Optimization of Process Parameters of Metal Spinning using Response Surface Methodology

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Abstract – Metal forming of metals involves deforming of metal physically into various derived shapes and sizes under the effect of externally applied forces. The spinning process is an advanced plastic working technology and is frequently used for manufacturing axisymmetric shapes. Over the last few decades, Sheet metal spinning has developed significantly and spun products have widely used in various industries. Nowadays the process has been expanded to new horizons in industries, since tendency to use minimum tool and equipment costs and also using lower forces with the output of excellent surface quality and good mechanical properties. The automation of the process is of greater importance, due to its wider applications like decorative household goods, rocket nose cones, gas cylinders, etc. This paper aims to gain insight into the conventional spinning process by employing experimental and numerical methods. The present work proposes an approach for optimizing process parameters are mandrel speed (rpm), roller nose radius (mm), thickness of the sheet (mm). Forming force and surface roughness are the responses.in spinning of Aluminum (2024-T3) using DOE-Response Surface Methodology (RSM).

Index Terms – RSM, Process parameters, Sheet metal spinning.

1. INTRODUCTION

METAL spinning, also known as spinforming or metal turning most commonly, is a sheet metal working process by which a disc or tube of metal is rotated at high speed and formed into an axially symmetric part. Spinning can be performed by hand tools, conventional lathe machine or by a CNC machine.

A. Classification of Metal Spinning Process:

1. Shear Spinning:Metal is deformed using high shear forces. It uses automated CNC machines for operation. Significant thinning of metal preform is made. It is suitable for high production runs.
2. Conventional Spinning:Conventional metal spinning involves localized bending of a sheet metal blank through a series of sweeping strokes to produce a desired shape with a reduction in diameter of the blank over the whole length or in defined areas without the change of the original blank thickness shown in Fig. 1. The incremental passes of the forming tool induce compressive tangential (hoop) stresses in the flange region. As the roller moves towards the edge of the blank, radial tensile stresses are generated, which produce a flow of material in the direction along the mandrel. The resulting tangential and radial compressive stresses generate a deformation of material towards the mandrel. In conventional spinning, defects occur when the radial tensile and tangential compressive stresses are not induced in the appropriate combination progressively through the material. It has been suggested that multiple tool passes are required to shape the blank to the profile of the mandrel without defects.

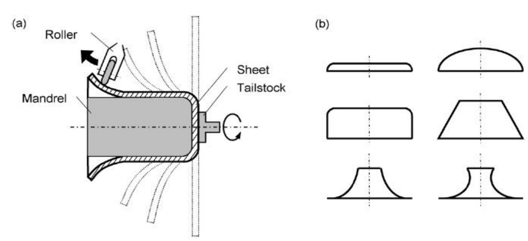

Fig. 1: Conventional spinning: (a) the process, (b) examples of feasible geometries.

2. PROCESS PARAMETERS

The following parameters are considered during experimentation of process on Aluminum 2024-T3 sheet.

Mandrel speed (rpm): The speed at which the mandrel is rotated along its own axis which is fixed in lathe chuck and holding the work sheet. Two levels of 310rpm & 500rpm are considered for experimentation.

Roller nose radius (mm): Two different size rollers have been taken for this experiment i.e. 3mm & 5mm nose radius.EN8 material is selected for mandrel & roller.

Sheet thickness (mm): Two different thicknessof sheets of Al 2024-T3 have been taken i.e. 0.91mm & 2mm respectively.

The following assumptions have been made in order to simplify the theoretical analysis:

- Wall thickness remains constant throughout the spinning process.
- Final diameter gradually reduces at the end.

3. EXPERIMENTATION

The present work is aimed to develop mathematical model considering various input parameters and finding their effects on output like forming force and surface roughness etc., by conducting experiments. The experiments were carried out on a Capstan Lathe Machine using EN8 Spinning Tool (Roller) on Aluminum material. The resultant force was measured by LATHE TOOL DYNAMOMETER (620 series). Each trial was replicated twice, which provide an internal estimate of the experimental error.The number of trials required to experiment is obtained from Design Expert Software by selecting the methodology as RSM, Three input parameters as Mandrel Speed, Roller Nose Radius, Sheet Thickness and output (Response) as Force, Surface roughness and Strain. The Table III shows the trials and the output values of resposes.X_1, X_2, X_3 are coded forms of Sheet thickness, Roller nose radius, Mandrel speed respectively.

TABLE I
RESPONSE VALUES FROM EXPERIMENT

Run	Process Parameters			Response	
	Sheet thickness (mm)	Roller nose radius (mm)	Mandrel speed (rpm)	Force (kgf)	Roughness (µm)
1	0.91	5	500	20.67	12.04
2	2	5	500	40.64	6.217
3	2	3	310	19.93	6.6305
4	2	3	500	31.78	9.3785
5	0.91	5	310	39.33	5.1465
6	0.91	3	310	28.15	9.9545
7	0.91	3	500	41.48	5.932
8	2	5	310	35.5	4.5965

Fig. 2: Experimentation set up

Fig 2 and Fig 3 shows the experimental setup and spinning process where asFig 4 and Fig5 are the initial and final shapes of the spun part.

Fig.3: Spinning Process

Fig.4: Initial sheet

Fig. 5: Spun part

4. DEVELOPMENT OF MODEL

Sequences of steps followed in development of model are

1. Calculation of regression coefficients:

Here the number of replications for the response are two i.e., y1 and y2 and average of these is 'y'. Regression coefficients

b_0, b_1, b_2, b_{12} etc., are calculated by using the formula given below

b_j=[$\sum x_{ij}y_i$]/N

Where N = number of trails (N=8)

Fisher test for adequacy of model (f-test for 5% significance level)

Variance for reproducibility=S_y^2 = [2∑(dely)²]/N

N=number of trails, dely = (y1-y)

Variance of adequacy,
S_{ad}^2=[2∑(y-y_p)²]/ DOF

y_p = predicted response.

y_p=b_0x_0[i]+b_1x_1[i]+b_2x_2[i]+…….

where DOF = degree of freedom=[N-(k+1)]

where N = number of trails
k = number of factors

F-model = S_{ad}^2/S_y^2

For given values of f1 and f2, F-table value is found from fisher table.

Here f1=N-(k+1), f2=N

If F-model ≤ F -table, model is adequate in linear form otherwise it is not adequate.

2. Student's t-test (for 5% significance level):When the model is adequate in linear form, then t-test is to be conducted to test the significance of each Regression coefficient.

Standard deviation of each coefficient,

S_{bj}=√S_y^2/N)

t-ratio = | b_j| / (S_{bj})

for f = N , t value is to be taken from t-table and compared with t-ratio of each regression coefficient. If t-ratio ≥ t-table corresponding regression coefficient is significant.non-significant coefficients are to be eliminated from the model to arrive the final form of mathematical model in coded linear form as
$Y=b_0+b_1X_1+b_2X_2+b_3X_3+b_{12}X_1X_2+b_{13}X_1X_2+b_{23}X_2X_3+b_{123}X_1X_2$

$^XY^3$is the response and X_1, X_2, are coded form of factors. The design expert software iterates the sequence of steps that are to be followed in development of mathematical model.

The final equation in coded factors for response 1(Force):

Force = 32.19 + (6.12* X_1) + (0.18* X_2) - (3.93* X_3)

The final equation in actual factors for response 1(Force):

Force= 31.92391+(11.22454*plate thickness)+(0.17737*roller nose radius)-(0.041420*mandrel speed)

The final equation in coded factors for response 2(Roughness):

Roughness = 9.24 - (0.57* X_1) + (0.50* X_2) + (0.33* X_3)

The final equation in actual factors for response 2(Roughness):

Roughness = 7.35016 - (1.04300*plate thickness) + (0.49981*roller nose radius) + 3.46908*10^{-3}*mandrel speed)

5. RESULTS AND DISCUSSIONS

Response Surface Methodology Results for optimum value:The maximum and minimum values of forming forces are obtained by these following parameters:

Plate thickness (t_{max}) = 0.9103, Roller nose radius (r_{max}) = 3.0109, Mandrel speed (v_{max}) =498.6384, Forming Force F_{Max}= 22.0217N, Plate thickness (t_{min}) =2.0000, Roller nose radius (r_{min})=3, Mandrel speed (v_{min}) = 310, Forming Force F_{Min}= 7.8390N.

The maximum and minimum values of Surface Roughness are obtained by these following parameters:

Plate thickness (t_{max})= 1.9999, Roller nose radius (r_{max})= 5, Mandrel speed (v_{max})=310.0313, Surface Roughness X_{Max}= -42.4176, Plate thickness (t_{min})= 1.9959, Roller nose radius (r_{min})=4.9999, Mandrel speed (v_{min})=310, Surface Roughness X_{Min}= 1.0229e+003.

6. CONCLUSION

In this paper, an experimental process is carried out to find the forming force, and the process parameters are optimized by applying Response Surface Methodology. The following conclusions may be drawn from the results obtained:

- Thickness of sheet has major contribution (38.96%) on spinning force and next parameter is Roller nose radius (31.8%).

Thickness of sheet has higher influence on (with 35.65% contribution) on surface roughness.

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