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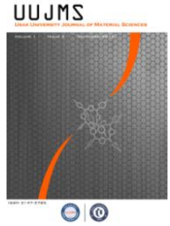

Research article

Analysis of tube end forming process using Taguchi design of experiments

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Abstract

In this study, the Taguchi method is used to find the optimum process parameters for maximum expansion of tube ends. The various process parameters namely the punch/die cone angle, the expansion ratio and the friction conditions are taken as the input process condition and the output; the maximum radial displacement is critically analyzed. Radial expansion is the increase in diameter of the tube by the die measured on the top most portion of the tube across its circumference. The optimal combination of the process parameters is obtained through the signal to noise ratio (*S/N*) analysis and the analysis of variance (ANOVA) methods. The parameters that affect the process are determined using Taguchi method and the most significant process parameters and their percentage contribution was determined by using ANOVA technique. Among all the three process parameters considered, it is found that the most significant factor is the die cone angle (α) and this factor contributes 43.56% on the total output response value while expansion ratio r_p/r_0 contributes 8.89% and the lubricant has contributed 38.59% on the total output. The experimental results are in acceptance with the predicted values for the 95% confidence interval and it is observed that the error is within the reasonable limit.

***Key words**: Tube end expansion, Taguchi analysis, ANOVA, AA6061 tubes*

1. Introduction

End forming of tubes finds application in many fields such as power transmission applications, fuel lines and exhaust pipes, hydraulic cylinders and heat exchangers etc. End forming is defined as forming the end of tubular forms, either by inverting the tube or by expanding it. A punch with a divergent end on one side will be inserted into the tube. The tube will get the shape of the punch after the die is retracted back due to plastic deformation. In this expansion process, formability is limited by the occurrence of local buckling or ductile fracture. In metal forming processes, it is essential that the metal deforms plastically without fracture.

Tube end forming process is governed by various process parameters namely punch/die cone angle, ratio between punch radius and initial reference radius, friction, punch speed, tube length and tube thickness. To develop the process for the tube end forming process,

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it is essential to know the process parameters that affect it and also the most significant and non-significant process parameters that affect the desired design requirement. This can be achieved by conducting large number of experiments. However, such a time consuming experimental procedure can be substituted with "Taguchi method", which is based on design of experiments concept. Many researchers have worked on the optimization techniques in recent years. Bing Li et al. [1] did multi-objective optimization of hydro forming process parameters by using Taguchi method and finite element method. They found that the internal pressure and the friction co-efficient have the greatest influence on the free bulging of tube hydro forming process. Dae-Cheol et al. [2] used Taguchi method and ANN to study the workability limited by the ductile fracture. The workability of the material along the path of the process was determined using ANN and Taguchi method was used to minimize the objective function.

Hsin-Te et al. [3] used design of experiments concepts to optimize the process parameters of chemical-mechanical polishing process in wafer manufacturing. Material removal rate and non-uniformity of surface profiles were selected as the target values, and the process parameters such as platen speeds, carrier speeds, back side pressure, slurry flow rate and a head down force were optimized. Jurkovic et al. [4] conducted experiments to know the influence of forming process parameters with an objective to minimize the load on the tool. The process parameters such as strain, die angle and coefficient of friction were optimized by using both classical optimization techniques and design of experiments concepts. The merits and demerits of both the classical and DOE methods were highlighted. In this study, the authors calculated the maximum expansion ratio of the tube and the fracture behavior of the tube. The corresponding changes in the hardness values were investigated. Padmanabhan et al. [5] studied the influence of process parameters on the deep drawing of stainless steel. Deep drawing process parameters such as die radius, blank holder force and friction-coefficient were studied to find the optimum condition for forming. It was found that the die radius followed by the blank holder force and friction coefficient have the greatest influence on the deep drawing of stainless steel blank. Rossella et al. [6] optimized aluminium foam manufacturing process with Taguchi method. In this study, the relative density of aluminium foams were minimized by optimally controlling three process parameters namely silicon carbide content in powder mixture, the compaction pressure and the forming temperature. Su-Hai et al. [7] applied the artificial neural networks (ANN) to predict the forming load of magnesium alloy under hot extrusion. In this study, ANN analysis was used to determine the die shapes for various extrusion ratios. Wei et al [8] implemented multi-objective optimization to optimize the gear warm forming process parameters.

Zhubin et al. [9] studied the formability and deformation behavior of AZ31B tube at elevated temperature by tube bulging test. Almedia et al. [10] performed expansion and reduction studies on AA 6060 tubes. They forced a tapered dedicated punch into the tube end retracted it after achieving the desired shape. The variation of tube end formability with the variation in tribological conditions of AA6060 tube was studied. The work reported three different modes of deformation. Alves et al. [11] performed tube end forming experiments on AA6060 alloy. External inversion of thin walled tubes was performed by Rosa et al. [12] on AA 6060 alloy. It was reported that, during external inversion, a smaller die radius lead to local buckling, whereas a larger die radius has led to ductile damage fracture. Experiments were performed on samples with two different mechanical and metallurgical conditions resulting from natural aging and annealing. Schaeffer et al. [13] gave the brief description of each forming process such as expansion, reduction, internal inversion and external inversion and focused on understanding the parameters that govern each process. The objective of the present work is to optimize the process parameters involved in tube expansion process by using Taguchi and ANOVA methods. The parameters that affect the process were determined using Taguchi method, and the most significant process parameters and their percentage contribution were determined by using ANOVA technique.

2. Plan of Experiments

2.1. Material Properties

The material used in the present work is AA6061 alloy. The major alloying elements are Al-1Mg-0-0.6Si-0.7Fe-0.25Cu-0.2Cr. AA6061 alloy is the most extensively used metal in the 6000 series aluminium alloys. It is a heat treatable alloy having good toughness characteristics and excellent corrosion resistance behavior. AA6061 alloy has ultimate tensile strength of 282.6 MPa, yield strength of 267 MPa and a percentage elongation of 7.58. Due to its excellent mechanical properties, the alloy is used in aircraft structures, bicycle frames, automotive parts, land based pipelines and aircraft support structures. Fig.1 shows the true stress-true strain curve obtained by means of compression test conducted in the laboratory.

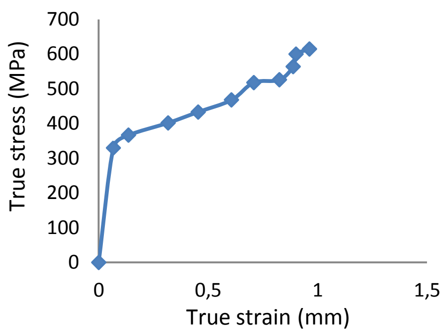

Fig.1 True stress-true strain curve of AA6061 aluminium alloy

2.2. Equipment

The present experiment was carried out on a hydraulic press of 50 ton capacity. The machine used in this work is shown in Fig.2.

Fig. 2 Hydraulic press

The die was mounted on the ram. A constant ram speed of 0.5 mm/s was taken. Before starting the test, the tube was adjusted in such a way that the axis of tube and punch were aligned. During the forming process, the load was increased by rotating the pressure valve manually. Punch displacements were measured using a LVDT. PC-based data logging system was used to record and store the loads and displacements. The process was continued until the complete punch moved inside the tube fully or a crack appeared at the tube tip. In the similar way, experiments were done by using different lubricants namely palm oil (vegetable oil), VG460 (mineral oil) and MOS_2 (solid lubricant). A tube that was expanded by inserting the punch as described above is shown in Fig. 3. A die with r_p/r_0=1.53, and α=30° was used in the above case.

Fig.3 Expansion of tube with the die of r_p/r_0=1.53, α=30°

2.3. Taguchi Method

Taguchi method was developed by Genichi Taguchi, a Japanese engineer. This process is based on statistical design concepts. In the present study, Taguchi method has been used to optimize the process parameters with the aim of achieving the maximum expansion of tube end. The factors and levels considered in the experiments are given in Table 1.

Table 1
Control factors and levels

Factors	Factor Designation	Level 1	Level 2	Level 3
Die angle (α)	A	15°	30°	45°
Expansion ratio r_p/r_0	B	1.39	1.53	1.67
Lubricant	C	Palm oil	VG460	MOS_2

The process parameters considered for the study are die cone angle (α), expansion ratio r_p/r_0 and lubricant. Three levels have been considered for each parameter. The experiments were designed using L_9.standard orthogonal array as given in Table 2.

3. Results and Discussions

3.1. Taguchi Analysis

The experiments were conducted as per the experimental layout given in Table 2. A total of nine experiments were done. Taguchi method uses the S/N (signal-to-noise) ratio. S/N ratio is used to determine the most significant factor. There are three types of S/N ratio criteria for optimization namely smaller the best, larger the better and nominal the best.

Table 2
Layout of experimental design

Experiment No.	Factor A	Factor B	Factor C	Radial expansion
1	15°	1.39	Palm Oil	53.50
2	15°	1.53	VG 460	50.50
3	15°	1.67	MOS_2	51.32
4	30°	1.39	VG460	51.80
5	30°	1.53	MOS_2	53.40
6	30°	1.67	Palm	56.00
7	45°	1.39	MOS_2	53.68
8	45°	1.53	Palm	54.82
9	45°	1.67	VG460	54.74

In the present study, to get the maximum expansion results, the quality parameter "larger the better" has been chosen. The S/N ratio for "larger the best" a criterion is as follows:

$$S/N\ Ratio = -10log[1/n \sum_{i=1}^{n} 1/Y_i^2] \quad (1)$$

where; Y_i is the measured value of quality characteristic and '*n*' is the number of repetitions for the experimental combination. Signal to noise ratio values for different levels and different factors are calculated from the above formula and given in Table 3.

Table 3
Response table for signal to noise ratios **(**Larger is better**)**

Level	A	B	C
1	34.28	34.48	34.77
2	34.60	34.47	34.37
3	34.71	34.65	34.45
δ	0.43	0.18	0.40
Rank	1.00	3.00	2.00

Based on the delta values, the process parameters are ranked. From Table 3, it is clear that the most significant factor is the die cone angle (α) followed by lubricant and expansion ratio r_p/r_0. Fig. 4 gives the main effects plots for the S/N Ratio.

The graph is plotted between the mean of the S/N ratio values and the number of levels for all the three factors. The optimum process parameters and levels are *A3, B3* and *C1*. In addition to the *S/N* ratio analysis, main effects of the process parameters on the mean response are also analyzed. The mean response refers to the average value of the quality characteristic for each factor at different levels. Thus, the average values of the expansion, for each factor, at the three levels have been calculated and are plotted in Fig. 5.

Calculated values of means are given in Table 4. The mean response analysis also indicates the same optimum level of the parameters (i.e. *A3, B3* and *C1*) as obtained in S/N ratio analysis.

Table 4
Response table for means

Level	A	B	C
1	51.77	52.99	54.77
2	53.73	52.91	52.35
3	54.41	54.02	52.80
δ	2.64	1.11	2.43
Rank	1.00	3.00	2.00

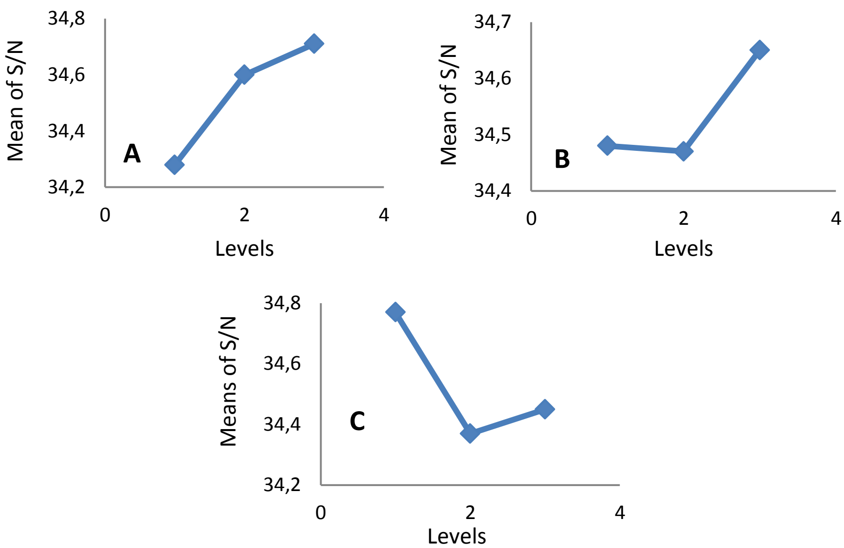

Fig. 4 Main effects plot for S/N ratios

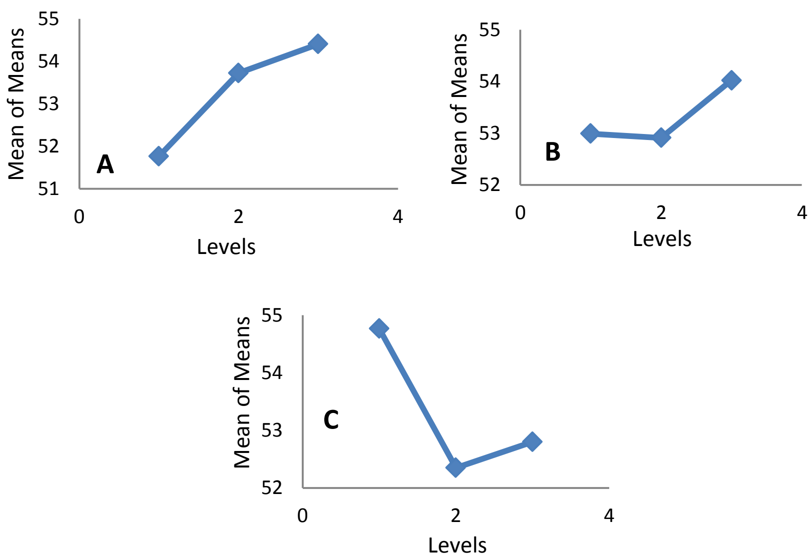

Fig. 5 Main effects plot for means

3.2. Analysis of Variance (ANOVA)

The analysis of variance (ANOVA) is used to determine the most significant factor among all the process parameters which are affecting the output quality characteristics using the quantities such as degrees of freedom, sum of squares, variance, F-ratio and percent contribution. Table 5 shows the computed results of the ANOVA with 95% confidence. The F-ratio and the percent contributions of the various parameters as quantified under the respective columns of Table 5 reveal that die cone angle (α) has the most significant parameter affecting the tube expansion process. This factor contributes 43.56% on the total value while expansion ratio r_p/r_0 contributes 8.89% and the lubricant has contributed 38.59% on the total value.

Table 5
Analysis of variance (ANOVA) for expansion

Source	Degree of Freedom	Sum of Squares	Variance	F-Ratio	Contribution Ratio (%)
A	2	11.274	5.637	4.87	43.565
B	2	2.301	1.151	0.99	8.891
C	2	9.988	4.994	4.31	38.590
% Error	2	2.315	1.158		8.945
Total	8	25.878			100.000

3.3. Prediction of Optimum Value

From the response values for S/N ratios and the response values from means, the optimum control factors and levels have been determined as A_3, B_3 and C_1. The predicted mean (M) of the response characteristic has been expressed as follows:

$$M=\bar{Y} + (\overline{A3} - \bar{Y}) + (\overline{B3} - \bar{Y}) + (\overline{C1} - \bar{Y}) \qquad (2)$$

where; $\bar{Y}$ is average expansion of all the 9 experiments, $\overline{A3}$, $\overline{B3}$ and $\overline{C1}$ are the response values of mean with process parameters at optimal levels. The calculated response values are $\bar{Y}$=53.306, $\overline{A3}$=54.41, $\overline{B3}$=54.02 and $\overline{C1}$=54.77, substituting all the values in Eq. 2, the mean optimum value of the expansion has been predicted as M=56.588.

3.4. Confirmation Test

In order to confirm the validity of the model developed, a confirmation test was conducted. The confirmation experiment is conducted in order to test the predicted results with optimum levels of the process parameters. Table 6 shows the results of confirmation experiments, and it is observed that the radial expansion of tubes obtained from experiments is within the range of predicted 95% confidence interval and it is observed that the error is within the reasonable limit.

Table 6
Results of confirmation experiments

Response	Optimum process levels	Predicted values (mm)	Experimental values (mm)	Error (%)
Radial expansion	A3B3C1	56.588	58.160	2.700

4. Conclusion

The effect of tube end forming process parameters on the expansion of tube ends is experimentally investigated. Taguchi method has been used to optimize the process parameters. The experiments were designed using L_9 standard orthogonal array. The process parameters considered for the study are die cone angle (α), expansion ratio r_p/r_0 and lubricant. The following conclusions are drawn from the present work:

- Among all the three parameters, the most significant factor is the die cone angle (α), and this factor contributes to 43.56% of the total expansion value.
- The optimum control factors and levels have been determined as A3, B3 and C1.
- An optimized value for expansion of tube ends for 95% confidence interval was predicted as 56.58 mm.
- The value obtained from the confirmation experiments is within the predicted range which is 58.16.
- The predicted values obtained from the Taguchi method are in good agreement with the experimental values. Thus, the developed model can be used to predict the tube expansion values for the chosen input parameters successfully.

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References

1. Bing L, Nye TJ and Metzger Don R. Multi-objective optimization of forming parameters for tube hydroforming process based on the Taguchi method. International Journal of Advanced Manufacturing Technology, 2006; 28: 23 – 30.
2. Dae-Cheol K, Dong-Hwan K and Byung-Min K. Application of artificial neural network and Taguchi method to preform design in metal forming considering workability. International Journal of Machine Tools & Manufacture, 1999; 39: 771 – 785.
3. Hsin-Te L, Jie-Ren S and Yung-Kuang Y. Applications of Taguchi and design of experiments methods in optimization of chemical mechanical polishing process parameters. International Journal of Advanced Manufacturing Technology, 2008; 38: 674 – 682.
4. Jurkovic Z, Jurkovic M and Buljan S. Optimization of extrusion force prediction model using different techniques. Journal of Achievements in Materials and Manufacturing Engineering, 2006; 17: 353 – 356.
5. Padmanabhan R, Oliveira MC, Alves JL and Menezes LF. Influence of process parameters on the deep drawing of stainless steel. Finite Elements in Analysis and Design, 2007; 43: 1062 – 1067.
6. Rossella S, Filippis LAC, Ludovico AD and Boghetich G. Application of Taguchi method for the multi objective optimization of aluminium foam manufacturing parameters. International Journal of Material Forming, 2010; 3: 1 – 5.
7. Hsiang SH and Jer-Liang K. Applying ANN to predict the forming load and mechanical property of magnesium alloy under hot extrusion. International Journal of Advanced Manufacturing Technology, 2005; 26: 970 – 977.

8. Wei F and Lin H. Multi-objective optimization of process parameters for the helical gear precision forging by using Taguchi method. Journal of Mechanical Science and Technology, 2011; 25: 519 – 1527.
9. Zhubin H, Yanli L, Jia W and Shijian Y. Study on the form ability and deformation behavior of AZ31B tube at elevated temperature by tube bulging test. Journal of Materials Engineering and Performance, 2010; 20(7): 1278 – 1284.
10. Almeida B, Alves PP, Rosa ML, Brito PAR and Martins PAF. Expansion and reduction of thin-walled tubes using a die: Experimental and theoretical investigation. International Journal of Machine tools & Manufacture, 2006; 46: 1643 – 1652.
11. Almeida B, Alves PP, Rosa ML, Brito PAR and Martins PAF. End forming of thin-walled tubes. Journal of Material Processing Technology, 2006; 177: 183 – 187.
12. Schaeffer L and Brito AMG. FEM numerical simulation and experimental investigation on end forming of thin-walled tubes using a die. Steel Research Int., 2007; 78: 10 – 11.
13. Rosa PAR, Rodrigues JMC and Martins PAF. External inversion of thin-walled tubes using a die: experimental and theoretical investigation. International Journal of Machine tools & Manufacture, 2003; 43: 787 – 796.