Investigation of Al 2024 metal spinning on surface roughness using conical mandrel

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ABSTRACT

Spinning is widely used metal forming process to fabricate components or products have rotational symmetry. It is a localized metal forming process which is mainly used due to its advantage of high quality associated with low cost for manufacture. In this process a tool is pressed against the rotating pre form of final product. The surface rough ness is one of the important parameters of spun product which are used in aerospace industry. In the present study an investigation is carried out on Al2024 material to get a conical product by adopting Taguchi OA methodology for experimentation. The experiment is carried out by using two different geometry rollers namely single roller and double radii roller at two different rotational speeds on different thickness of sheets as input parameters. The surface roughness is the target response in this investigation. Regression model for surface roughness is developed using MiniTAB software. Further Analysis of Variance was carried out to find the contribution of each parameter on the response.

KEYWORDS

Conical Mandrel,
Surface Roughness,
Regression Model,
Taguchi Method.

1. Introduction

Conventional spinning process is basically combination of bending and shearing operations of forming of sheet metal, where in a local plastic defamation zone is generated at the roller contact area. When the roller is moved towards the edge of the blank, tensile radial stresses and compressive tangential stresses are induced. The tensile radial stresses a material flow towards edge of the blank causing thinning of the sheet, whereas compressive tangential stresses causes thickening of the sheet. So, finally with this phenomenon the thickness of the sheet metal remains constant during the whole spinning process. When deforming thin sheets the effect of tool path and its geometrical profile has influence on surface roughness of fabricated component. The roughness of surface is one of the main parameters for the components of aerospace which influences the propulsion efficiency of the overall system. The surface texture has direct contact with the functioning of machine parts, load carrying capacity, tool life, fatigue life, bearing corrosion and wear qualities. Different requirements demand different types of surfaces so measurement of surface texture quantitatively is essential. The imperfections on the surface are in the form of succession of hills and valleys varying both in height and spacing. Any material cannot be finished perfectly due to some departures from ideal conditions is known as Surface Roughness. The literature survey indicates that the nose radius of the roller is one of the parameter which influences the surface roughness. [1] M.D.Chen et al. has conclude that the inner surface roughness tends to decreases initially within increase in blank thickness and at about 3mm thickness it is minimum and above 3mm it is increase with thickness. Whereas the outer surface of the blank is directly contact with roller, the larger nose radius resulted into smoother deformation of material and better surface finish. [2] K. Essa et al. in his work stated that a feed rate of the roller and larger nose radius increases the maximum axial force significantly which in turn causes the large amount to be deformed and large contact area. And also stated that increase in the feed rate increases the roughness which is attributed to less time available for deformation to be completed and results into scallop heights left behind. [3] G. Venkateswarlu et al. in their investigation it is found that the surface finish is better at

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high speed in dry condition for cylindrical cup spinning. It is also concluded that the increase in the speed from 220 rpm to 375rpm, the surface roughness is reduced by 10%. [4] in cone spinning process the feed rate controls the work piece finish and fit to workpiece to the mandrel. With all parameters remains constant, decrease in the feed rate will improve surface finish an increase in the feed rate will make the work piece fit tighter on the mandrel and finish of the work piece become coarser. The use of preform with included angle of cone when less than 350 the surface finish is coarser.

2. Material and Methodology

A Mathematical model is developed to optimize process parameters for estimation of Surface Roughness by Design of Experiments. In design of experiments, number of trials for conducting experiments is adopted as per the philosophy of Taguchi. Experiments are carried out as per the design matrix. Then regression coefficients are calculated. Adequacy of model is tested by fisher test at 5% significance level. Student's t-test is done for each regression coefficient to check the significance. The final mathematical model is formulated by neglecting non-significant coefficients. Finally Analysis of Variance (ANOVA) is done to find out the significance of higher contribution parameter percentage to the Surface Roughness.

Design of Experiments - Taguchi Method

Taguchi has envisaged a new method of conducting the design of experiments which are based on well-defined guidelines. This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulate the way of conducting minimal number of experiments which could give the full information of all the factors that affects the performance parameters. The crux of the orthogonal arrays method lies in choosing the level combinations of the input design variables for each experiment.

There are many standard orthogonal arrays unavailable, each of the arrays is meant for a specific number of independent design variables and levels. For example, if one wants to conduct an experiment to understand the influence of 4 different independent variables with each variable having 2 set values (level values), then an L8 orthogonal array might be the right choice. The L8 orthogonal array is meant for understanding the effect of 3 or 4 independent factors each having 2 factor level values. This array assumes that there is no interaction between any two factors. While in many cases, no interaction model assumption is valid, there are some cases where there is clear evidence of interaction. A typical case of interaction would be the interaction between the material properties and temperature.

Postulation of Mathematical Model

The regression equation is an algebraic representation of the regression line and describes the relationship between the response and predictor variables. The regression equation takes the form of:

Response = constant value+ coefficient value* predictor (factor) +.. + coefficient value * predictor (factor)
i.e. ,

$$y = C_o + C_1X_1 + C_2X_2 + ... + C_kX_k$$

$C_{o,} C_{1,} C_{2.......} C_k$ are regression coefficients.

Regression

Regression investigates and models the relationship between a response (Y - axis) and Predictors (X - axis). The response must be continuous, but you can have both continuous and categorical predictors. You can model both linear and polynomial relationships.

In particular, regression analysis is often used to determine how the response variable changes as a particular predictor variable change. Minitab stores the last regression model that you fit for each response variable. You can use stored models to quickly generate predictions, contour plots, surface plots, overlaid contour plots, and optimized responses. For analyses that can use multiple responses, you will need to fit a model for each response.

Analysis of Variance

The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This is to be accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error.

The sum of squared distances. SS Total is the total variation in the data. SS Regression is the portion of the variation explained by the model that is by the designed parameters, while SS Error is the portion not explained by the model and is attributed to error. The calculations are in Table 1.

Notation:

y_p = fitted or predicted response value

y_i= ith observed response value

y_m = mean response value

The percentage contribution r by each of the design parameters in the total sum of squared deviations SST is a ratio of the sum of squared deviations SSD due to each design parameter to the total sum of squared deviations SST.

F Test:

If the calculated F-value is greater than the F-value from the F-distribution, then at least one of the coefficients is not equal to zero. The F-value is used to determine the p-value. The formula for the calculated F-value is:

$$\text{F VALUE} = \frac{\text{MS Regression}}{\text{MS Error}}$$

The value of MS Regression is

MS Regression = SS Regression / DF Regression

Table 1
Formulas for sum of squares.

Sources of variation	Sum of squares
SS Regression (SSD)	$\sum(y_{p-} y_m)^2$
SS Error	$\sum(y_{i-} y_p)^2$
SS Total (SST)	$\sum(y_{i-} y_m)^2$

Mean Square Error:

It is the variance around the fitted regression line.

MS Error = SS Error / DF Error

3. Experimention

Experimentation using conical mandrel

The experimentation was carried out in two stages with different input parameters with three levels and factors on Lathe machine.

Selection of process parameters

The initial input parameters were as follows: mandrel speed 133 rpm; thickness of sheet 0.8 mm and Single Roller spinning tool. The feasible space for the spinning parameters was defined by varying the speed in the range 133-207 rpm, the thickness of sheet in the range 0.8 to 1.2 mm and with two different roller types- Single roller and Double radii roller. In the spinning parameter design, 2 levels of the parameters were selected. The output parameter that is to be measured is surface roughness. The various input variables used to perform the experimentation is shown in Table 2.

Selection orthogonal array

For these set of experiments, as there are four parameters at 2 levels, the experiments can be carried out by L8 orthogonal array. The layout of a typical L8 orthogonal array is shown in Table 3. There are four independent variables, each at two different levels. The number of experiments to be conducted is eight .

Experimental Setup

Fabrication of conical mandrel:

The conical mandrel is fabricated with cone angles of 22.5^0, and 27.5^0. The figure 3 shows the fabricated pieces of mandrel.

Table 2
Input parameters for experimentation.

Level	Speed (rpm)	Thickness (mm)	Mandrel angle (Degrees)	Type of roller
1	133	0.8	22.5	Single roller
2	207	1.2	27.5	Double radii roller

Table 3
Layout of L8 orthogonal array.

Experiment no.	Speed (rpm)	Thickness (mm)	Mandrel angle (degrees)	Roller Type	Surface Roughness (μm)
1	1	1	1	1	*
2	1	1	2	2	*
3	1	2	1	2	*
4	1	2	2	1	*
5	2	1	1	2	*
6	2	1	2	1	*
7	2	2	1	1	*
8	2	2	2	2	*

Fig. 1. Specimen (Al2024) after experimentation.

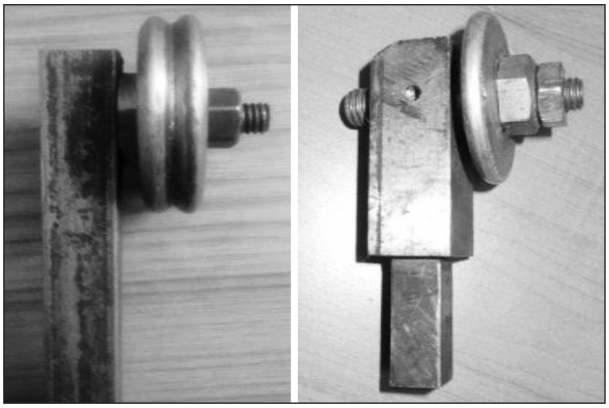
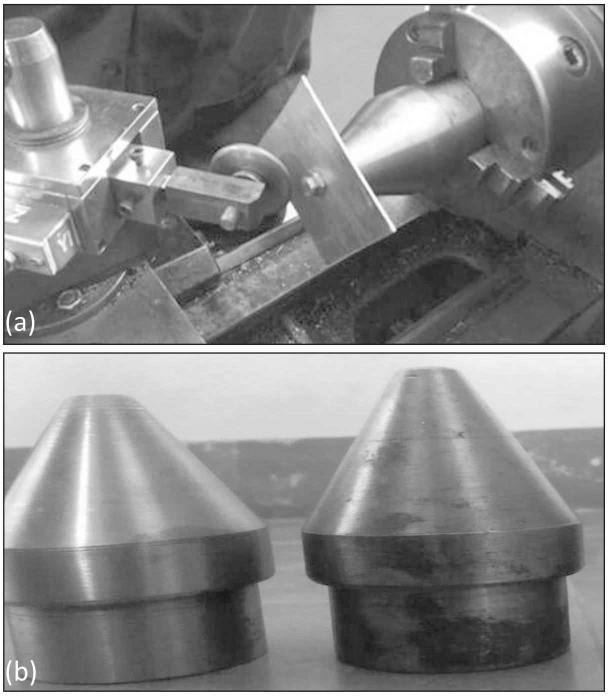


Fig. 2. Rollers.

Design and fabrication of Rollers:

Two types of rollers were selected to be used in the present experimental work. Firstly they were modelled in the CAD software and then fabricated. The types of rollers that were selected are as follows:

1. Single roller
2. Double radii roller



(a)

(b)

Fig. 3. (a). Spinning Experiment (b). Conical Mandrel.

Experimental procedure

The setup for the experimentation is made as mentioned previously. It is checked that all the parts are fastened properly. The experimentation is performed according to the orthogonal array selected i.e. at different speeds, for different thicknesses, with different rollers and on different mandrels. The mandrel is made to rotate in anti-clockwise direction and the feed is given manually to the roller so that the curved portion of the roller makes the contact with the sheet normally. In this condition the roller stats rotating about its own axis thus giving less scope for tool wear and increasing the metal forming rate. The feed is to be given carefully and at a constant

Table 4
Experimental results.

S.No	Speed (rpm)	Thickness (mm)	Mandrel	roller	Average Surface Roughness (R_a - µm)
1	133	0.8	22.5	1	(2.28+2.01+2.41)/3 = 2.23367
2	133	0.8	27.5	2	(4.31+3.03+3.66)/3 = 3.66733
3	133	1.2	22.5	2	(3.65+4.07+3.99)/3 = 3.87900
4	133	1.2	27.5	1	(2.292+2.32+2.13)/3 = 2.24767
5	207	0.8	22.5	2	(3.12+3.58+3.10)/3 = 3.26867
6	207	0.8	27.5	1	(1.69+1.90+1.70)/3 = 1.76367
7	207	1.2	22.5	1	(1.38+1.34+1.43+)/3 = 1.38633
8	207	1.2	27.5	2	(3.23+3.63+3.29)/3 = 3.38733

Fig. 4. Experimentation on surface roughness.

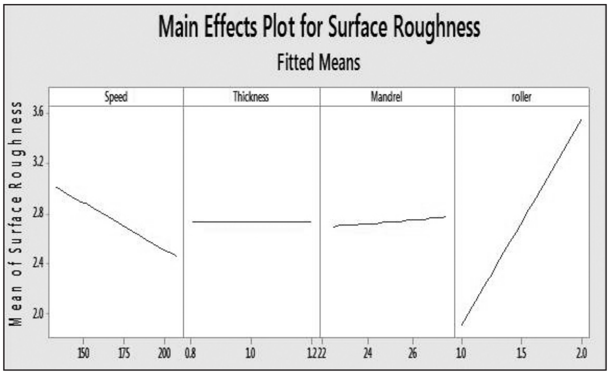


Fig. 5. Main effects on input parameters to surface roughness.

rate so that the sheet will not crack because of unusual application of forming force. After the machining the sheets should be undergone for surface roughness test using digital surf test and note the values in µm.

Procedure for taguchi design and regression analysis using MiniTAB

1. To Get Taguchi L8 Orthogonal Array

   Go to →stat → DOE → Taguchi → Crate Taguchi Design → Taguchi Design tab (Select number of factors 4, 2 Level Design, Design L8) → Ok → You will get the L8 design on the worksheet.

2. Fill the values of all factors and surface roughness results in a worksheet.

   Then Go to Stat → Regression → Regression → Fit Regression model → Enter

   Then Go to Regression Tab → Select the response and predictors → Results (Select Expanded Tables) → Ok → you will get the regression equation.

3. Go to Stat → Regression → Regression → Factorial plots → Factorial plots tab select the variables → Ok → you will get graph.

Experimental results and analysis

Table 4 shows the experimental results obtained by conducting the experiments according to the L8 orthogonal array. The Surface Roughness measured in µm. Figure 4 shows the values of surface roughness using surf test.

Table 5
Analysis of variance.

Source	DF	Sequence SS	% Contribution	F value
Speed	1	0.61698	10.05	16.27
Thickness	1	0.00014	0	0.00
Mandrel	1	0.01113	0.18	0.29
Roller	1	5.39726	87.91	142.31

Regression equation for surface roughness

Surface Roughness = 1.189 - 0.00751 Speed - 0.021 Thickness + 0.0149 Mandrel + 1.643 roller

Where SR= Surface Roughness, S= Speed, T= Thickness, R= Roller.

Analysis of variance

ANOVA is performed for the obtained experimental results and the percentage contribution of each parameter on the spinning force is calculated.

4. Results and Conclusions

The following conclusions are drafted from the investigation. The roller of double radii is generating outer surface of conical component with higher value of roughness. The higher roughness is attributed to lesser forming force applied to deform the sheets which may cause the uneven contact of double radii roller with the workpiece. Hence it is concluded that the tool developed is generating higher value of roughness with lesser forming force in comparing with single roller.

a) The developed regression models For Conical Mandrel:

   Surface Roughness = 1.189 - 0.00751 Speed - 0.021 Thickness + 0.0149 Mandrel + 1.643 roller

b) The developed models for sets of experiments are validated by substituting the optimum conditions to get the minimum force. The magnitude of minimum surface roughness after experimentation using conical mandrels is 1.38633µm for the combination of Speed: 207, Thickness:1.2 ,Mandrel:22.5^o, Roller:1.

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