Investigation on effects of process parameters on surface roughness for spinning process using cylindrical mandrel

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ABSTRACT

Keywords:
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Thickness of Sheet (mm),
Surface Roughness (µm)

Flow forming is an advanced, near net shape, chip less metal forming process, which employs an increment rotary point deformation technique for manufacturing seamless symmetrical products. Spinning is an advanced continuous and localized metal forming process, which is widely used in many fields due to its advantages of flexibility, high quality and low cost. It is frequently used for manufacturing axisymmetric shapes where press tooling might not be justified on grounds of size and production volumes. It is characteristic of this process that the deformation does not occur in an annular zone around the axis of rotation but that the tools act upon a much localized area in which plastic flow takes place. During spinning tools are moved relative to the rotating work piece. In this paper, a regression model showing the relation among input process parameters, Mandrel speed (rpm), Roller type and Thickness of sheet (mm) and output (response) as surface roughness (µm) is developed using Minitab Software. The experiments were conducted on Aluminium 2024 T-3 sheets with cylindrical mandrel using Taguchi orthogonal arrays (L9). Further Analysis of Variance was carried out to find the contribution of each parameter on the surface roughness.

1. Introduction

The term metal forming refers to a manufacturing methods by which the given shape of work piece is converted into another shape without change in the in the mass and material composition of the work piece. The term metal conventional spinning is different from shear and flow forming in terms of deformation characteristics, the set of process variables governing conventional spinning also determines the qualities of a shear or flow formed product. There are numerous process variables that contribute to the successful production of a spun product. Inconventional spinning, the wall thickness remains nearly constant throughout the process, so the final wall thickness of the formed part is equal to the thickness of the blank. Industrial buyers and designers always have the problem of deciding the most economical method for obtaining a cylindrical product.

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Surface roughness is one of the essential quality control parameter to ensure that functional surfaces of manufactured parts conform to specified standards. surface roughness of parts can significantly affect their friction, wear, fatigue, corrosion, tightness of contact joints, positioning accuracy, etc. surface roughness is important for spun product as it may affect aerodynamic forces on control surfaces for aerospace components and temperature profiles for domestic utensils. A change in any part of the production process will result in a change in one or more measurable parameters of the component. Surface roughness in particular is very sensitive to changes in production, even alteration in the composition of the material or hardness of surface will be reflected as a change in the texture of the machined component. Tool wear, strains in the material and incorrect machining conditions can all leave their mark measured at the end of the chain of production processes; it is an important control means. The imperfections on the surface are in the form of succession of hills and valleys varying both in height and spacing. Any material being machined by chip removal process cannot be finished perfectly due to some departures from ideal conditions is known as Surface Roughness. Surface Roughness is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth.

The measurement of engineering surface roughness is becoming increasingly important due to the benefits incorporated with it. The benefits of measuring surface finish with respect to quality and cost- control are as follows:

- The efficiency of the manufacturing process is improved through performance evaluation.
- The number of parts rejected by the customer (scrap) due to inferior surface finish is reduced.
- A part is manufactured with the maximum permissible roughness, thereby reducing manufacturing costs.
- The part quality is enhanced by optimizing surface finish.

Average Roughness Parameter (Ra) can be measured in micrometer (μm) or micro inches (μ inch). Figure - 1 indicates the method adopted for measurement of surface roughness.

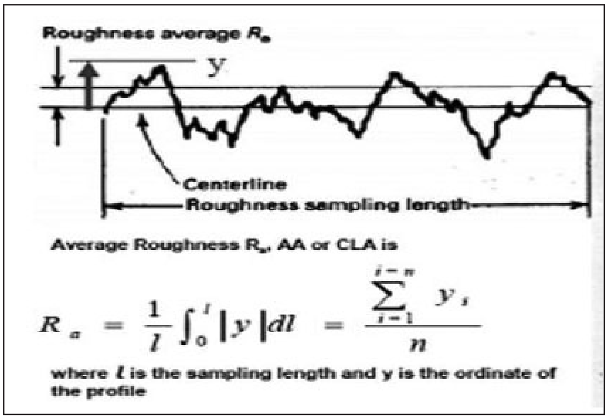

Fig.1. Surface roughness measurement method.

2. Objective 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 available, 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 3 different independent variables with each variable having 3 set values (level values), then an L9 orthogonal array might be the right choice. 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 + coefficient * predictor + ... + coefficient * predictor

i.e.,

$y = b_o + b_1X_1 + b_2X_2 + ... + b_kX_k$

$b_o, b_1, b_2 .... b_k$ are regression coefficients.

Regression

Regression investigates and models the relationship between a response (Y) and Predictors (X). 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 2.

Notation:

y_p = fitted or predicted response value , y_i= i^{th} 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.

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)	$\sum(y_{i-}y_m)^2$

3. Experimentation

The experimentation was carried out using cylindrical mandrel 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 1mm 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 1 to 1.5mm and with three different roller types- Single, double roller and Double radii rollers. In the spinning parameter design, 3 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.

Table 2
Input parameters for experimentation.

Level	Speed (rpm)	Thickness (mm)	Type of roller
1	133	1	Single roller
2	150	1.2	Double roller
3	207	1.5	Double radii roller

Table 3
Layout of L9 orthogonal array.

Experiment no.	Speed (rpm)	Thickness (mm)	Roller Type
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Selection orthogonal array

For these set of experiments, as there are three parameters at 3 levels, the experiments can be carried out by L9 orthogonal array. The layout of a typical L9 orthogonal array is shown in table 3. There are Three independent variables, each at three different levels. The number of experiments to be conducted is 9.

Experimental setup

Design and fabrication of cylindrical mandrel

CAD model of a cylindrical mandrel was designed and then fabricated with radius (fillet) of 10mm. The figure -4 represents the experimentation of spinning on lathe machine, Figure-3 indicates the rollers used for spinning process and Figure -3 represents the final components made as per trials(Orthogonal Array).

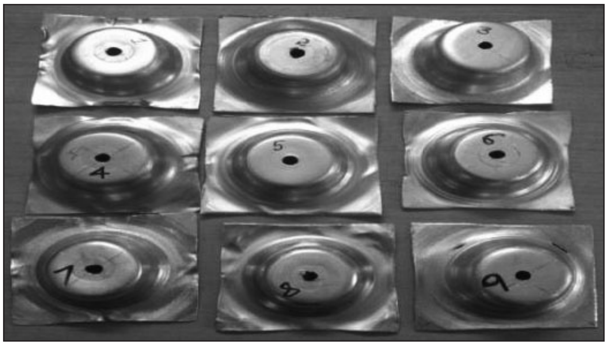

Fig.2. Experimental specimens using cylindrical mandrels.

Fig.3. Rollers.

Fig.4. Cylindrical mandrel.

Design and fabrication of rollers

Three 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
3. Double roller

Fig.5. Experimentation on surface roughness.

Table 4
Experimental results.

S no	Speed	Thickness	roller	Surface Roughness
	S	T	R	SR
1	133	1	1	0.602
2	133	1.2	2	0.778
3	133	1.5	3	0.435
4	150	1	2	0.568
5	150	1.2	3	0.453
6	150	1.5	1	0.444
7	207	1	3	0.353
8	207	1.2	1	0.699
9	207	1.5	2	0.348

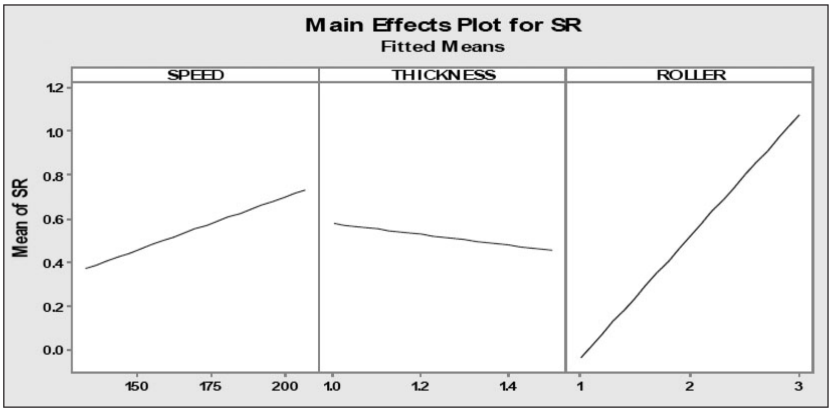

Fig.6. Main effects on input parameters to surface roughness.

Table 5
ANOVA.

Source	DF	Sequence SS	Contribution	F value
Speed	1	0.0200084	11	0.16
Thickness	1	0.022516	12.33	0.03
Roller	1	0.042336	23.19	0.41
S*T	1	0.000315	0.17	0
T*R	1	0.007372	4.04	0.04
S*R	1	0.038786	1.24	1.52

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. 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 starts 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 rate so that the sheet will not crack because of unusual application of forming force.

Experimental Results

Table 4 shows the experimental results obtained by conducting the experiments according to the L9 orthogonal array. The Surface Roughness measured in µm. Figure – 5 shows the values obtained by Talysurf machine.

Regression equation for surface roughness

Regression equation using Minitab is as follows: SR = 0.19 + 0.0049 S - 0.25 T + 0.557 R + 0.00000 S*T - 0.084 T*R- 0.00329 S*R.

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

The figure -6 indicates the graphical relation among input parameters to Surface Roughness

Analysis of variance:

ANOVA is performed for the obtained experimental results and the percentage contribution of each parameter on the surface roughness is calculated obtained is shown in table -5

4. Results and Conclusions

The following conclusions are drafted from results.

1. The developed regression models For Cylindrical Mandrel:
   SR = 0.19 + 0.0049 S - 0.25 T + 0.557 R + 0.00000 S*T - 0.084 T*R- 0.00329 S*R.
   Where, SR=Surface Roughness; S = Speed of Mandrel; T = Thickness of sheet and R = Roller type.
2. The developed models for sets of experiments are validated by substituting the optimum conditions to get the minimum surface roughness. The magnitude of minimum surface roughness after experimentation using cylindrical mandrels is 0.348µm for the combination of Speed : 207, Thickness:1.5, Roller:2.
3. From Fig-6 as speed increases surface roughness increases, as thickness increases surface roughness decreases, and use of double radii roller increases surface roughness.

5. References

1. Music, O; Allwood, JM; Kawai, K: A review of the mechanics of metal spinning, 'Journal of Materials Processing Technology', 2010, vol. 210, no. 1, 3–23.
2. Avitzur, B; Yang, C: Analysis of power spinning of cones, 'Journal of Engineering for Industry', vol. 82, no. 3, 1960, 231–244.
3. Sortais, HC; Kobayashi, S; Thomsen, EG: Mechanics of conventional spinning, 'Journal of Engineering for Industry', 1963, vol. 85, no. 4, 346–350.
4. Kalpakcioglu, S: A Study of Shear-Spinnability of Metals, Journal of Engineering for Industry, 1961, vol. 83, no. 4, 478-483.
5. Harewood, FJ and McHugh, PE: Comparison of the implicit and explicit finite element methods using crystal plasticity, 'Computational Materials Science', vol. 39, no. 2, 2007, 481-494. doi:10.1016/S0924-0136(00)00580-X.
6. Sebastiani, G; Brosius, A; Homberg, W; Kleiner, M: Process Characterization of Sheet Metal Spinning by Means of Finite Elements, Proceedings of the 12th International Conference of Sheet Metal, Palermo, Italy, 2007, 637–644.
7. Essa, K., Hartley, P. (2010). Optimization of conventional spinning process parameters by means of numerical simulation and statistical analysis. Journal of Engineering Manufacture, vol. 224, no. 11, 1691-1705,DOI:10.1243/09544054 JEM1786
8. Kleiner, M; Göbel, R; Kantz, H; Klimmek, C; Homberg, W: Combined Methods for the Prediction of Dynamic Instabilities in Sheet Metal Spinning, 'CIRP Annals', 2002, vol. 51, no. 1, 209–214.
9. Wang, L; Long, H; Investigation of material deformation in multi-pass conventional metal spinning, 'Materials & Design', 2011, vol. 32, no. 5, 2891-2899.
10. Wang, L & Long ,H: A study of effects of roller path profiles on tool forces and part wall thickness variation in conventional metal spinning, 'Journal of materials processing technology', vol. 211, no. 12, 2011, 2140-2151 ◘

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