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STUDY ON EFFECT OF TOOLING ANGLES DURING FLOW FORMING PROCESS

***Ravi J Bhatt[1] and Harit K Raval[2]**

[1]Research Scholar, [2]Professor S V National Institute of Technology, Surat-395007, Gujarat, India.

ABSTRACT

Flow forming is normally used to produce seamless tubes of high precision. Rocket launcher cases, cartridge case, missile casing, rocket nose cones are the typical examples of aerospace and defense sector which are made by flow forming process. Literatures state that the flow forming is influenced by many parameters like leading/attack and trailing/smoothing angles, rotational speed, axial feed, forming depth etc. The understanding of effect of parameters on the process is quite important because it is useful for the designing of tools (rollers and mandrel) for various material and geometrical conditions. Hence, the present analysis is carried out for different leading and trailing angles. The effect of leading and trailing angle is studied for von mises stress and equivalent plastic strain. It has been noted that as the leading angle increases the von mises stress is gradually increases, whereas equivalent plastic strain decreases. It also observed that as the trailing angle increases the von mises stress remains almost constant, while small reduction is found in the maximum equivalent plastic strain.

Key words: *Flow Forming, Leading Angle, Trailing Angle, Von mises stress, Equivalent plastic strain, ABAQUS.*

1. Introduction

The metal gets deformed axially in flow forming. The internal diameter of the work material remains constant. The workpiece is fitted on the mandrel, the rollers approaches the blank and plasticize the workpiece under contact zone. Hence the wall thickness reduces and length of the blank/workpiece increases. Normally two strategies adopted during the process viz. forward and backward (reverse). In forward approach the direction of material deformation and roller feed are same as per Fig. 1 (a). While in the backward approach, the direction of material deformation and roller feed are opposite as shown in Fig. 1 (b).

There are several experimental studies had reported on flow forming. Srinivasulu et al. [1] had done experiments using AA6082 on CNC flow forming machine. A single roller arrangement was used. Based on this study, it was reported that mechanical properties of flow formed tubes increases by annealing. Molladavoudi et al. [2] had done experimental study using NC lathe machine and reported that operating parameters are influencing the mechanical properties and reduction rates. Wong et al. [3] studied the combined effect of roller configuration (flat roller and nosed roller) with different feed rates on reduction rates during flow forming process.

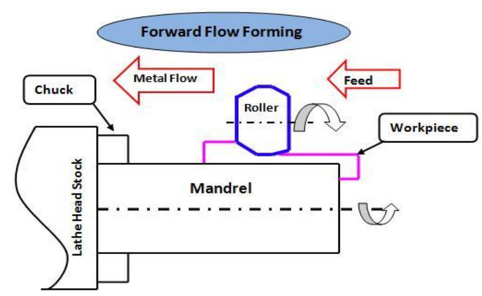


Fig.1 (a) Schematic of Forward Flow Forming

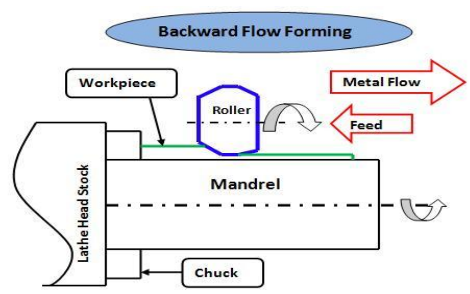


Fig.1(b) Schematic Backward/Reverse Flow Forming

**Corresponding Author - E- mail: ravi_bhatt9988@yahoo.co.in*

Taguchi approach was employed by Davidson et al. [4] for AA6061 and found that the spindle speed is the second most significant factor, affecting the flow forming process. Bhatt and Raval [5] reviewed that the feed ratio, roller path, roller shape, spindle speed, depth of forming and power & forces are the process variables of the flow forming process. Razani et al. [6] have done experimental study on AISI 304 stainless steel using RSM (Box-Behnken design) to analyze the final hardness of workpiece. Kishore Nath N [7] used taguchi method to optimize the parameters dueing tape widening. Lade et al. [8] demonstrated some aspects of formability under warm working of metals in deep drawing operation. Later, Raman Goud R et al. [9] investigated on metallurgical behavior of deep drawing steel at elevated temperature under stretching. However, effect of roller leading and smoothing angles on stress & strain has not been studied yet. Hence a simulation study is carried out. Forward strategy of forming and single pass deformation has been considered during analysis. The material is chosen as AA6063 due to several advantages and its applications in defense & aerospace industries. Von mises stress and equivalent plastic strain have been obtained and reported. The analysis is carried out using ABAQUS/Explicit, commercially available FE package.

2. Modeling and Analysis

2.1 Modeling

Flow Forming is influenced by many factors viz. roller geometrical conditions (leading/attack angle, trailing/smoothing angle, size of roller and nose radius), rotational speed, axial feed, forming depth, initial conditions of the blank etc. To understand the deformation phenomenon knowledge of forces acting during the process is important. There are basically three forces acting on the roller during forming; axial (z-direction), radial (x-direction) and circumferential (y-direction). The initial 3D model and the direction of forces acting on the roller are given in Fig. 2.

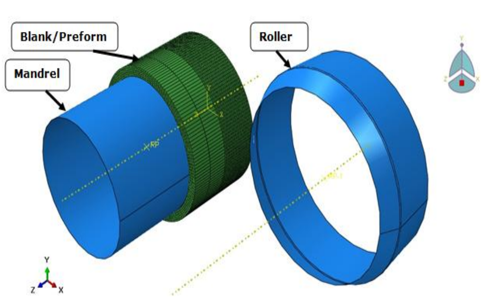


Fig. 2(a) Initial 3D model with meshed blank

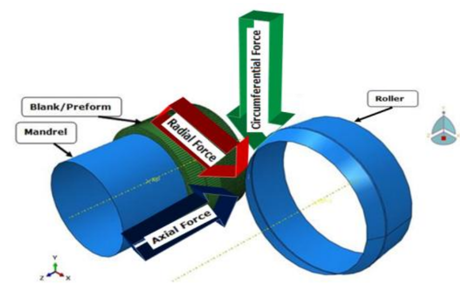


Fig.2(b) Forces acting on the roller

2.2 Material Properties and Type of Element

In the present study the workpiece material is taken as AA6063 because it serves certain advantages like light weight, excellent corrosion resistance, higher ductility, recyclability, availability and various application in automotive, defense and aerospace industries. Here, the operating conditions have been used from reported literature by Mohebbi and Akbarzadeh [10]. Five different combinations of leading and trailing angle have been used for analysis (Table 1). The analysis is carried out for total of 25 set (keeping trailing angle constant and varying leading angle and vice versa). The operating conditions and material properties are respectively given in Table 1 and Table 2. The analysis is done for forward strategy.

Table 1. Configuration of the Model

Factors	Value				
Work Material					
Inside Diameter	35 (mm)				
Thickness	2.5 (mm)				
Starting Length	50 (mm)				
Roller (Tool)					
Diameter (mm)	54				
Leading/Attack angle (degree)	25	30	35	40	45
Relief/Smoothing angle (degree)	5	10	15	20	25
Conditions of Flow Forming					
Axial Feed	0.1 (mm/rev)				
Percentage Reduction	40				
Rotational Speed	30 (RPM)				

Table 2. Material Properties [10]

Density	2700 (Kg/m^3)
Modulas of Elasticity	68.9 (GPa)
Yield Strength (YS)	48.3 (MPa)
Ultimate Strength (UTS)	89.6 (MPa)
Poisson's Ratio	0.33

Undeformable analytical rigid element was used to model mandrel and roller. This eliminates the meshing requirements of rigid components. Therefore computational time is reduced. The deformable tube is meshed with C3D8R (8-node) element. Finer mesh (0.5 mm) has been adopted in the deformation zone. 25200 nodes and 20250 elements are used in the simulation. ALE (Arbitrary Lagrangian Eulerian) technique was used to prevent mesh distortion during the analysis.

3. Results and Discussion

Present study concentrates on the effect of tooling angles during flow forming process viz. leading and trailing angles of the roller. Five different combinations of leading as well as trailing angles have been taken based on the literature review for the analysis. Different leading angles were used to investigate effect on von mises stress and equivalent plastic strain. The analysis is done by varying leading angles and keeping trailing angle constant. Later the trailing angles have been varied and keeping leading angles constant. It made a total of 25 sets of combinations for different leading and trailing angles. Here, Fig. 3 shows the force variation with respect to time for 25° leading and 5° trailing angle. Initially the forces are raising gradually and after 15 seconds those remains constant. The maximum value for axial, radial and circumferential force is found to be 2500 N, 1000 N and 58 N respectively. It can be noted that the axial force value is higher compared to radial and circumferential force as shown in Fig. 3. As the material is deformed in the axial direction with the roller feed, shear and compressive phenomenon rises therefore axial force is found to be higher as shown in Fig. 3. The radial force is found to be second predominant (Fig. 3) because of the depth of forming is applied and hence reaction force is encountered on the roller which is compressive in nature.

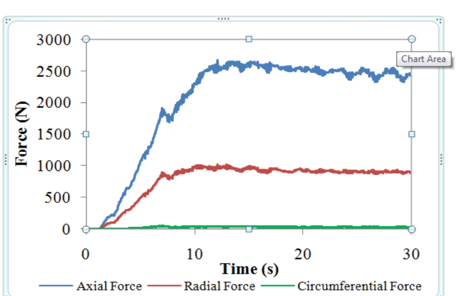
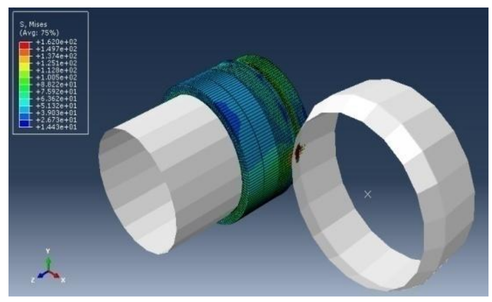


Fig. 3 Forces acting during flow forming for 25° leading and 5° trailing angle

The roller is rotating while in the contact with the workpiece and due instantaneous contact the circumferential force is found least (Fig. 3) compared to other two forces. The max. von mises stress (Fig. 4 (a)) is found to be 162 MPa for 25° leading and 5° trailing angle. Max. Effective plastic strain (Fig. 4 (b)) for same set is found to be 1.622. Similarly, for other sets the von mises stress and equivalent plastic strain have been obtained.



(a)

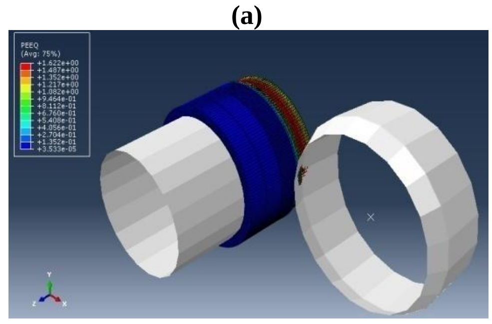
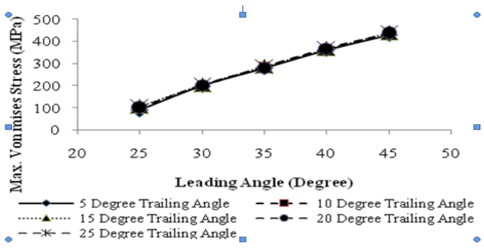
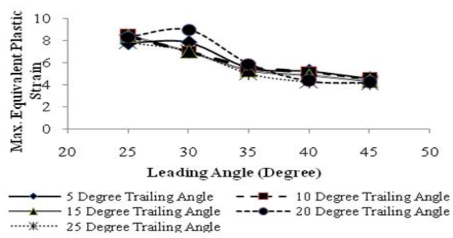


Fig.4 (a) Von mises stress (b) Effective Plastic Strain for 25° leading and 5° trailing angle

As discussed earlier that the different combinations of leading and trailing angles have been analyzed, the von mises stress value increases with the increase in leading angles. The maximum and minimum values are found to be 450 MPa and 100 MPa respectively (Fig. 5(a)). On the other hand the equivalent plastic strain value decreases with the increase in the leading angle. The maximum and minimum values are found to be 8.2 and 4.1 respectively. It has been observed that as the leading angle increase, the max. von mises stress increases gradually (Fig. 5(a)). It is due to the condition that; as the leading angle increases, contact area between workpiece and roller decreases. Hence the material deformations accumulated and create build up. So that, higher forces required for deformation and that increases stresses. Even, the max. Equivalent plastic strain reduces with the increase in the leading angle (Fig. 5 (b)). The reason is, as the leading angle increases, smaller is the contact surface of roller contacting the workpiece. So that, deformation phenomenon reduced that leads to decrease in the plastic strain.



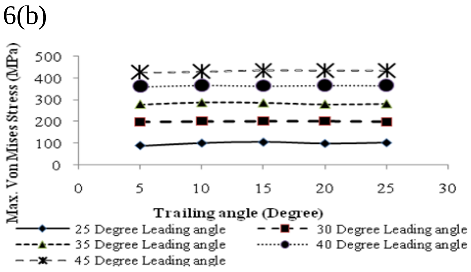
(a)



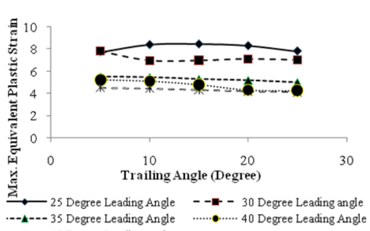
(b)

Fig. 5Effect of leading angle during Forward Flow Forming (a) Max. Von mises stress (b) Max. Equivalent Plastic Strain

It can be seen that von mises stress value is maximum for the 45° trailing angle and minimum for 25° trailing angle. Also the von mises stress remains almost constant for all the trailing angles (Fig. 6(a)). The equivalent plastic strain value is found to be maximum 8.2 for 10 degree trailing angle and minimum for 25 degree trailing angle. The trend of the plastic strain is decreasing for all the trailing angles as shown in Fig. 6(b)



(a)



(b)

Fig. 6 Effect of trailing angle during Forward Flow Forming (a) Max. Von mises stress (b) Max. Equivalent Plastic Strain

It can be observed that, with the increment of trailing angle the max. von mises stress remains almost constant. As the material leaving the contact zone, there can be no effect of trailing angle on von mises stress, as no forces exerted on the trailing face of the roller. Similarly equivalent plastic strain shows linear trend with minor variation for the change in trailing angle.

In present work, analyses of flow forming process have been carried out for forward strategy. Von mises stress and equivalent plastic strain have been obtained and reported. Different combinations of the tool angle i.e. leading and trailing have been studied. It has been noticed that the leading angles having significant effect compared to trailing angles. Hence, the deformation is mainly governed by leading angle. It will help to reduce the trial and error method to optimize the tooling before actual production.

4. Conclusions

Based on the simulation study it has been found that axial force is higher compared to other two forces i.e. radial and circumferential. Whereas, radial force is found to be second predominant force and circumferential is the least force. Also, least forces are encountered with the combinations of 25° leading and 5° trailing angles compared to other tooling angle combinations. Moreover, it can be noticed that as the leading angle increases, max. von mises stress increases while max. Equivalent plastic strain decreases. While, trailing angle does not have much significant effect on max. von mises stress and equivalent plastic strain during the flow forming process.

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