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Effect of friction on combined radial and axial ring rolling process

Xinghui Han, Lin Hua *

School of Automotive Engineering, Hubei Key Laboratory of Advanced Technology of Automotive Parts, Wuhan University of Technology, Wuhan 430070, China

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ABSTRACT

Combined radial and axial ring rolling is a complicated incremental metal forming process used to manufacture the thin-walled cylindrical rings. During the process, the friction is a critical factor because it has a significant effect on the deformation characteristics of the process. This paper is aimed to reveal the effect of the friction coefficient on the combined radial and axial ring rolling process. For this purpose, a 3D elastic–plastic FE model of the process is first established and its validity is verified by the experiment. Based on this reliable 3D FE model, the effect of the friction coefficient on the geometry development, inhomogeneous deformation of the ring and the power parameters is then investigated numerically.

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1. Introduction

In metal forming processes, friction conditions between the dies and workpiece are of great importance because they significantly influence the material flow, surface quality, forming limit of the workpiece and die life. However, the subject of friction is still somewhat of a mystery because the die–workpiece interface is under a high pressure, high temperature and complicated dynamic state.

By now, lots of studies have been carried out on the subject of friction in metal forming. To evaluate the friction in metal forming, some friction test methods, such as ring compression [1,2], forward extrusion [3,4], double-cup extrusion [5–7], upsetting-sliding [8,9], spike test [10] and T-shape compression test [11] were presented. Some studies have been carried out on the effect of friction on the metal flow [12–14], forming limits [15] and die wear [16] in sheet metal forming. In the studies of the friction in bulk metal forming, the friction models comparison has been investigated and thus the proper friction model could be suggested [17,18]. Meanwhile, the effect of friction on the metal flow [19,20], contact interaction [21–24] and die wear [25,26] in bulk metal forming has also been carried out. It should be pointed out, nevertheless, that the large majority of the aforementioned studies were limited to the overall metal forming processes, and the studies on the friction mechanisms in the complicated incremental metal forming processes were scant. Comparing with the overall metal forming processes, the friction mechanisms in the complicated incremental metal forming processes are more complicated due to some important features of the contact interactions, such as the local contact, asymmetry, time varying, non-steady-state and high nonlinearity. Therefore, it is necessary to achieve a comprehensive understanding of the friction mechanics in the complicated incremental metal forming processes.

Ring rolling is an advanced but complicated incremental metal forming technology which is widely used to manufacture precise seamless rings, such as bearing races, ring gears, aero-engine casing, nuclear reactors parts and various connecting flanges. A typical radial ring rolling process is illustrated in Fig. 1. During the process, the driven roll rotates actively around its axis at a constant rotational speed. Under the action of the friction force, the driven roll takes the ring to rotate together. Simultaneously, the idle roll feeds towards the ring radially and the guide roll takes translational motions and always contacts the outer surface of the ring to keep the stability of process. Under the action of the rolls, the ring produces the incremental deformation of wall-thickness reduction and diameter expansion and its height basically remains unchanged. Obviously, it is difficult for the above ring rolling process to achieve a large increase in the ring height. Therefore, this paper proposes a new combined radial and axial ring rolling process which can achieve a large increase in both the ring diameter and height. Fig. 2 shows the schematic diagram of the proposed combined radial and axial ring rolling process. During the process, the constraint roll rotates actively around its axis at a constant rotational speed. Under the action of the friction force, the constraint roll takes the ring to rotate together. Simultaneously, the idle roll feeds radially towards the ring. The whole rolling process includes three stages: radial ring rolling stage, axial ring rolling stage and extruding stage.

1. Radial ring rolling stage. In this stage as shown in Fig. 2(a) and (b), the radial ring rolling process is established and under the actions of the constraint roll and idle roll, the ring mainly produces the deformation of thickness reduction and diameter expansion and its height increases slightly.

* Corresponding author. Tel./fax: +86 27 87168391.
E-mail addresses: hanxinghuihlp@126.com (X. Han), lhua@whut.edu.cn (L. Hua).

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2. Axial ring rolling stage. When the outer diameter of the ring gradually increases until its outer surface completely contacts the inner surface of the constrained roll, the axial ring rolling process is established. In this stage as shown in Fig. 2(c and d), the outer diameter of the ring is completely constrained by the constraint roll and thus the ring produces the deformation of thickness reduction, inner diameter expansion, outer diameter constancy and height increase.
3. Extruding stage. When the thickness of the deformed ring reaches its predetermined value, the idle roll returns and the deformed ring is extruded by the extruding die, as shown in Fig. 2(e).

From the above description, it can be seen that the proposed combined radial and axial ring rolling process can achieve a large increase in the height of the ring and thus it has the potential and prospect in manufacturing thin-walled cylindrical rings, such as wide bearing ring, pressure vessel ring and pressure cylindrical ring in aerospace industry, etc. The above description also indicates that the friction between the rolls and ring is of great importance. The contact conditions in the process are complicated and the friction role between the constraint roll/idle roll and ring is influenced each other. Therefore, the friction has an important effect on the deformation characteristics of the process.

Up to now, there are no relevant published reports on the new combined radial and axial ring rolling process. In view of the complexity and importance of the friction between the rolls and ring, this paper is aimed to reveal the effect of the friction coefficient on the combined radial and axial ring rolling process. First, a 3D elastic–plastic FE model of the process is established and its validity is verified by the experiment. Based on this reliable 3D FE model, the effect of the friction coefficient on the geometry development, inhomogeneous deformation of the ring and the power parameters is then investigated numerically.

2. 3D FE modeling for combined radial and axial ring rolling

In this study, the FE method is adopted to investigate the effect of the friction coefficient on the proposed combined radial and axial ring rolling process. Using the FE code ABAQUS, a 3D elastic–plastic dynamic explicit FE model of combined radial and axial ring rolling is developed, as shown in Fig. 3. The FE model has following features.

1. The elastic–plastic formulation is adopted to improve the computational accuracy and the dynamic explicit FE procedure is used to avoid the huge computational time and convergence problem of the static implicit procedure.
2. The two rolls are treated as the rigid bodies and the ring is treated as the deformable body. The ring is meshed by the 3D linear reduction integration continuum element with eight nodes (C3D8R). An adaptive mesh domain is created for the

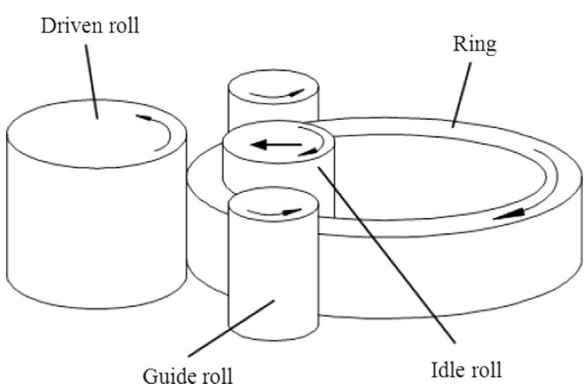

Fig. 1. Schematic diagram of radial ring rolling.

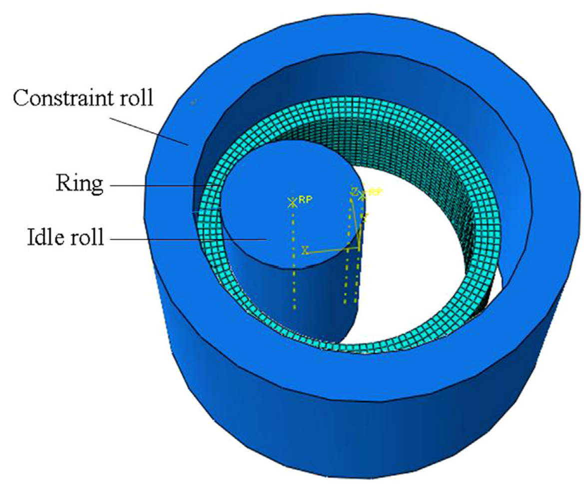

Fig. 3. 3D FE model of combined radial and axial ring rolling.

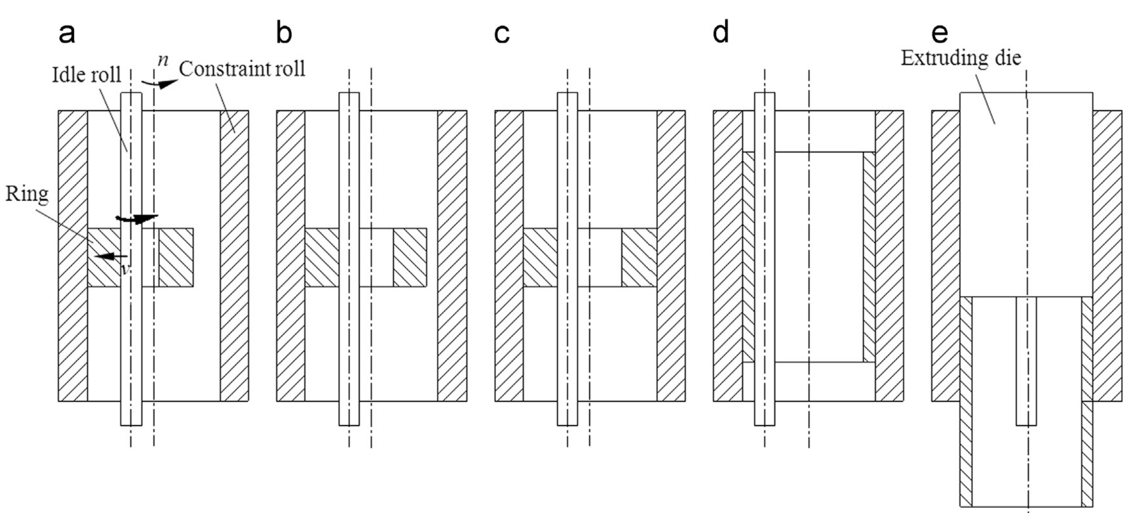

Fig. 2. Schematic diagram of combined radial and axial ring rolling. (a) Rolling beginning, (b) radial ring rolling, (c) axial ring rolling, (d) rolling finishing and (e) extrusion of ring.

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