Numerical and Experimental Investigation of Deformation Characteristics during High-Frequency Radial Forging of AA7075

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Abstract. Deformation characteristics during high-frequency (1200 strokes /min) radial forging of AA7075-O bar and tube at room temperature were investigated using A GFM SKK-10/R radial forging machine. A comprehensive process model taking account of complex process kinematics, and elastoplastic material behaviour was developed in DEFORM (version 12.1) to investigate the material flow, temperature, and strain evolution during the radial forging process. To verify the simulation results, a novel experimental approach has been used to reveal the material flow behaviour during the radial forging process, in which copper wires were embedded into an AA7075-0 blank prior to the radial forging process and the whole radial forged part was scanned using a Nikon XT H 225 LC X-ray computed tomography system after radial forging. The experimental results provide quantitative characterizations of the material flow in 3D. The experimental and numerical results shed light on the mechanism of fishtail and crack formation during the high-frequency radial forging of AA7075-O and provide guidance to minimise these defects.

Keywords: Radial forging · Process simulation · AA7075-O · X-Ray CT · fishtail formation

1 Introduction

Radial forging is an open-die forging process that uses sets of radially moving hammer dies to produce cylindrical/tubular components with various internal and external profiles. The process offers high reliability in producing high-integrity forgings with tight tolerances, smooth surfaces, and improved mechanical properties at relatively high production rates and low costs. This leads to extensive application potential in the aerospace, automotive, and oil and gas industries. However, establishing a radial forging procedure remains an expensive and time-consuming process based on trial and error, due to the lack of understanding of complex deformation characteristics that can lead to various types of defects in the components, such as internal cracks/cavities and fishtail formation during the radial forging process.

One material of particular interest for radial forging is AA7075, a high-strength aluminum alloy commonly used in aircraft structures and other critical applications. Understanding the flow behavior of AA7075 during radial forging is essential for optimizing process parameters and ensuring the quality of the finished product. Several studies have investigated the deformation behavior of AA7075 during forging, with some focusing on the effects of temperature and strain rate on flow behavior [4, 5, 1].

Process modeling of radial forging using finite element analysis has proven to be an effective approach for improving and designing radial forging processes [2, 3]. The challenge of modeling and simulating the radial forging process lies in the large number of short, high-frequency strokes around the workpieces, which makes the simulation excessively time-consuming. A comprehensive process model, accounting for complex process kinematics and elastoplastic material behavior, was developed in DEFORM (version 12.1) to investigate material flow, temperature, and strain evolution during the radial forging process.

In this paper, we present a study of the flow behavior of AA7075 during radial forging using process modeling and simulation, as well as X-ray CT to detect material flow and internal cracks due to widespread usage in the aerospace industry. The focus is on the deformation characteristics of the alloy, including material flow, strain distribution, and fishtail formation. The results of this study provide insights into the behavior of AA7075 during radial forging and can be used to optimize the process for producing high-quality, defect-free parts while also detecting and mitigating any internal defects that may arise.

2 Material

An AA7075-O alloy cylinders with 70 mm diameter were chosen to investigate in this research since this aluminium alloy are used in a number of aeroplane and helicopter parts. The chemical composition of this alloy is shown in Table 1.

Table 1. Chemical composition of AA7075.

Zn	Mg	Cu	Al
6.2	2.0	1.7	balance

3 Experiment

3.1 Radial forging setup

Radial forging trials of AA7075-O were carried out at room temperature using a GFM SKK10/R machine at the Advanced Forming Research Centre, University

of Strathclyde. During the radial forging process, the workpiece is deformed by 4 radially oscillating dies through high-frequency short-strokes, which is 1200 strokes per minute. The part rotates at a speed of 55 rpm. The oscillating hammer dies can move in a radial direction to reduce the diameter of the part, which we call the 'plunge forge' stages. After the 'plunge forge,' the axial hammer die feeding will stop when the radius of the part reaches the desired diameter, and the relative axial movement of the part will produce a constant radius in the forged part, which is called 'feed forge'. The outer diameter is reduced from 70 mm to 55 mm with a reduction of 15 mm in diameter in the first 'plunge forge,' followed by a 120 mm 'feed forge,' and then the second 'plunge forge,' in which the outer diameter of the part is reduced from 55 mm to 30 mm with a reduction of 25 mm in diameter, and then the part is finished by another 'feed forge' all the way to the end. During the radial forging process, the part moves along the axial direction at a constant speed of 500 mm/min. During the 'plunge forging' process, the hammer dies close at a constant speed of 100 mm/min. Coolant was used during the whole process to prevent temperature rise in the part.

4 Process Modelling

Radial forging process model setup A comprehensive process model was developed using the commercial software DEFROM (V12 MO) to capture the instantaneous deformation characteristics of during radial forging of AA7075. During the radial forging process, an axial spring is mounted to the chuck head to stabilise the contact between the hammer and blank as shown in Figre 1. The axial spring allows the billet to move forwards and backward when the hammer die strikes the billet. The maximum amount of compression of the axial spring is 1 mm with stiffness of 10^4 N/mm. More details of the effect of the axials spring on material flow is described in reference [3].

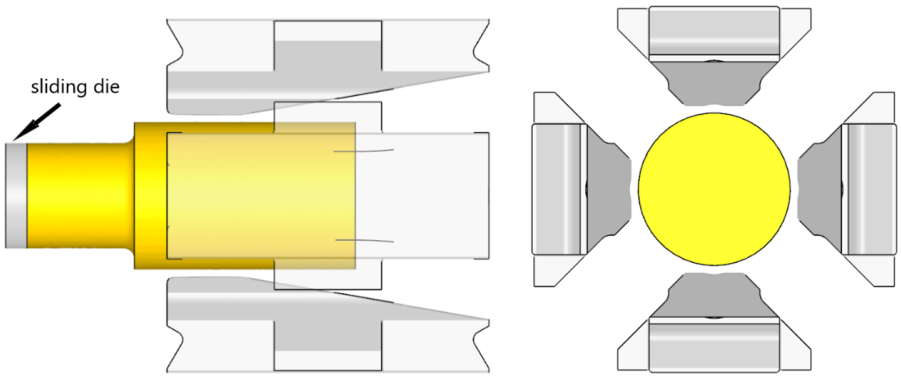

Fig. 1. Illustration of radial forging process setup in DEFORM.

Two pairs of hammer dies oscillate at a frequency of 20 Hz with an amplitude of 3.5 mm, and the sinusoidal movement is described as: sinosoidal movement equation:

$$d = Asin(2\pi ft) \tag{1}$$

where d is the hammer die displacement, A is the oscillation amplitude, and f is the oscillation frequency and t is the time.

The initial billet length is 100 mm and diameter of 50 mm, during the radial forging process, the feed rate is 1 mm/s, and 8 mm/s during plunge forging and feed forging, respectively. Key process parameters are listed in Table 2.

Table 2. Key parameters used in radial forging simulation.

Length of die inlet (mm)	120
Length of die land (mm)	30
Die inlet angle (°)	10
Axial spring stiffness(N/m)	10000
Hammer die radial feed rate(mm/s,plunge forge)	1.5
Hammer die axial feed rate(mm/s,plunge forge)	1.0
Billet axial feed rate(mm/s, feed forge)	8

Table 2 lists all key process parameters used in simulation. Figure 3 illustrates the sinusoidal hammer movement and impact time, which determines the instantaneous deformation rate during the radial forging process. Figure 4 shows the chuck head and hammer die position during the radial forging process. The recorded hammer position is presented in the form of outer diameter of the workpiece achieved when the hammer is in that position.

4.1 X-Ray CT

In order to investigate materials flow during the radial forging process, a Cone beam X-ray microtomography have been used. To do that, before radial forging operation, a set of copper wires were embedded into the billet throughout the billet as shown in Figure 2 . Any displacement of these copper wires could be translated into aluminium displacement at different points. The equipment used in this study was a Nikon Metrology X-CT at the University of Strathclyde, with 180 kV transmission target fitted and housed in a large cabinet. To uncover copper wires displacements and consequently aluminium flow, the maximum X-ray setting of 180 kV were used. Additionally, 3141 angular projections were collected during a full 360 degree rotation of the sample which reconstructed into a 3D volume using a filtered back projection algorithm with Nikon Metrology CT PRO 3D software.

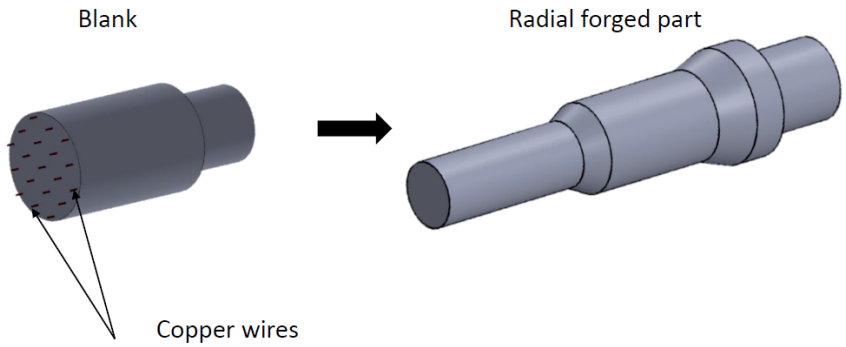

Fig. 2. Illustration of a set of copper wires embedded in the blank for X-Ray CT study.

5 Results and discussion

Figure 3 shows the predicted strain distribution in the radial forged part. A line probing results show a strong non-uniform strain distribution in the middle of radial forged part,and the strain at the surfaces tends to be higher and reduced towards the core of the part. At the end of the part, a large blue area was found just at the bottom concave end surface (fishtail), which indicate low plastic strain deformation in this region. This explains the reason of fishtail formation.

Figure 4 provides further details of material flow and fishtail formation by showing the evolution of the flownet at the surface. In the early stage of deformation, all flownet were relatively straight along the axial direction, however towards the end of froging with the increasing reduction in diameter, the flownet start twisting, which indicated a shear plastic deformation has also been introduced into deformed part in the later stage of radial forging. These phenomena has been verified from the X-Ray CT scanning results, as shown in Figure 5

Figure 6 shows comparison of the predicted and measured fishtail formation in the radial forged part.

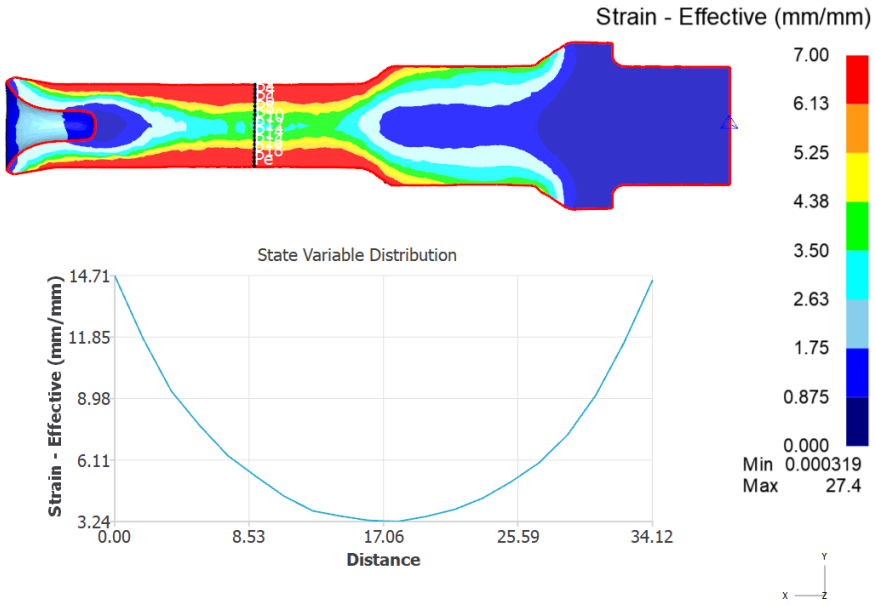

Fig. 3. Predicted effective strain distribution of radial forged part

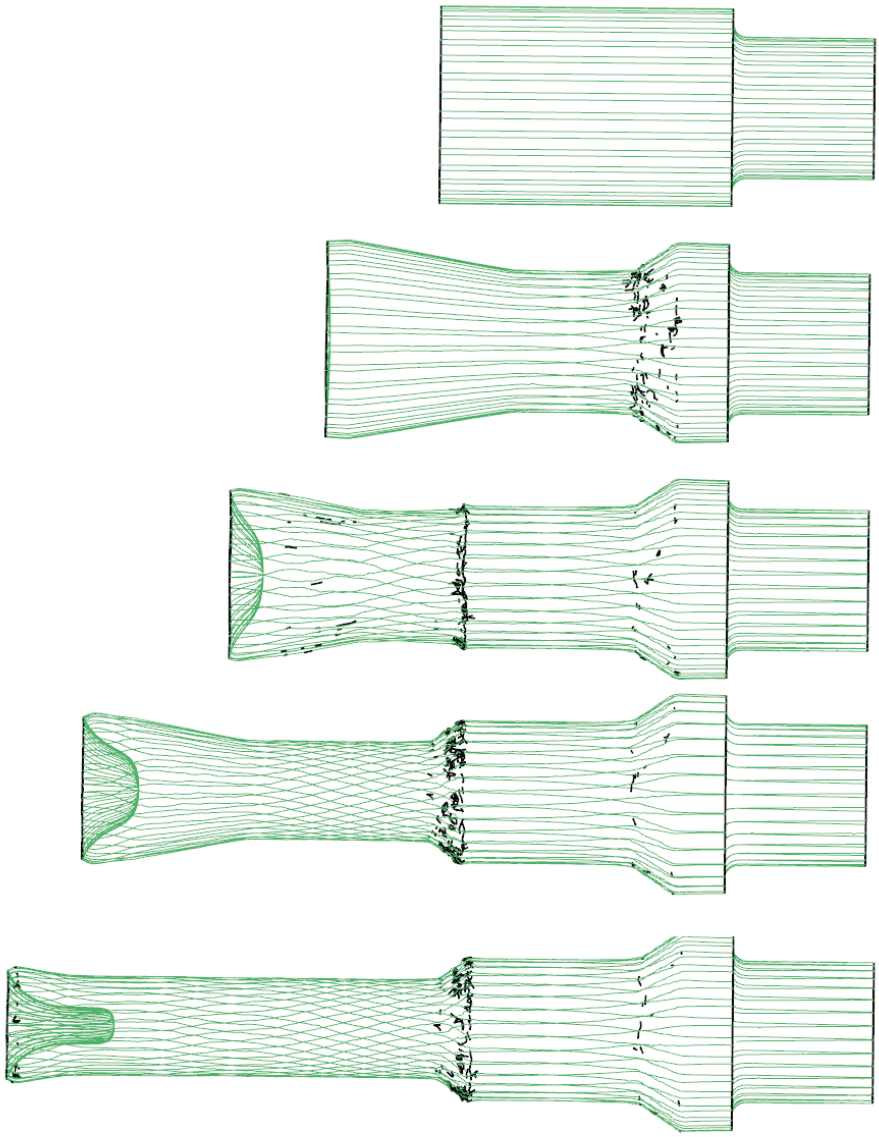

Fig. 4. Predicted effective strain distribution of radial forged part

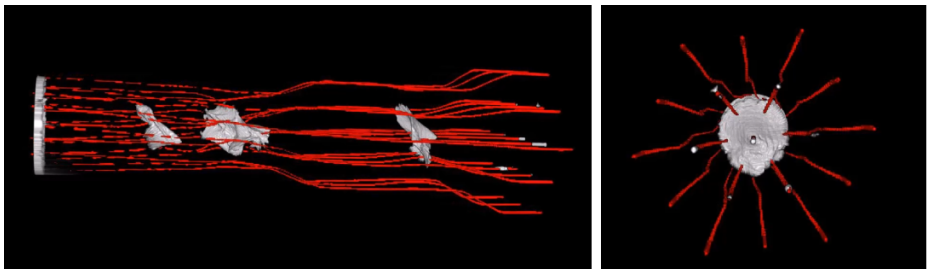

Fig. 5. Reconstructed X-Ray CT results showing the distribution of copper wires in the radial forged part

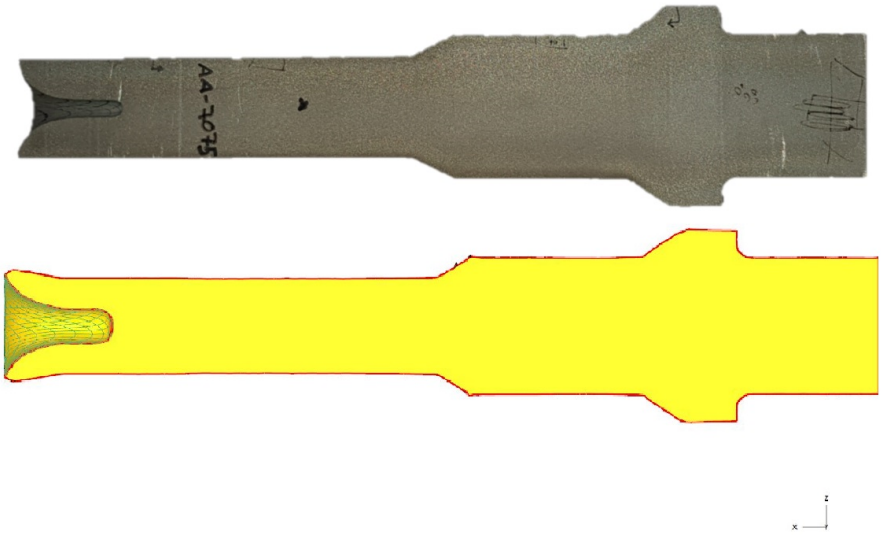

Fig. 6. Comparison of predicted fishtail formation with experimental results

6 Summary and conclusion

A comprehensive radial forging process model were developed to investigate the deformation characteristics during high-frequency (1200 strokes /min) radial forging of AA7075-O bar and tube at room temperature. The simulation results show a strong non-uniform strain distribution along the radial direction, which is the root course of fishtail formation. Both Simulation results and X-Ray CT results indicated a shear plastic deformation has also been introduced into deformed part in the later stage of radial forging. The predicted fishtail formation is in relative good agreement from the experimental results. This verified model could be used to optimize the process for producing high-quality, defect-free parts while also detecting and mitigating any internal defects that may arise.

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