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Experimental Study of Flow forming Process Parameters on Thickness variation of Aluminum Alloy AA6061 Tubes

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Abstract: Flow forming is an advanced chip less incremental metal forming process, which employs point deformation technique used to produce dimensionally precise long tubes. In this study, a fully annealed Aluminum Alloy 6061tubular preform was cold flow-formed by using three rollers with a single pass forming. In this study, effect of flow forming process parameters viz; feedspeed ratio, percentage of reduction and roller axial stagger on thickness variation have been analyzed. It is found that with increased feed rate, percentage of reduction and axial stagger the thickness is varying along length and also circumference of formed tube. The flow formed component has been analyzed using Design of Experiments technique (ANOVA) to find most influence factors; axial stagger and percentage of reduction on thickness variation and MINITAB software is used for multiple regression equation is formulated for estimating predicted values of thickness variation analysis.

Keywords: AA6061, ANNOVA, Incremental forming, Thickness variation, stagger

1. Introduction

Flow forming is an incremental forming process used for making long, thin-walled seamless tubes with high strength and dimensional accuracy. This process is carried out by compressing the pre-formed tube using one or more rollers, leading to the plastic flow of material in the radial, axial, and tangential directions. This will ultimately result in the reduction in thickness and elongation of the tube. Short production runs, a variety of symmetrical shape, smaller deformation force, less investment in equipment are the advantages of Flow forming.

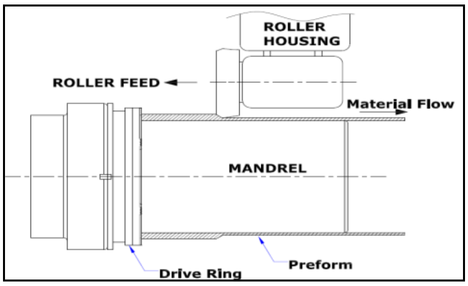

Fig.1. Schematic diagram of backward flow forming [8]

In the present work backward flow forming operation was used, Figure 1 illustrates the backward operation of forming a tube with both ends fully open the metal and the roller move in opposite directions. Mohebi and Akbarzadeh [1] probed the local plastic deformation of AA 6063 alloy during a flow-forming process. They comprehended that high shear strains happened on both longitudinal and transverse directions of the preformed tube. Davidson et al. [2] studied the effect of flow forming process parameters on the quality of flow formed AA6061 aluminum alloy tube. They concluded that the quality of the final product depend on the depth of cut, feed, initial dimensions of the preform, the initial heat treatment of the preform, and the speed of mandrel. M. Joseph Davidson et al [3] have carried experiments on a four-axis CNC flow-forming machine with a single roller and predicted the percentage of elongation by Taguchi method. Srinivasulu et al. [4] optimized the process parameters for minimum surface roughness in flow forming of AA6082 tubes employing Design of Experiments. G.Venkateshwarlu et.al [5] formed aluminum cups by spinning and studied the effect of process parameters viz; mandrel speed, feed of roller and roller nose radius, on surface finish of formed cups and also studied the dimensional accuracy of spring back, wall thickness. From the experimental investigations, it was found that the surface finish of formed cups is better with high speeds of mandrel and at lower feed rates. Radial spring back at the top of cup is higher when compared to bottom of the cup. Hossein Jafarzadeh et.al [6] analyzed the forward flow forming process and found that the influence of feed rate as a major parameter on the quality of AA7075 alloy and also studied the surface roughness, diametral growth and forming load numerically and experimentally. N. A. Razani & Abdolhossein Jalali Aghchai [7] has considered the hardness which is the important mechanical property of flow-formed tubes. In this study, design of experiments (DOE) is utilized to determine the influence of the parameters such as rotational speed of mandrel, feed rate, and wall thickness reduction on the hardness of flow-formed AISI 321 steel tube.

However, no work has been reported on axial stagger of three roller flow forming process. The aim of the present investigation is to study the process parameters on thickness variation.

2. Experimental work

2.1. Equipment

The forming operation was performed on a 3 roller CNC Flow Forming Machine (Make: Leifeld; Model: ST 56-75 CNC). In flow forming of tubes, the work piece is held on the mandrel, the forming roller moves along the work piece axially to reduce the thickness shown in Fig 2. The specifications of the machine are given in Table 1.

Table1. Specification of the Flow Forming Machine

Minimum forming diameter	60mm
Maximum forming diameter	560mm
Speed range	36-820 Rpm
Spindle power	75 KW
Radial force on each roller	180 KN
Axial force on the saddle	300 KN

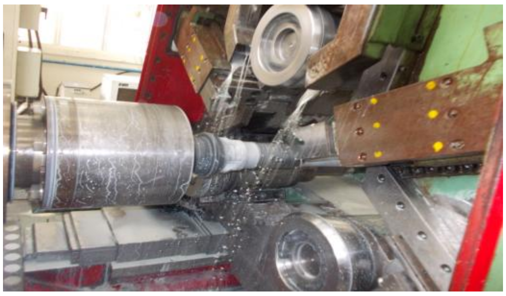

Fig. 2 The flow forming machine (Three – Rollers)

2.2. Tooling

Mandrel is the main tool used for flow forming of any component. The mandrel is made up of Die Steel (AISI D2/D3). Hardness of the finished mandrel lies in between 58 to 62 HRc. Similarly Roller is an important factor in flow forming and is subjected to rigorous loading in operation. Rollers are made of AISI D2/D3 steel and hardened to 58 to 62 HRc. Stripper ring is made of low carbon steel and it facilitate the removal of finished tube and toothed segment is used to ensure the rotation of preform along with the mandrel and it is made of AISI D2/D3 with hardness of 50 to 54 HRc. The serration of toothed segments helps in interlocking of work piece during the actual forming process. It ensures the same rotational speed of perform, and also used lubricant as a paste called MOLY KOTE paste is applied on the mandrel before preform is loaded in order to avoid sticking of the preform to the mandrel. During flow forming, work pieces and tools are flooded with a coolant, such as an emulsion of soluble oil in water.

2.3. Material

In the present investigation AA6061 alloy is used for flow forming. Before forming, Hardness is measured as 44.24Hv. AA6061 alloy has excellent joining characteristics, corrosion resistance and has good acceptance for coatings. Table2. Shows the chemical composition of the work material.

Table2. The nominal compositions of AA6061 alloy

Element	Si	Fe	Cu	Mn	Mg	Cr	Al
AA6061	0.60	0.16	0.24	0.17	0.88	0.16	Bal

2.4. Preform specification

The preform is machined from forged rod and subsequently annealed. The preform of AA6061 machined on a CNC Lathe. Fig.3a gives the Schematic diagram of Preform and Fig.3b gives the machined preforms before forming. The specifications of the preform are given in Table 3.

Table3. Preform Specifications

Length of the preform	175mm
Inner diameter of the preform	74.5mm
Outer diameter of the preform	81.5mm
Thickness of the preform	7mm

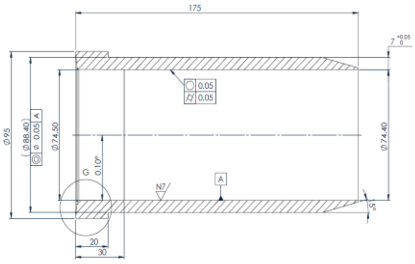

Fig. 3a Schematic diagram of Preform

Fig. 3b Machined Preform before forming

3. Experimental plan

Design of experiments have been regarded as one of the most favorable techniques in covering a large area of practical statistics and obtain unambiguous results with least expense. The present investigation employed full factorial method to obtain optimum results. It is well known that the speed feed ratio have greater effect on flow forming. When three rollers are used, the axial stagger of the rollers is needed to be investigated. The roller makes the material too plastically, when in contact with the work piece. The input parameters chosen for the experiments are axial stagger, feed rate and percentage of reduction. The response parameter is thickness variation of the formed component. Table 4, gives the details of input process parameters and their levels

Table4. Input process parameters and their levels

S. No	%Reduction	Feed Speed Ratio	Axial stagger	
			Z-X	Y-X
Level 1	30	0.3	10.5	5.0
Level 2	45	0.45	15.8	7.5
Level 3	60	0.6	21.0	10.0

Table 5, gives the details of input process parameters L-27 Array with Actual Factors and their levels

Table5. L-27 Array with Actual Factors and their levels

Expt. No	% reduction	Feed ratio	Axial stagger (mm)	
			Z-X	Y-X
1	30	0.3	10.5	5.0
2	30	0.45	10.5	5.0
3	30	0.6	10.5	5.0
4	45	0.3	10.5	5.0
5	45	0.45	10.5	5.0
6	45	0.6	10.5	5.0
7	60	0.3	10.5	5.0
8	60	0.45	10.5	5.0
9	60	0.6	10.5	5.0
10	30	0.3	15.8	7.5
11	30	0.45	15.8	7.5
12	30	0.6	15.8	7.5
13	45	0.3	15.8	7.5
14	45	0.45	15.8	7.5
15	45	0.6	15.8	7.5

16	60	0.3	15.8	7.5
17	60	0.45	15.8	7.5
18	60	0.6	15.8	7.5
19	30	0.3	21.0	10.0
20	30	0.45	21.0	10.0
21	30	0.6	21.0	10.0
22	45	0.3	21.0	10.0
23	45	0.45	21.0	10.0
24	45	0.6	21.0	10.0
25	60	0.3	21.0	10.0
26	60	0.45	21.0	10.0
27	60	0.6	21.0	10.0

3.1. The design matrix

Analysis is carried with three factors and three levels. Therefore 27 experiments were conducted using full factorial to study the flow forming process. The experimental layout is shown in Table 6.

Table6. The experimental layout

Factors	3	Replicates	1
Base runs	27	Total runs	27
Base blocks	1	Total blocks	1
Number of levels	3	3	3

3.2. Analysis of variance (ANOVA)

The main aim of ANOVA is to investigate the design parameters and to indicate which input parameters are significantly affecting the output parameters. Parameters make a big change on the performance. Standard commercial statistical software package MINITAB was used to derive the models with the obtained experimental results. From the experiments thickness variation is noted and then fed into a DOE/STAT programme to construct statistical regression equation.

The flow formed tube is shown below in the Fig.4.

Fig.4 flow formed tube with 30%, 45%, and 60% of reduction

4. Results and Discussions

The thickness of the flow formed components is listed with respect to different levels of experimental trials. The thicknesses of the tubes after each experimental trial are measured at three places along length in three sections and at different orientations i.e., 0^0, $90^{0,}$ 180^0 and 270^0 shown in Fig. 5. The thickness variation is estimated by difference between achieved thicknesses on the tube to be targeted thickness on flow formed component.

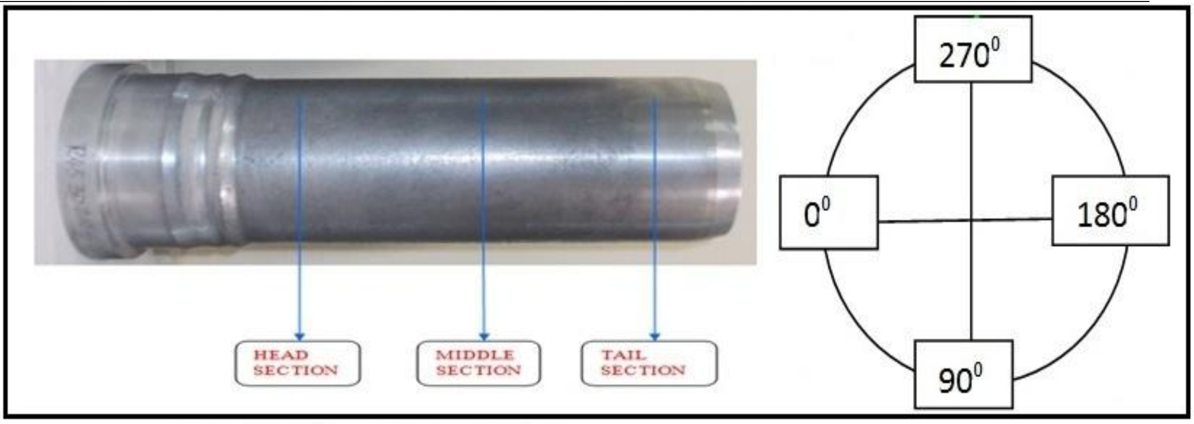

Fig 5. Flow Form Tube

The effect of process parameters on variation in thickness are tabulated in the Table 7.

Table 7 Experimental results

Std Order	Run Order	Pt Type Blocks	%Reduction	Feed Speed Ratio	Stagger (mm)	Thickness variation(mm)
1	1	1	30	0.3	10.5	0.05
2	1	1	30	0.3	15.8	0.05
3	1	1	30	0.3	21.0	0.08
4	1	1	30	0.45	10.5	0.05
5	1	1	30	0.45	15.8	0.06
6	1	1	30	0.45	21.0	0.1
7	1	1	30	0.6	10.5	0.04
8	1	1	30	0.6	15.8	0.05
9	1	1	30	0.6	21.0	0.06
10	1	1	45	0.3	10.5	0.05
11	1	1	45	0.3	15.8	0.09
12	1	1	45	0.3	21.0	0.08
13	1	1	45	0.45	10.5	0.03
14	1	1	45	0.45	15.8	0.2
15	1	1	45	0.45	21.0	0.25
16	1	1	45	0.6	10.5	0.07
17	1	1	45	0.6	15.8	0.15
18	1	1	45	0.6	21.0	0.1
19	1	1	60	0.3	10.5	0.1
20	1	1	60	0.3	15.8	0.33
21	1	1	60	0.3	21.0	0.4
22	1	1	60	0.45	10.5	0.15
23	1	1	60	0.45	15.8	0.3
24	1	1	60	0.45	21.0	0.42

25	1	1	60	0.6	10.5	0.1
26	1	1	60	0.6	15.8	0.3
27	1	1	60	0.6	21.0	0.35

4.1. Analysis of variance

The analysis of variance is used to appraise the influence of the input parameters on the thickness variation. The summary of the model is given in the Table 8.

Table8. Analysis of Variance for Thickness variation, using Adjusted SS for Test

Source	DF	Seq SS	Adj SS	Adj MS	F	P
%reduction	2	0.219385	0.219385	0.109693	92.84	0.000
Feed ratio	2	0.008319	0.008319	0.004159	3.52	0.080
Stagger	2	0.086230	0.086230	0.043115	36.49	0.000
%red*Feed ratio	4	0.006237	0.006237	0.001559	1.32	0.341
%reduction*Stagger	4	0.052193	0.052193	0.013048	11.04	0.002
Feed ratio*Stagger	4	0.005926	0.005926	0.001481	1.25	0.363
Feed ratio*Stagger	8	0.009452	0.009452	0.001181	-	-
Total	26	0.387741	-	-	-	-

S = 0.0343727   R-Sq = 97.56%   R-Sq (adj) = 92.08%

In this case, the model is very useful because it declares that the factors in the model have an important effect on the response. The significance of each coefficient can be determined by Model 'F' value and 'P' value shown in Table 8.

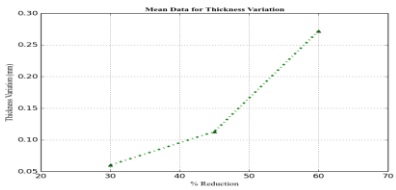

Fig 6: Effect of %Reduction on Thickness Variation

Figure 6 shows the effect of thickness variation of the formed component which tends to increase when the percentage of reduction is increased from 30 to 60% due to effect of spring back. When release of the forming force, the material has a tendency to partially retain to its original shape because of the elastic recovery of the material increasing the thickness variation.

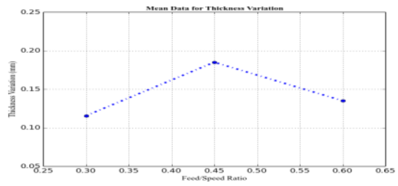

Fig 7: Effect of Feed/Speed Ratio on Thickness Variation

Thickness variation of the formed component tends to increase with increase in the feed ratio from 0.30 to 0.45 and it decreases with increase in feed ratio from 0.45 to 0.60. The Fig 7 gives that the rollers gets less time to shear the component. As mentioned by Sortais et al. [9] at higher feed, the thickness accuracy is less as compared to the lower feeds. Less feed ratio has enough time to shear and deform the material. Hence it gives accurate thickness.

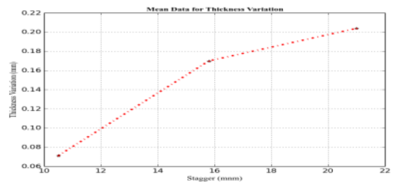

Fig 8: Effect of Stagger on Thickness Variation

The thickness variation of the flow formed component tends to increases, when the roller axial stagger increase 10.5 to 21.0mm as shown in Fig 8. If the axial stagger increases sufficient time gap is maintained between the rollers for elastic recovery.

Fig 9 shows the as percentage of reduction and stagger are increased, there an increase in thickness variation. This is more predominant at higher percentage of reduction and stagger. The possible reason may be due to the plastic deformation leading to cold working.

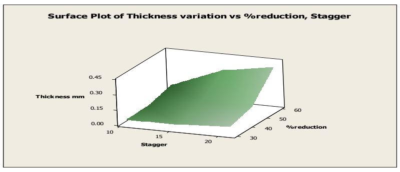

Fig.9. 3D Surface plot of thickness variation vs % reduction, stagger

From the Fig 10 it can be observed that the thickness reduced as feed ratio is increased from 0.45 to 0.60 and beyond that the thickness increased as feed ratio increased, and there is a drastic increase in thickness with respect to increase in stagger 10.5 to 21.0mm.

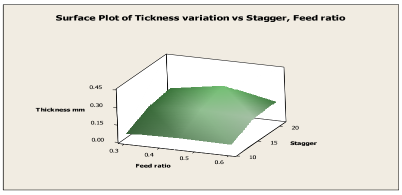

Fig.10. 3D Surface plot of thickness variation vs feed ratio, stagger

Fig 11 shows thickness is almost constant when feed ratio is increased from 0.3 to 0.6 and there is a drastic increase in thickness with respect to increase in % of reduction 30 to 60. The possible reason may be due to less feed ratio has enough time to shear and deform the material.

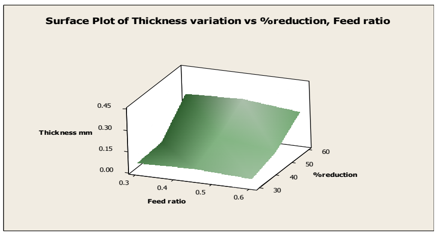

Fig.11. 3D Surface plot of thickness variation vs feed ratio, stagger

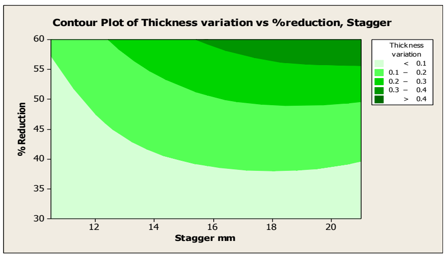

Fig.12. 3D Contour plot for thickness variation

Fig. 12 gives the 3D contour plot for thickness variation; from the plot stagger and percentage of reduction is more predominant factors on thickness variation.

5. Regression Analysis

In this case multiple linear mathematical models for forming parameters such as percentage of reduction, feed rate and axial stagger were obtained from regression analysis using MINITAB 14 statistical software and thickness variation is predicted. The insignificant coefficients identified from ANOVA have been omitted from the equations for various responses. The regression coefficients have been obtained by using experimental data.

The regression equation is

Thickness variation = - 0.369 + 0.00707 %reduction - 0.004 Feed ratio + 0.0127 Stagger

6. Conclusions

In this present work importance of the thickness was observed from the flow formed tubes. The processes parameters considered such as feedrate, percentage of reduction and roller axial stagger have been experimentally studied with respect to different levels of each parameter and results stated below.

- The effect of thickness variation of the formed component which tends to increase when the percentage of reduction is increased from 30 to 60% due to effect of spring back. When release of the forming force, the material has a tendency to partially retain to its original shape because of the elastic recovery of the material increasing the thickness variation.
- Thickness variation of the formed component tends to increase with increase in the feed ratio from 0.30 to 0.45 and it decreases with increase in feed ratio from 0.45 to 0.60. The Fig 7 gives that the rollers gets less time to shear the component. As mentioned by Sortais et al. [9] at higher feed, the thickness accuracy is less as compared to the lower feeds. Less feed ratio has enough time to shear and deform the material. Hence it gives accurate thickness.
- The thickness variation of the flow formed component tends to increases, when the roller axial stagger increase 10.5 to 21.0mm. If the axial stagger increases sufficient time gap is maintained between the rollers for elastic recovery.
- Percentage of reduction and stagger are increased, there an increase in thickness variation. This is more predominant at higher percentage of reduction and stagger. The possible reason may be due to the plastic deformation leading to cold working.
- Results obtained from the regression equations agree well with the experiments

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