3D FEAnalysis of Metal Spinning Process

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Abstract – Metal Spinning is one of the metal forming processes, where a flat metal blank is rotated at high speed and formed into an axi-symmetric part by a roller which gradually forces the blank on to a mandrel, resulting in final shape of the spun part. Spinning have gradually matured as metal forming process for the production of engineering component in small to medium batch quantities. Such components mostly find application in the automotive, aerospace, aircraft missile industries which require a high strength to weight ratio for their component. This paper proposes an approach of optimizing process parameters mandrel speed(rpm), roller nose radius(mm) and blank thickness. The parameters observed as output are forming force and surface roughness.The FEA software is used for modeling and analysis. The process parameters considered in the experimentation.

Index Terms – FEA, 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.

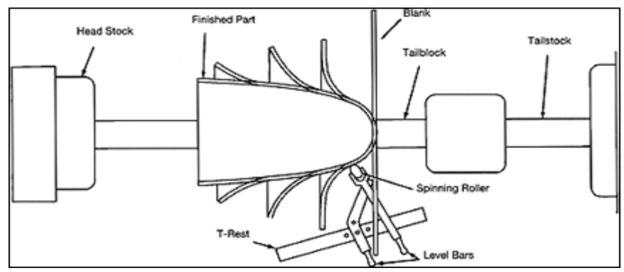

Fig. 1: The process of Spinning

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.

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)	Strain
1	0.91	5	500	20.67	12.04	0.46
2	2	5	500	40.64	6.217	0.69
3	2	3	310	19.93	6.6305	0.37
4	2	3	500	31.78	9.3785	0.68
5	0.91	5	310	39.33	5.1465	0.45
6	0.91	3	310	28.15	9.9545	0.54
7	0.91	3	500	41.48	5.932	0.53
8	2	5	310	35.5	4.5965	0.28

Fig.2: Spinning Process

4. FINITE ELEMENT ANALYSIS OF SPINNING PROCESS

Finite Element analysis is carried out using ABAQUS software is used for various conditions as labelled from fig 4- fig 10

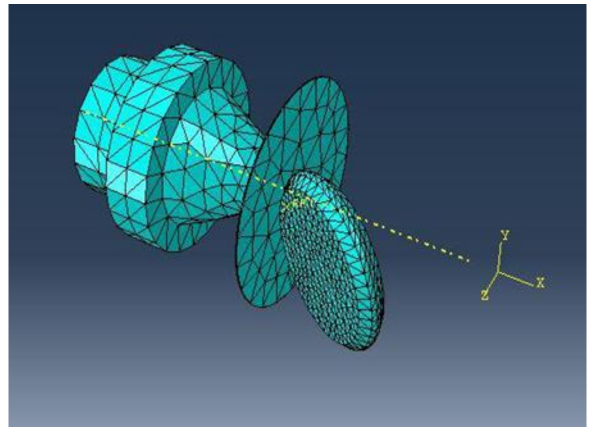

Fig.3: Meshing of CAD Model (Tetrahedral)

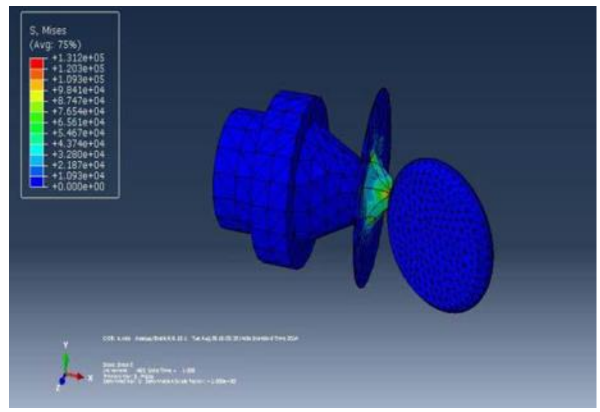

Fig 4: FEA Model for stress, condition 1: Roller nose radius=5mm, Sheet thickness=0.91mm, Mandrel speed=500rpm

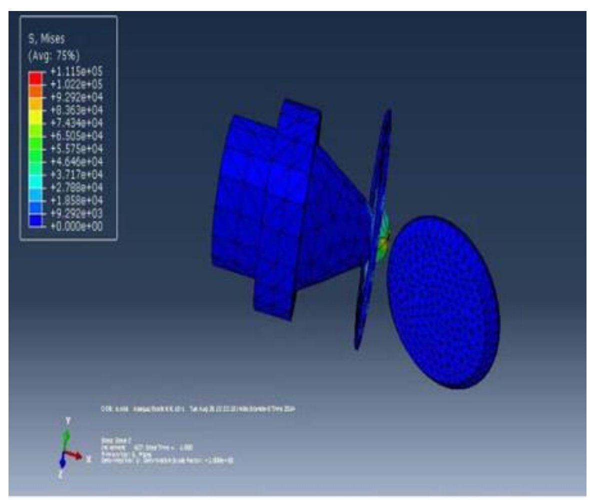

Fig 5:FEA Model for stress, condition 2: Roller nose radius=3mm, Sheet thickness=2mm, Mandrel speed=500rpm

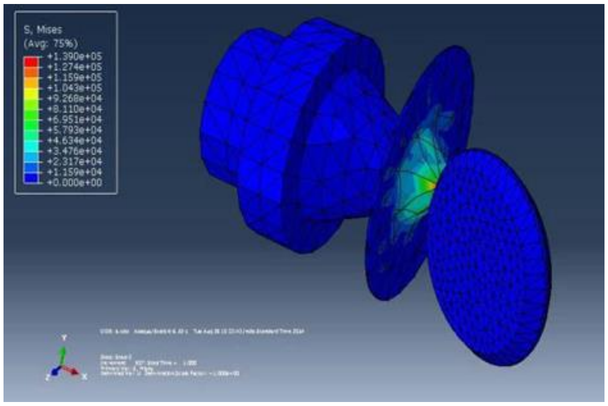

Fig.6: FEA Model for stress, condition 3: Roller nose radius=3mm, Sheet thickness=0.91mm, Mandrel speed=500rpm

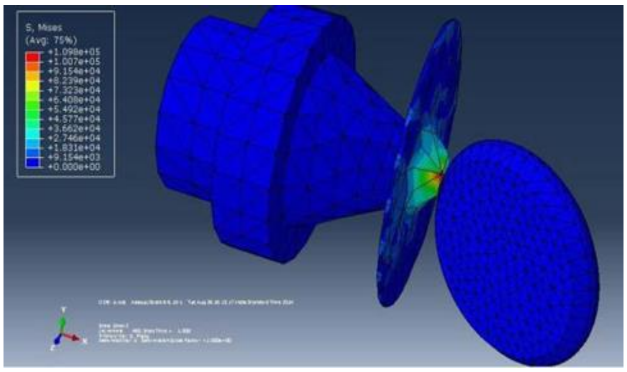

Fig 7: FEA Model for stress, condition 4: Roller nose radius=5mm, Sheet thickness=2mm, Mandrel speed=500rpm

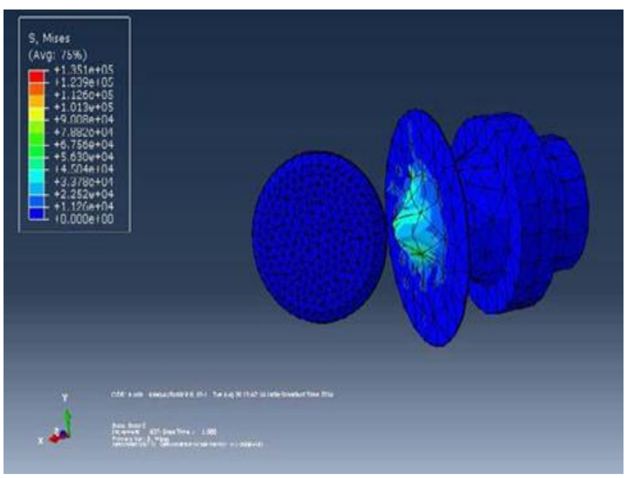

Fig 8: FEA Model for stress, condition 5: Roller nose radius=3mm, Sheet thickness=2mm, Mandrel speed=310rpm

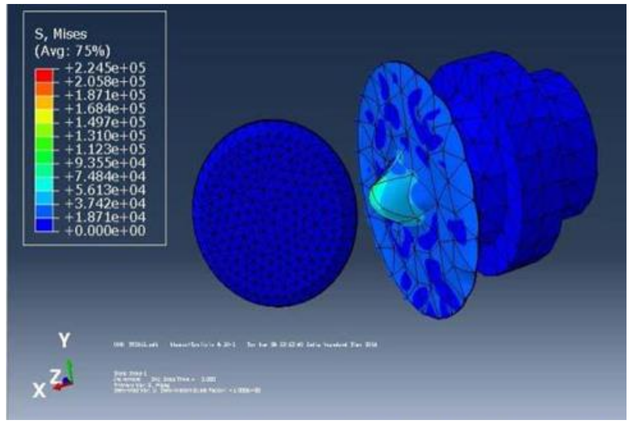

Fig 9: FEA Model for stress, condition 6: Roller nose radius=3mm, Sheet thickness=0.91mm, Mandrel speed=310rpm

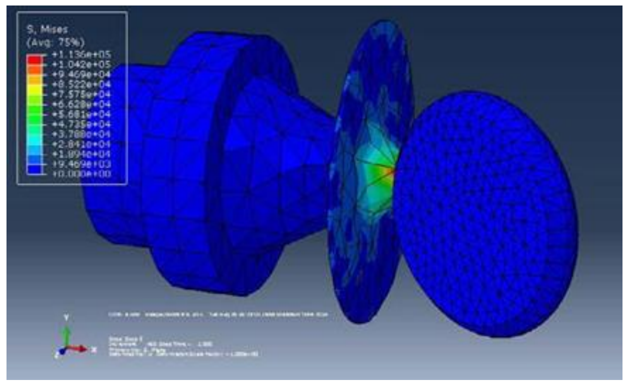

Fig 10: FEA Model for stress, condition 7: Roller nose radius=5mm, Sheet thickness=2mm, Mandrel speed=310rpm

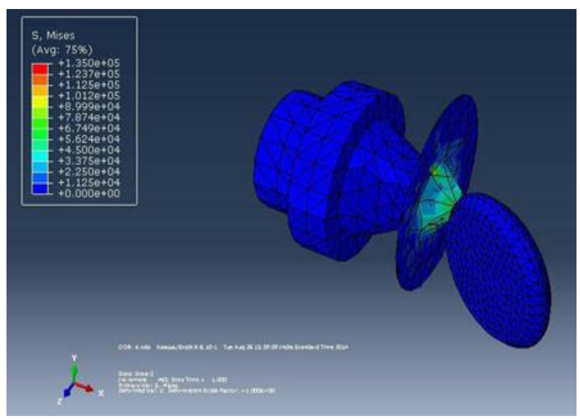

Fig 11: FEA Model for stress, condition 8: Roller nose radius=5mm, Sheet thickness=0.91mm, Mandrel speed=310rpm

The Results of Finite Element Analysis are Tabulated in Table II.

TABLE II

FEA RESULTS OF STRESS

condition 1	$1.312*10^5 N/mm^2$
condition 2	$1.115*10^5 N/mm^2$
condition 3	$1.390*10^5 N/mm^2$
condition 4	$1.098*10^5 N/mm^2$
condition 5	$2.245*10^5 N/mm^2$
condition 6	$1.351*10^5 N/mm^2$
condition 7	$1.136*10^5 N/mm^2$
condition 8	$1.350*10^5 N/mm^2$

5. ANALYSIS OF VARIANCE

Analysis of variance is done to find out the percentage contribution of each factor and relative significance of each factor. The ANOVA table for 2^3model is shown in Table IV.Table V and VI show the percentage contribution of factors on responses.

TABLE III

ANOVA TABLE

Source of variation	Sum of squares	Degrees of freedom	Mean square	F-ratio
A treatments	SSA	a-1	MSA=SSA/(a-1)	FA=MSA/MSE
B treatments	SSB	b-1	MSB=SSB/(b-1)	FB=MSB/MSE
Interaction	SSAB	(a-1)(b-1)	MSAB=SSAB/(a-1)(b-1)	FAB=MSAB/MSE
Error	SSE	ab(n-1)	MSE=SSE/ab(n-1)	
Total	SST	abn-1		

$SS_{x1} = \{ Sum(x_1[i] \times y_t[i])\}^2 / (N \times n)$

$SS_T = Sum\{(y_1[i])^2+(y_2[i])^2\}-(Sum(y_t[i]))\}^2/(N*n)$

$SS_E = (SS_{total})-(SS_{model})$

Where $SS_{model}= SS_{x1}+SS_{x2}+SS_{x3}+\ldots.$

TABLE IV
PERCENTAGE CONTRIBUTION OF THE FACTORS AND THEIR INTERACTIONS FOR FORMING FORCE

Factor	% contribution
X1	6.64
X2	31.8
X3	38.96
X1X2	16.84
X2X3	0.3
X3X1	2.39
X1X2X3	2.49

X1= Mandrel speed, X2=Roller nose radius, X3=Sheet thickness

TABLE V

PERCENTAGE CONTRIBUTION OF THE FACTORS AND THEIR INTERACTIONS FOR SURFACE ROUGHNESS

Factor	% contribution
X1	1.533
X2	19.75
X3	35.65
X1X2	2.50
X2X3	9.00
X3X1	20.3
X1X2X3	10.55

X1= Mandrel speed, X2=Roller nose radius, X3=Sheet thickness

6. 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.

7. CONCLUSION

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

- The percentage of variation of forming force in experimentation to simulation is of 13.93%, which justifies the adequacy of Finite Element model.

From the optimized process parameters following conclusions can be drawn:

- 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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