Research of PEEQ for Conical Ring with Outer Steps Ring Rolling

Gong Xiaotao*, Yang Fan

Department of Aeronautical Material, Xi’an Aeronautical Polytechnic Institute, Xi’an 710089, China

Abstract

Based on the platform ABAQUS, a 3-D FEM model of conical ring with outer steps ring rolling process has been developed to investigate the ring’s deformation behavior and the equivalent plastic strain PEEQ distribution. During the ring rolling, the average equivalent plastic stain (PEEQa) is increasing with bigger idle roll speed and lower drive roll rotational velocity. And the changing of the standard error criterion of the equivalent plastic strain (SDP) is similar to the equivalent plastic strain PEEQ. So the bigger idle roll speed and lower drive roll rotation velocity can help to improve the mechanical property.

PACS: Type pacs here, separated by semicolons;
Keywords: Conical ring with outer steps, PEEQ, Ring rolling

1. Introduction

Profile ring rolling is one of the attractive challenging fields in the metal forming. It is an advanced process typically used to manufacture parts with revolved geometries, and reduce the wall thickness, enlarge the diameter of the workpiece and form the section of the ring. During the forming, the complicated cross-section shape can be manufactured directly by plastic deformation instead of machining, which guarantee the higher mechanical property and result in significant cost saving. Profile ring rolling process is widely used in aviation, aerospace, machinery, energy and other industrial fields [1]. Conical ring with outer steps is one of the typical profiled rings, which is widely used in the aircraft engines.

* Corresponding author. Tel.: +86-29-86855794; fax: +86-29-86852300.
E-mail address: gxt239@163.com.
Generally, such profile ring has special contours inside and outside. During the ring rolling, because the law of metal flow is difficult to study, so the motion control and forming control are imprecise. Researching the equivalent plastic strain (PEEQ) can help the study the metal flow in the ring rolling.

Some researches on profile ring rolling have been done by analytic, experiment, and simulation. K.H.Kim used the finite element analysis method and experiment to analyze the profile ring rolling process for large slewing rings of alloy steel [2]. M.S.Joun presented a rigid-viscoplastic finite element method for approximate predicting the deformation of material in ring rolling [3]. Z.J.Szabo described the main components of a state-of-the-art manufacturing system for the production of seamless rolled rings and the research work carried out to provide the relevant technological know-how and database necessary for the production of a wide range of ring-shaped products [4]. However, limited work has been reported in open literature about the equivalent plastic strain (PEEQ) of profile ring.

2. Establishment of 3D FEA model of ring rolling

![Fig.1 Structure of conical ring with outer steps and assembly mould](image)

In this paper, the part drawing was shown as Fig.1 (a). This part is widely used in the aero engine as aero engine casings which demands high mechanical properties and great comprehensive capability. The material was superalloy GH536 (Ni-21.5 Cr-18.3 Fe-9.05 Mo-1.83 Co-0.67 W-0.075 C-0.19 Si, Wt pct) with low plasticity. And the contour of the ring was very easy to appear discontented problems during forming. An optimal blank was designed for solving the problem as was shown in Fig.1 (b). Based on the platform ABAQUS, a 3-D FEM model of conical ring with outer steps ring rolling process has been developed to investigate the ring’s deformation behavior.

3 Law of equivalent plastic strain PEEQ distribution

3.1 Define of equivalent plastic strain PEEQ

The rotated ring bites into the deformation zone between the idle roll and the drive roll continuously with the ring rolling, the ring produce plastic deformation. It is possible that the diameter may not increase during the forming. This is mainly due to that the deformation zone is fail to satisfy the forging penetration efficiency. In the platform of ABAQUS, equivalent plastic strain was used to judge the
forging penetration efficiency. And it is the sum of direct plastic strain components, if $\text{PEEQ} > 0$, then the material in the deformation zone yield. The Equivalent plastic strain $\text{PEEQ}$ is defined as

$$\varepsilon^p = \varepsilon^p_0 + \int_0^t \sqrt{\varepsilon^p : \varepsilon^p} \, dt$$

(1)

Where $\varepsilon^p_0$ is the initial equivalent plastic strain (zero or user-specified).

The standard error criterion of the equivalent plastic strain (SDP) is used to measure the non-uniform extent of the ring, the bigger of the SDP means the more non-uniform in the ring, at the same time, the internal defects are more arising. And SDP is defined as

$$SDP = \sqrt{\frac{\sum (\text{PEEQ}_i - \text{PEEQ}_a)^2}{N - 1}}$$

(2)

Where $N$ is the number of the total node number of the ring. $\text{PEEQ}_i$ is the $i$th of the $\text{PEEQ}$ value, $\text{PEEQ}_a$ is the average value of the $\text{PEEQ}$ in the ring, which

$$\text{PEEQ}_a = \frac{1}{N} \sum_{i=1}^N \text{PEEQ}_i$$

(3)

For the volumetric hardening model, the initial value of the volumetric compacting plastic strain can be specified for elements that use the crushable foam material model, as described above. The volumetric compacting plastic strain (output variable PEEQ) provided by Abaqus contains the initial value of the volumetric compacting plastic strain plus any additional volumetric compacting plastic strain due to plastic straining during the analysis. However, the plastic strain tensor (output variable PE) contains only the amount of straining owing to deformation during the analysis.

### 3.2 Effect of idle roll speed on the equivalent plastic strain $\text{PEEQ}$

![Diagram](image1.png)

(a) $v=0.66\text{mm/s}$

![Diagram](image2.png)

(b) $v=0.88\text{mm/s}$
Fig. 2 PEEQ distribute with difference idle velocity

Fig. 2 and Fig. 3 showed the equivalent plastic strain (PEEQ) and the changing of average and standard errors estimated of equivalent plastic strain with different idle velocity separately. It can be seen from the graph that the average and standard errors estimated of equivalent plastic strain becomes smaller with the increasing of the idle speed, This is mainly due to the feeding magnitude per revolution $\Delta h$ increasing while the deformation extent in the outer ring decreasing with idle velocity increasing. And more material in the inner deformed during the forming, the PEEQ increasing, the differences of the PEEQ in the inner and in the outer ring reduce. The standard error criterion of the equivalent plastic strain (SDP) reduces, the deformation become more non-uniform.
3.3 Effect of drive roll rotational velocity on the equivalent plastic strain PEEQ

Fig. 4 showed the average equivalent plastic strain (PEEQa) and the changing of average and standard errors estimated of equivalent plastic strain with different rotational velocity. In fig.4, it can be seen that the average equivalent plastic strain (PEEQa) rising with the rotational velocity of drive roller increasing. It is chiefly because of the feeding magnitude per revolution $\Delta h$ decreasing with the rotational velocity of the drive roller increasing, and the deformation on the outer ring and the average equivalent plastic strain (PEEQa) is increasing. It indicates that with the increasing of drive roll rotation speed, the standard error criterion of the equivalent plastic strain (SDP) increasing at the beginning, and keep constant and even decline later. This is mainly due to the feeding magnitude per revolution $\Delta h$ decreasing, and the deformation on the outer ring is increasing, but the blank in the inner ring is hard to deform, and the deformation distribution along the radial direction become more non-uniform. With the drive roll increasing, the deformation zone and contact time decreasing respectively, the temperature rising, it is help to improve the plasticity of the ring, meanwhile the deformation of the ring becomes uniform. It may be one of the causes of SDP decreasing.

4. Conclusions

For the ring rolling, more rapid idle roll speed and low drive roll rotational velocity can increase the average equivalent plastic strain (PEEQa). In this case the deformation distribution in the ring is uniform; which is beneficial to enhance the mechanical property of the ring.

Acknowledgements

This work has been supported by Scientific Research Program Funded by Shaanxi Provincial Education Department (Program No.11JK0815), Ministry of Science and Technology Sino-German Cooperation Project (Program No.2010DFA51860).

Reference