03
3	1	3	3	0.06	0.07	23.71
4	2	1	2	0.21	0.20	13.76
5	2	2	3	0.12	0.10	19.13
6	2	3	1	0.18	0.19	14.65
7	3	1	3	0.31	0.32	10.03
8	3	2	1	0.25	0.24	12.21
9	3	3	2	0.22	0.23	12.95

4. Analysis of experiments

In the present work each experiment is replicated twice to reduce the effect of noise factor. Taguchi analysis is performed based on the S/N ratio 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 flow formed tube is shown in Figure. 3. The experimental values are shown in Table-2.

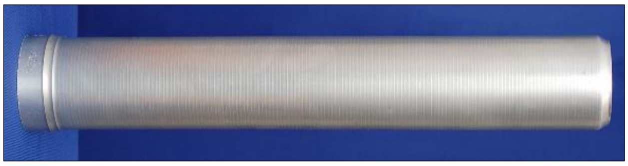

Figure 3 Flow formed tube

The main effects and their differences for the response parameter are given in Table-3. The change of roller feed from 50 to 75 mm/min causes maximum decrease in the main effect from an average value of 23.84 to 15.85, whereas increases of roller feed from 75 to 100 mm/min decreases the average value from 15.85 to 11.73. Higher value of roller feed (100 mm/min) produces, higher plastic deformation as the roller travels slowly over the preform. This uneven plastic deformation leads to greater thickness variation. When the roller feed is at 25 mm/min, the plastic deformation becomes optimum and produces localized uniform deformation which results in lower thickness variation.

Table 3 Main effects and their differences on Thickness variation

Factors	Level 1 (L_1)	Level 2 (L_2)	Level 3 (L_3)	Difference between levels	
				L_2-L_1	L_3-L_2
F, mm/min	23.84	15.85	11.73	-7.99	-4.11
S, rpm	14.19	20.12	17.10	5.93	-3.02
t, %	15.21	18.58	17.62	3.36	-0.95

The increase of mandrel speed from 150 to 200 rpm increases the main effects from 14.19 to 20.12, and the increase in speed from 200 to 250 rpm reduces the average value of response function from 20.12 to 17.10. At low speed (150 rpm), the material is not completely plasticized, which leads to increase in the value of thickness variation. The increase in speed from level 1 to level 2 decreases the thickness variation due to increase in uniform deformation. Further increase in speed from level 2 to level 3 produces the tubes with higher thickness variation as it results in vibrations.

The change of thickness reduction from 25 to 50% results in the increase in the main effects from 15.21 to 18.58. However, the change of thickness reduction from 50to 75 % decreases the main effects by 0.95. Lower value of thickness reduction cannot plasticize the material completely, leads to non-uniform deformation of pre-form and produces tubes with higher thickness variation. The thickness reduction reaches to uniform plastic zone (Level 2), the process produces tubes with minimum thickness variation. If the thickness reduction increases to level 3, which is beyond the uniform plastic zone, again produces non-uniform plastic deformation and results in higher thickness variation.

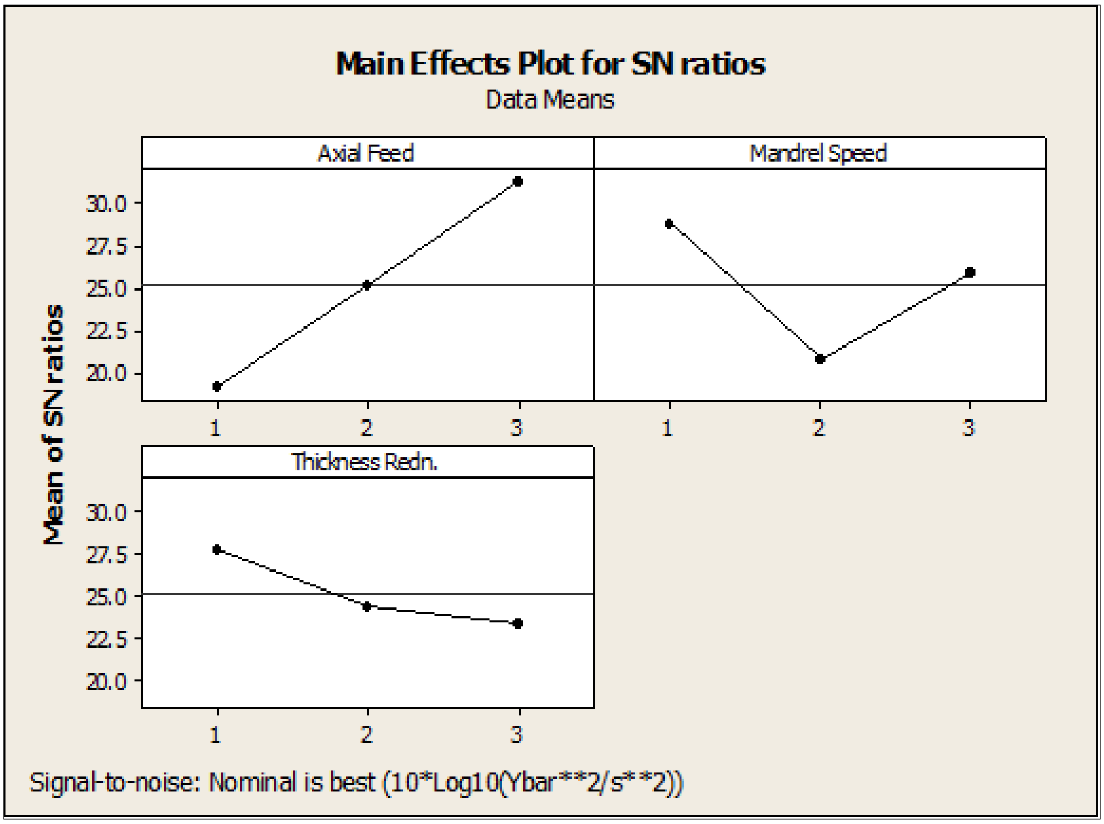

Figure 4 Main Effects of process parameters on Thickness variation

The main effects and their differences between the levels of parameters on the thickness variation are shown in Figure. 4. The relative slope of linear graph expresses the significance of parameters. From the graph, it is evident that, the slope of line indicating the roller feed is higher as compared to slopes of other parameters. From the main effects and graphs of factor parameters, it is clear that the roller feed is having significant influence on the thickness variation of flow formed tube, followed by thickness reduction and mandrel speed.

The results of ANOVA performed for the response functions 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. 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 thickness variation of flow formed tube followed by mandrel speed. This also confirms with the graph shown in Figure. 4.

Table 4 ANOVA Table

Factor	**D.O. F**	**Sum of Sqrs., S**	**Variance, V**	**F-Ratio,F**	**Pure Sum S"**	**Percent, P (%)**
Roller feed	2	227.4	113.6	79.6	224	74.5
Mandrel speed	2	53.8	26.4	18.5	50	16.6
Thickness redn.	2	18.0	9.03	6.3	15	5.1
Others/Error	2	2.8	1.42			3.8
Total	8	302.0				100

The contour plot of roller feed and mandrel speed on thickness variation is shown in Figure. 5. The lower Thickness variation can produce when lower feed is combined with middle range of mandrel speed.

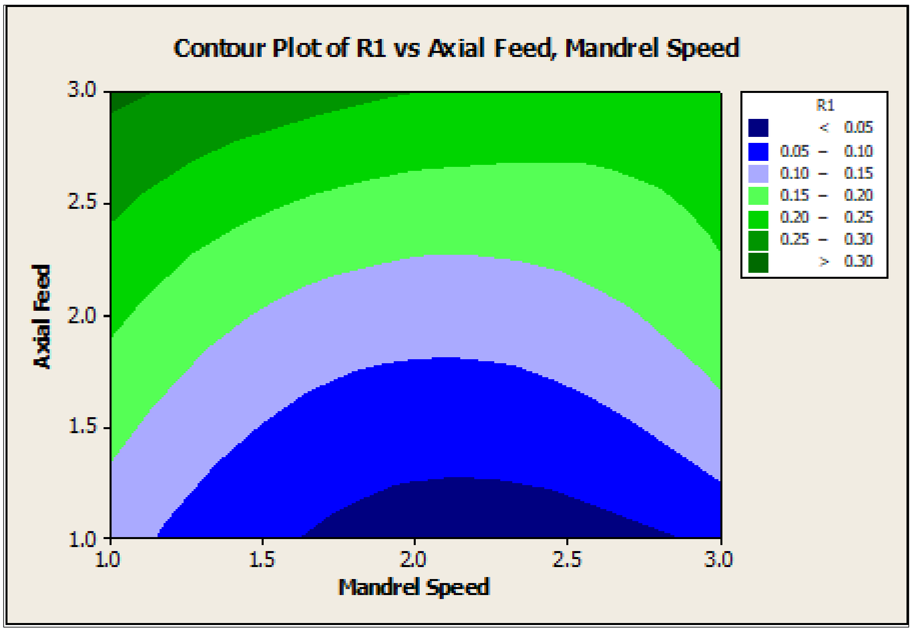

Figure 5 Contour plot of roller feed and mandrel speed on thickness variation

The contour plot axial feed of roller and thickness reduction on thickness variation is shown in Figure. 6. Lower value of feed and middle level of thickness reduction is required to produce the tubes with lower thickness variation.

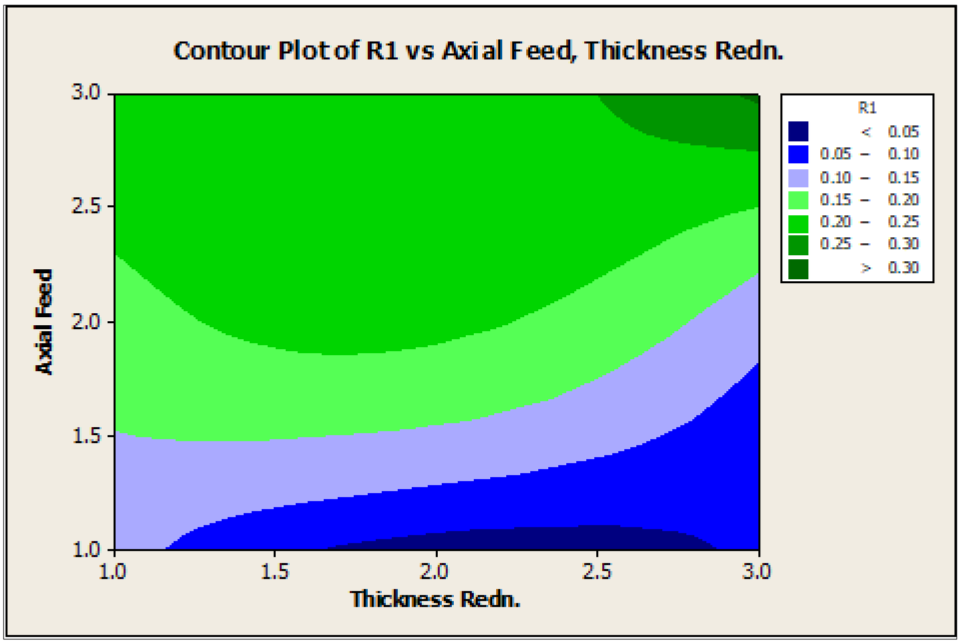

Figure 6 Contour plot of roller feed and thickness reduction on thickness variation

The contour plot of mandrel speed and thickness reduction on thickness variation is shown in Figure. 7. Mid value of mandrel speed and middle level of thickness reduction is required to produce the tubes with lower thickness variation.

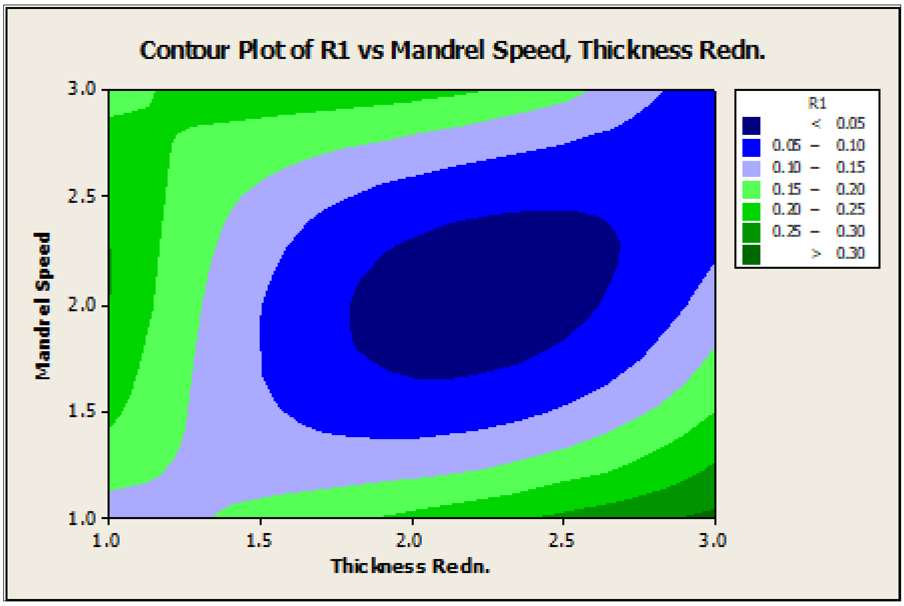

Figure 7 Contour plot of mandrel speed and thickness reduction on thickness variation

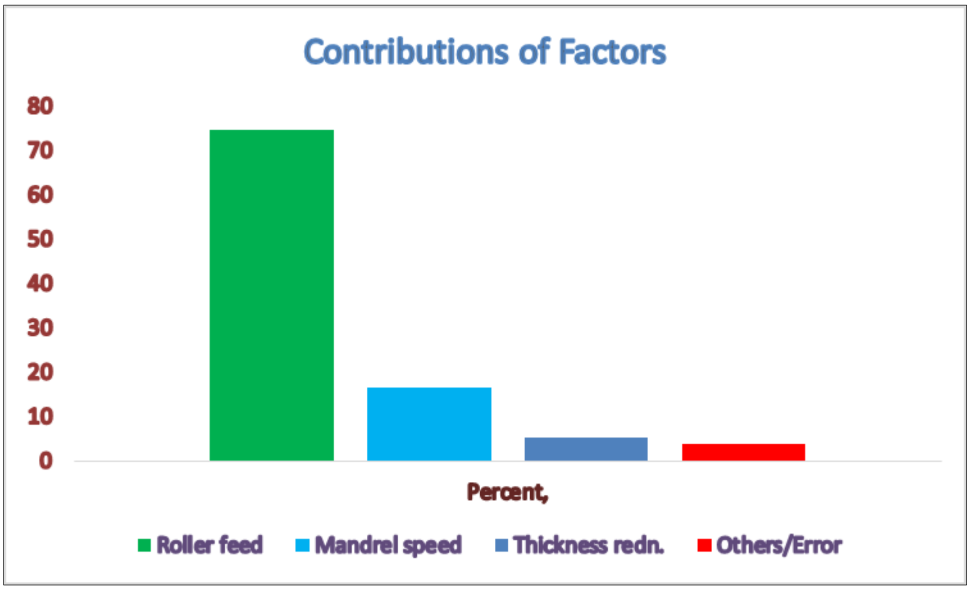

Figure 8 Contribution of parameters on thickness variation

Table 5 Optimum Conditions for minimum Thickness variation

Factors	Level Description	Level	Contribution
F, mm/min	50	1	6.69
S, rpm	200	2	2.98
t, %	50	2	1.44

Expected Result at Optimum condition is 0.04.

4.1. 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 conditions for smaller thickness variation are shown in Table-5. It reveals that the roller feed should be at level 1, the mandrel speed should be at level 2 and the thickness reduction should be at level 2, for production of flow formed tube with smaller thickness variation. The developed model predicts an optimum value of 0.04 mm for thickness variation. A confirmation test is conducted by setting the parameters at their optimum values and response parameter obtained is in good agreement with predicted value.

5. Conclusion

In the present study, the influences of process parameters on the thickness variation of AA6082 flow formed tubes have been investigated by Taguchi method. It is concluded that the parameters that have relative significant influence on thickness variation are roller feed (74.5%), mandrel speed (16.6%) and thickness reduction (5%) respectively. The contribution of parameters on thickness variation is shown in Fig. 8. The optimum conditions for smaller thickness variation are roller feed at 50mm/min, mandrel speed at 200 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.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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