CIRP Annals - Manufacturing Technology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

CIRP Annals - Manufacturing Technology

journal homepage: http://ees.elsevier.com/cirp/default.asp

Ring rolling with variable wall thickness

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ARTICLE INFO

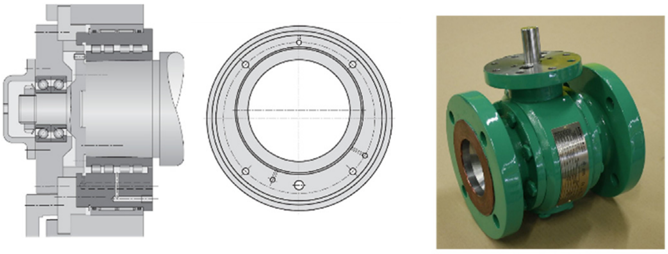
Keywords:
Rolling
Process-control
Ring rolling

ABSTRACT

Ring rolling processes today produce axisymmetric rings, wasting material, energy and labour if non-axisymmetric components such as eccentric bearing races and bossed pipe fittings are required. A new process is proposed to roll rings with variable wall thickness. In this work, roll gaps and speeds are controlled online in physical experiments to achieve a defined variable wall thickness, enabled by photogrammetry to capture the ring's shape and position. The trials revealed two new process limits for which new analytical explanations have been developed: a maximum rate of change of thickness around the circumference and a loss of circularity.

1. Introduction

Until now ring rolling has been used to produce notionally axisymmetric rings. Yet, if non-axisymmetric features are required in a component they must be machined from larger rings, wasting material, energy and labour inputs and increasing downstream machining burden. Such components could include eccentric bearing races or rings with one or more bosses around the circumference; both broadly circular but with variable wall thickness – as suggested in Fig. 1. If it was possible to control wall thickness and/or curvature around the ring during ring rolling, this could be valuable to customers of such components.



Triple Ring Eccentric Bearing,
FAG Industrial Bearings AG[1]

Side Entry Trunion Ball Valve,
Ereesse S.r.l. [2]

Fig. 1. Possible uses of variable thickness ring rolling [1,2].

In the typical ring rolling process illustrated in Fig. 2 a pierced preform is deformed between two pairs of rolls acting on the radial and axial surfaces. The radial roll pair comprise a powered forming roll, and idle mandrel and the axial roll pair are an upper and lower axial roll.

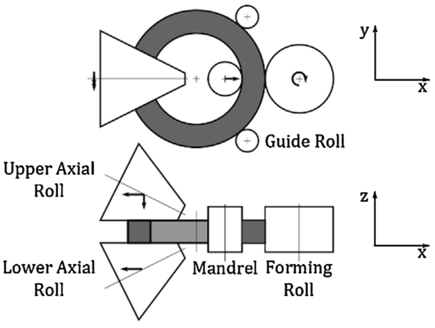


Fig. 2. Typical radial–axial ring rolling process.

A review of research into ring rolling in German and English languages [3,4] showed that effort has historically centred on understanding and controlling the conventional process [e.g. 5,6]; recent innovations include incremental techniques for producing profiled rings [e.g. 7,8]. However, despite related applications in fields such as plate rolling [9], variable thickness ring rolling has not yet appeared in the literature. This paper describes how rolled rings could be produced with variable wall thickness for the first time.

2. Method for creating variable wall thickness rings

A novel method for production of rings with variable wall thickness is proposed and implemented on a model machine.

2.1. Experimental set-up

Experiments are performed on a desktop-scale ring rolling machine at the University of Cambridge, as shown in Fig. 3 [10]. The machine uses modelling clay as a model material. Similar

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http://dx.doi.org/10.1016/j.cirp.2016.04.002
0007-8506/© 2016 CIRP.

Please cite this article in press as: Cleaver CJ, et al. Ring rolling with variable wall thickness. CIRP Annals - Manufacturing Technology (2016), http://dx.doi.org/10.1016/j.cirp.2016.04.002

materials have been used previously for predicting geometrical outcomes in hot metal working processes [11].

The principal set-up and degrees of freedom are as described in Fig. 2. Two differences are that guide rolls are not used and the ring is instead centred along the *y*-axis by differential speed control of the axial roll (discussed below). To simplify sensing, the radial roll pair is moved so the ring centre remains stationary along the *x*-axis, but this does not affect the process mechanics.

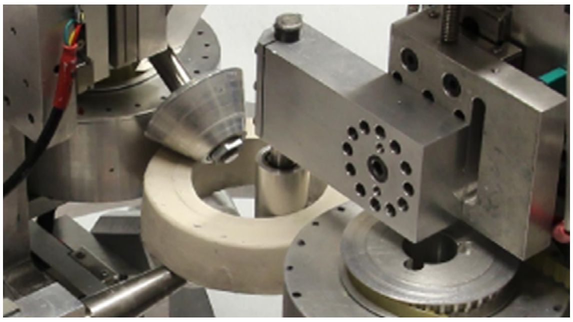

Fig. 3. Model ring rolling machine at University of Cambridge.

The model material is a proprietary oil–clay mixture produced by Newclay Products Ltd., UK. To make the preform, the material is heated in a water bath, kneaded and pressed in a closed mould. The material behaviour shown in Fig. 4 is similar to high-temperature steel [11]; elastic deformation is followed by strain-rate dependent plasticity with little strain hardening. The strain rate in the experiment, around 0.07/s, is similar to that for the lowest curve in Fig. 4.

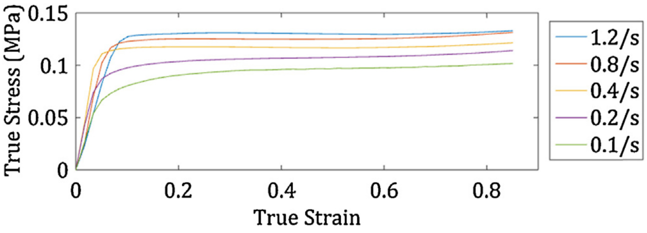

Fig. 4. Modelling clay compression tests on cylindrical specimens.

2.2. Measuring the current state of ring geometry

To control the ring's radial wall thickness, its current geometric state must be measured to provide feedback to the controller: an open loop approach to control would probably fail since the rotation of the ring is difficult to predict with sufficient accuracy.

Measurement is achieved by a calibrated optical camera mounted above the ring, as described in [12]. It measures thickness around the circumference by standard edge detection techniques and infers the location of the current ring centre and midline in the camera's frame of reference. The nominal midline radius is estimated around the circumference as the distance from ring centre to the midline.

In contrast to conventional ring rolling, the ring rotation must be monitored as well as its thickness, to allow precise control of thickness and strain around the ring circumference. To achieve this, 12 coloured markers are placed on the top ring surface and their location detected by changes in hue around the ring midline.

2.3. Control of the process

The control of variable wall thickness requires a different approach to that used previously. Conventionally, the radial roll gap is smoothly controlled to achieve a target rate of ring diameter growth. In variable wall thickness rolling, the roll gap must change dynamically to accommodate differences in thickness around the circumference whilst also reducing the overall mean ring thickness as the diameter grows.

An outline of the approach is shown in Fig. 5. The target shape and initial preform are defined first. The target shape (which would in principle include a machining allowance) is specified as a final thickness distribution around the circumference, and the ring has a constant, specified, midline radius. The process controller then calculates a target thickness for each current material point around the circumference, assuming that volume is conserved during deformation, that plane rectangular sections remain plane and rectangular and that there is no axial flow. If the material behaves as expected then the final radius and thickness distribution will be as intended.

A schedule of planned reduction is required. Early trials highlighted three main problems. The first was complete slipping of the forming roll. In Section 4.1 it is shown that this can be avoided if rates of thickness change in the target ring are constrained and the reduction per pass is limited. Secondly, if the reduction is too small then the rolls lose contact with the ring – this is avoided by imposing a minimum reduction, set to achieve the yield strain through the thickness. Finally, circularity can be compromised if the forming of the thickest sections completes ahead of the rest of the ring; therefore the strain was scheduled so that the deformation at all points around the circumference is completed after the same number of passes.

To cope with disturbances in incoming ring thickness and avoid violating process limits the controller is designed to track a schedule of through-thickness strain rather than exit thickness. The actual duration of processing is therefore set by the controller and may exceed the targeted number of revolutions.

In early trials without axial or guide rolls the variable thickness rings lost circularity regardless of reduction scheduling. This is unlike conventional rolling and is analysed in Section 4.2 where it is shown that use and control of axial rolls can improve circularity. The forming roll speed and axial roll gap are both set to be constant throughout the process.

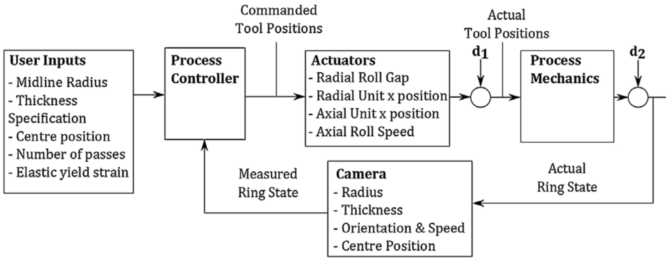

Fig. 5. Block diagram of variable thickness controller.

3. Demonstration of the new method in two test cases

More than 50 trials have been conducted with the process; of which two test cases are described to demonstrate the method.

3.1. Demonstration part specifications

The demonstration parts are shown in Fig. 6; the first part is representative of the middle ring of a triple ring eccentric bearing, requiring a gradual change in thickness around an approximately-circular ring midline. Thickness strain varies from -0.14 to -0.52. The second product is a ring with a single radial boss of boss arc angle, $\beta = 5^\circ$, that is 58% thicker than the main circular ring. There are two transition regions over arc angle $\alpha = 20^\circ$. The thickness strain varies from -0.05 to -0.51.

3.2. Results of controlled process

The final ring shapes are shown in Fig. 7. The main features of both parts clearly resemble the design in Fig. 6.

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