NUMERICAL AND EXPERIMENTAL STUDY OF FEED RATES AS A PROCESS PARAMETERS IN THE FLOW FORMING OF AA7075 SOLID TUBES

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ABSTRACT

Flow forming, as a kind of metal spinning process, is mainly used to produce thin walled high-precision tubular components. In this study, the analysis of forward flow forming process was carried out. The influence of feed rates amount as a major flow-forming process parameters on the quality of an AA7075 alloy such as surface roughness and diametral growth and forming load were studied numerically and experimentally. A three dimensional FE model was developed to analyze the process. The FE code of ABAQUS was employed. A series of experimental tests were carried out to verify the FE results. The simulation work has been performed by the rigid-plastic FE method. Comparison between FE and experiment results showed good agreement. Both the simulation and experimental results highlight the major role of feed rate parameter on the finished products quality and flow forming loads. Microstructure evaluations showed the homogeneous distribution of grains in the flow formed tubes.

KEYWORDS: Flow Forming; Feed Rate; FEM; experiment.

Flow forming is an effective method to produce long thin-walled high-precision tubes. Flow forming technology has emerged as the most advanced metal forming technique due to its manifold advantages over traditional metal forming methods such as extrusion and tube drawing. In the flow forming process, a thick-walled tubular blank rotates with a mandrel while one or more rollers move axially along the workpiece axis from one end of the blank to the other and reduce its thickness. Several researchers have studied the flow forming process numerically and experimentally to evaluate the power and load requirements as well as the effects of process variables such as feed rate, attack angle and percentage of reduction on surface finish of the formed tubes and forming loads(Yao and Mokoto, 2002; Jahazi and Ebrahimi, 1979; Wang et al., 1989; Gur and Tirosh, 1982). Hayama and Kobayashi(1962) have investigated the mechanics of process via theoretical analyses approach. Their analyses evaluate the power and load requirements in the process. Some effective output parameters like residual stresses, strain distribution etc, is difficult to obtain with experimental and theoretical methods. Several researchers have also attempted to study the flow forming process using numerical methods. Kemin et al (1997) have studied the residual stresses and diametral growth with elasto-plastic FE model analyses. Li et al (1998) built a FEM program to simulate the process of backward flow forming. Their model was three dimensional and the internal surface nodal points of the tube contacting the mandrel are restrained in the radial direction and the nodal points at the end of the up-spun tube are restrained in three directions. Wong et al (2004) have investigated the explicit FE method to analyses the flow forming of solid cylindrical billet, using ABAQUS software and reported the influence of mass scaling on dynamic effects which may lead to unsound analyses outputs. Recently, Hua et al (2005) used the 3D elastic-plastic FEM analyses for three-roller backward tube flow forming and studied some major process defects such as the bell-mouth, build-up and diametral growth. There are several geometrical and process conditions parameters that influence the flow forming load and quality of finished products. The major process parameters are identifies as the rollers feed rate, mandrel speed of rotation and reduction percentage. The influences of critical parameters mentioned above on the quality of deformed parts such as surface roughness, out of roundness and diametral growth with numerical and experimental analysis are not well documented. In fact, the mutual influence of major parameters along with the complexity of the process can lead to various defects that result in the rejection of many finished products. In this investigation, the influence of feed rates amount as a major flow-forming process parameters on the quality of an AA7075 alloy such as surface roughness and diametral growth and forming load were studied numerically and experimentally. A three dimensional FE model was developed to analyze the process. The FE code of ABAQUS was employed. A series of experimental tests were carried out to verify the FE results. The simulation work has been performed by the rigid-plastic FE method. Comparison between FE and experiment results showed good agreement. Both the simulation and experimental results highlight the major role of feed rate parameter on the finished products quality and flow forming loads.

EXPERIMENTAL PROCEDURES

In a forward flow forming process multiple rollers (or single roller) are used to deform the cylindrical tube over the rigid mandrel (Fig. 1).
In this work, single-roller forward flow forming operations were performed over a smooth cylindrical mandrel using a common lathe as a flow forming machine (Fig. 2).

The preformed initial tube was fitted over the mandrel clamped into the chuck of the lathe. The one end of tube was fixed by the tail stock. To minimize the frictional shear stresses at contact surfaces, the mandrel-tube interface was lubricated as good as the roller-tube one. The process was carried out at room temperature and the heat of deformation and strain rate effects can be neglected because of small speed. The material used in this study was an annealed AA7075 alloy and mounted onto the mandrel. Process conditions parameters along with perform tube and roller dimensions are given in table 1.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Dimensions of tools and preformed tube and process conditions parameters used in experiment</th>
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<tbody>
<tr>
<td>parameter</td>
<td>value</td>
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<tr>
<td>material</td>
<td>Al 7075</td>
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simulations. Mass scaling speeding up the time of simulation also increases the inertia forces that in extreme case will change the predicted response. In this FE model mass scaling factor of 200 were selected by trial and error. Figure 3 (a) and (b) show that the ratio of the kinetic energy to the internal energy is quite negligible, conforming the quasi static response of the explicit method with used mass scaling factor. (Wong et al 2004, Abaqus Analysis user’s manual 2003).

![Fig. 3 (a) Kinetic energy and (b) internal energy.](image)

The initial and simulated one model set-up is shown in Fig .4.
Fig. 4. Proposed FE model (a) Initiation of process (b) in the middle of process and (c) the final steps of forming. The roller and the mandrel were chosen to be rigid parts in the model. In order to overcome the difficulties in simulation with regards to rotating the workpiece, the workpiece and the mandrel were fixed and the roller was chosen to rotate about their axis. By using this method, computational time reduction will be significant. In this study, the material used for the experiment and the simulation is AA7075 aluminum alloy. The mechanical properties of AA7075 alloy were obtained through compression test. True stress-strain curve is shown in Fig. 5.

Fig. 5 True Stress-Strain curve resulted from compression test of AA7075 billet

The friction at the roller-tube and mandrel-tube interfaces was assumed to be quite low because of good lubrication so all contact areas were modeled as frictionless interfaces.

RESULTS AND DISCUSSION
Flow forming forces are the important process parameter for the tube flow forming because they concern the selection of process tools. To verify the simulation obtained results, variations of the flow forming force in the axial direction during flow forming at 10% and 25% reduction ratios in same conditions with simulations one has been extracted via load cell attached on the roller. Fig. 6 shows that with an increase in the reduction ratio, the axial flow forming force increases, and also a good agreement between the proposed FE model and the experimental results.
Fig. 6. Axial force: (a) 10% reduction ratio and (b) 25% reduction ratio

Figure 7 shows the predicted FE simulation model of flow formed AA7075 tube along its axis. As can be seen from the figure there are some process defects that will affect the produced final workpiece precision such surfaces (surface roughness and internal diameter growth were studied).

Fig. 7. Predicted material flow along the tube axis with FE proposed model

Four different feed rates of roller along the tube axis were applied in four different preform materials. Depending on preforms thickness and diameters feed rates of 1, 1.5, 2, 2.5 mm/rev were applied. In the all cases the reduction ratio of materials was 10%. As can be seen from figure 8, the experimental obtained results have shown that when high feed rates of roller are employed, the surface roughness will increase. This behavior is due to the fact that increasing of feed rates for every revolution of the workpiece will cause to increase in the axial movement of the roller, so the contact surface of the roller-material will be high and the material does not stand under the roller but escape from it, leading to the rough surface of flow formed tubes.

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Fig. 8. The influence of the feed rate on the surface roughness (experimental)

Figure 9.a shows the selected node path on the preform surface to measure its roughness amount. To do so, 35 mm length of flow formed tube from the end side was selected and the maximum radial distance of each nodes from the initial position were extracted (Fig. 9.b). The mean roughness amount of the flow formed surface of tube (Ra) can be extract from the obtained surface profile from the following equation (P.C. Sarma, 2005).

\[ Ra = \frac{\sum d}{l} \]

For the same conditions was about 81%. Figure 10 shows the influence of the feed rate on the internal diametral growth of the flow formed tubes in the experimental studies. Four different feed rates (1, 1.5, 2, 2.5 mm/rev) were applied in the four different preform materials. The internal diametral growth of each specimen was measured in same position in the 35 mm length of flow formed tube from the end side. As shown in the fig. 10 increasing of feed rates will decrease the diametral growth of flow formed tubes. For instance, increasing feed
rates from 1 (mm/rev) to 2 (mm/rev) will decrease diametral growth about 78%.

Form the experimental obtained results it can be concluded that free end side of flow formed tubes will have maximum diametral growth amount. This behavior is due to the fact that this section of tube was not constrained well. Figure 11 shows the diametral growth variations along the tube length.

![Fig. 10. The influence of the feed rate on the diametral growth (experimental)](image)

To measure the diametral growth of flow formed tubes in the simulations, the radial node path on the preform surface, in the same position with the experimental samples, was selected to measure its radial displacements. To do so, 35 mm length of flow formed tube from the end side was selected and the maximum radial distance of each nodes from the initial position were extracted (Fig. 12). For instance, in the simulation obtained results, increasing feed rates from 1 (mm/rev) to 2 (mm/rev) will decrease diametral growth about 67% in the same position of the flow formed tubes in experimental studies.

![Fig. 11. The diametral growth variations along the tube length (experimental)](image)

![Fig. 12. The radial displacement of selected node path along the tube length (simulation)](image)
Figure 13 shows that increasing of feed rates amount will decrease the axial flow forming forces along the tube axis. From the results obtained, it is clear that the feed rate influence the product quality (surface roughness, diametral growth) and flow forming forces and an inappropriate selection of this parameter leading to specific types of defects as mentioned.

![Fig. 13. The radial displacement of selected node path along the tube length (simulation)](image)

The Changes in microstructure of cross section of tubes before and after flow forming process for Reduction ratio of 25% is given in fig. 14. The dendrites of the preform aluminium alloy are successfully eliminated by the flow forming process and the homogeneous distribution of grains is obtained in the flow formed tubes.

![Fig. 14. Changes in microstructure of tubes before and after flow forming process for Reduction ratio of 25% (a) preform and (b) after flow forming](image)

**CONCLUSIONS**

In this paper, the influence of feed rates amount as a major flow-forming process parameters on the quality of an AA7075 alloy such as surface roughness and diametral growth and forming load were studied numerically and experimentally. A three dimensional FE model was developed to analyze the process. Comparison between FE and experiment results showed good agreement. Both the simulation and experimental results highlight the major role of feed rate parameter on the finished products quality and flow forming loads. Based on the results the following conclusions can be drawn:

- Increasing of the reduction ratio will increase the axial flow forming force.
- When high feed rates of roller are employed, the surface roughness will increase. Under experimental conditions, where feed rates increases form 1 (mm/rev) to 2 (mm/rev), the surface roughness will increase about 92%. These results are in good agreement with the simulation obtained results where the predicted roughness for the same conditions was about 81%.
- Increasing of feed rates will decrease the diametral growth of flow formed tubes. For instance, increasing feed rates from 1 (mm/rev) to 2 (mm/rev) will decrease diametral growth about 78%.
- The dendrites of the preform aluminium alloy are successfully eliminated by the flow forming process and the homogeneous distribution of grains is obtained in the flow formed tubes.
The forward flow forming process can be used to produce high precision and high strengths tubes components. Feed rate of rollers is as major process parameters to produce defect-free products. The quantitative analyses of this process in this paper, made it possible to produce complex parts by controlling the parameters within the design limits.

REFERENCES

Abaqus Analyses User’s Manual.; 2010. ABAQUS Inc.V6.9.1