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Incremental profile ring rolling with axial and circumferential constraints

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ABSTRACT

If profile ring rolling could be achieved without part-specific tooling, significant savings in material, energy and downstream processing could be realised. One approach, 'incremental ring rolling' previously suffered difficulties controlling material flow, resulting in multiple form errors. Inspired by studying an expert using a potter's wheel, two additions to this process are proposed; the use of axial and circumferential constraints. A 12-axis ring rolling machine has been built to demonstrate these process enhancements, producing metal rings up to 1 m in diameter. The production of both rectangular and L-shape rings is examined, showing significant improvements in ring cross-sectional form and circularity.

1. Introduction

Rolled rings are used in annular components in aerospace, oil and gas, electricity generation and other industrial sectors, often with shaped, or 'profiled', cross-sections (Fig. 1a).

In the typical ring rolling process, a pierced preform prepared by open-die forging is rolled in a machine between two pairs of tools acting on the radial and axial surfaces of the ring. Currently the only way to produce profiled rings such as railway wheels or aerospace casings is to use shaped tooling (Fig. 1b). This is costly; the shape of the preform must be designed, shaped tooling for both rolling (often multistage) and forging must be produced. Frequently, rectangular cross-section rings are produced instead and the final shape is cut away (Fig. 1c). The aim of this work is to create profiled rings without part-specific tooling to either reduce tooling costs or save material and other inputs.

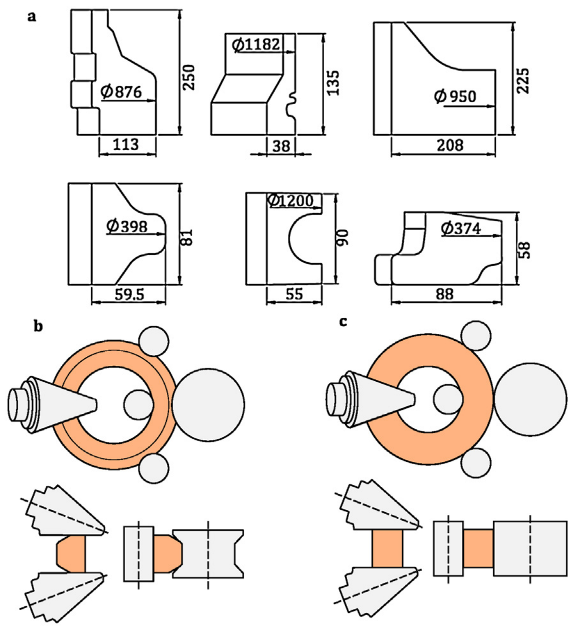

Fig. 1. (a) Profile ring half sections from Marczinski in mm [1]; (b) profile ring rolling to produce shaped ring; (c) plain ring rolling.

Incremental profile ring rolling (IRR) was previously proposed as a way to produce profiled rings with a single tool-set albeit with an initially more complex machine [2]. To generate an inner profile by IRR a short vertically moving inner radial tool is used to reduce the wall thickness of the ring by different amounts along its axial height (Fig. 2a). Equivalently, an outer profile shape could be generated with a short outer radial tool.

IRR was studied at IBF, RWTH Aachen, Germany, firstly on an experimental wax ring rolling machine [3]. The results in Fig. 2b show that whilst it is possible to create a difference in ring thickness along the height, the resulting rings suffer from conicity and dishing defects driven by non-uniform circumferential extension. Similar

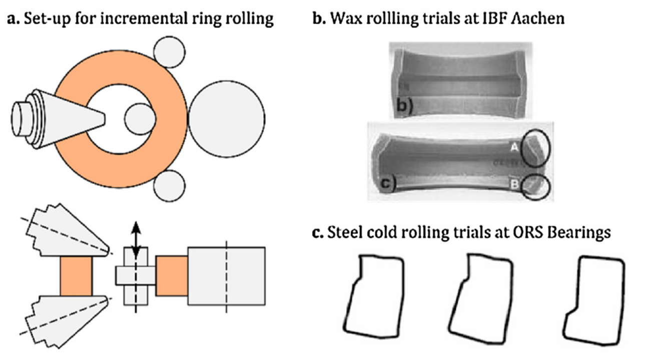

Fig. 2. (a) Set up for incremental ring rolling, (b) results of trials in wax [3], (c) results of trials in bearing steel [2].

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results were obtained on trials on cold-rolled steel rings carried out at ORS Bearings, Turkey, as shown in Fig. 2c [2]. These defects are so large that there is little or no material saving and to date the incremental ring rolling process has not been taken up.

2. Concepts for increased flow control in IRR

To overcome these difficulties increased control over material flow seems necessary; two ways to achieve this are discussed.

One way is to achieve shaping by axial displacement of material, leading to an increase in workpiece height. This is similar to both axial profile tube forming in which a short tool acts on a large tubular workpiece which restricts circumferential flow and also pottery throwing, in which the workpiece rotates on a potter's wheel and a craftsperson 'lifts' and shapes the side walls.

Numerous trials were carried out on the University of Cambridge model rolling machine – machine described in Ref. [4] – using modelling clay. Two novel set-ups are highlighted here: the first uses a set of constraining rolls around the ring added to the basic incremental ring rolling set-up—Fig. 3b. The second is like the potter's wheel; the ring is fixed at its base onto a rotating platen and passes between radial tools as shown in Fig. 3c.

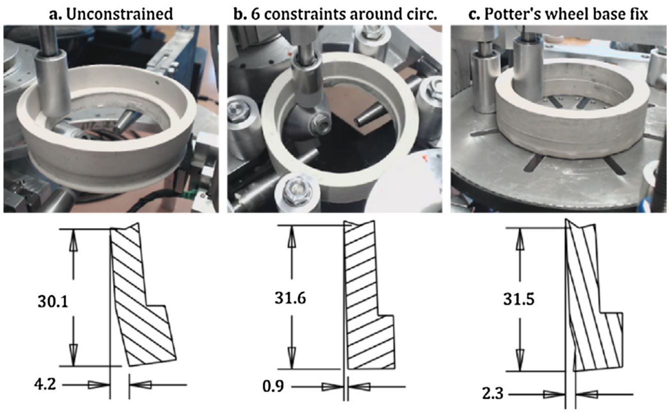

Fig. 3. Shaping by increasing the ring height: preliminary clay trials.

The effect of these constraining features was studied on the creation of many ring shapes; three key results are shown in Fig. 3. In each, an L-shape ring is made by reducing the upper region wall thickness by 40% whilst the lower region was undeformed. With the conventional unconstrained set-up the as-measured ring cross-section shows significant conicity and dishing but with both the additional circumferential constraints and the potter's wheel set-up, axial flow is greater and the conicity is much reduced.

A second shaping method is to create a change in thickness whilst the ring diameter also increases. In this, for compatibility, internal axial material flow is required from the thinnest into the thickest regions. Previous work suggested that such flow can be enhanced by using a 'closed' radial pass [5].

A novel set-up to achieve this was implemented on the model machine by using a pair of cylindrical axial rolls (Fig. 4b). This was trialled on the production of an L-shape ring in which both the upper region was reduced in thickness by 50% and the lower region was reduced in thickness but by only 25%. The results suggest that the novel set-up *can* enhance internal axial flow: a difference in thickness is achieved whilst the ring increases in diameter by 20%.

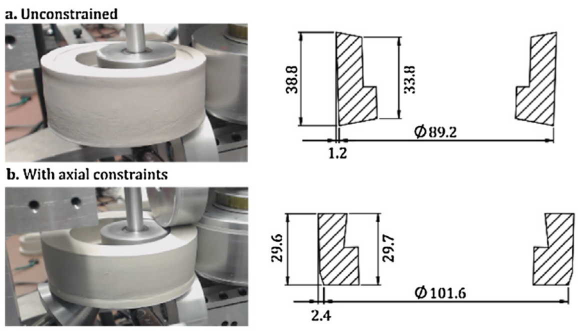

Fig. 4. Shaping whilst increasing the diameter: preliminary clay trials.

These physical trials on a model clay material give confidence about the kind of additional tooling that might be required to achieve predictable ring forms in incremental ring rolling.

3. New process and equipment for incremental ring rolling

To investigate a selection of these concepts on an industrially relevant scale and material, new equipment was commissioned.

The chosen tool arrangement combines the axial and circumferential constraint concepts. There are four overlapping working tools in a novel 'combined radial and axial stage' and six constraint rolls around the ring circumference. Plain radial-axial ring rolling (Fig. 5a) can be achieved by rotating the outer radial tool and reducing the radial and axial roll gaps. Inner and outer incremental rolling (e.g. Fig. 5b) is enabled by vertical motion of the inner and outer tool respectively.

The 12-axis machine was designed and commissioned as shown in Fig. 6 with radial force and axial force capacity of 55 kN and 45 kN respectively, and maximum main roll torque of 1800 Nm. This was estimated to be sufficient to process lead rings with maximum wall thickness and height 52 and 78 mm, and pure aluminium (1050-H6) rings up to 21 and 32 mm, as justified next.

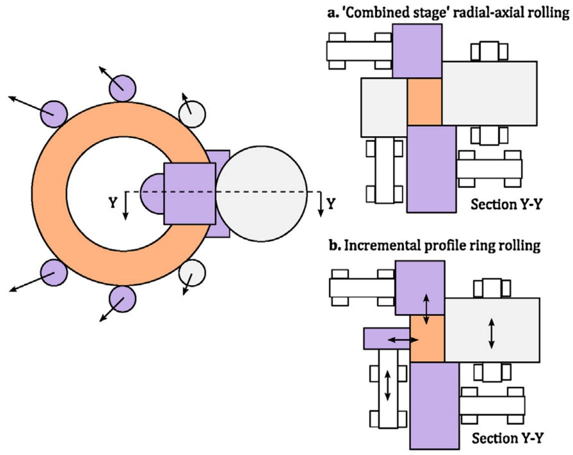

Fig. 5. Concept for ring rolling with flexible axial and circumferential constraints. (a) Plain ring rolling, (b) inner incremental profile rolling [6].

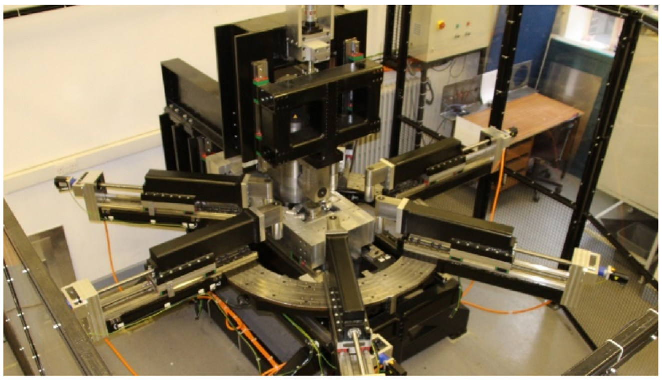

Fig. 6. Constrained incremental rolling research machine.

3.1. Force and torque in 'combined stage' radial-axial rolling

The four-roll 'combined stage' arrangement is unique and its effect on roll force and torques was unknown. As a brief aside, the analytical estimate used for sizing the machine is now compared to experimental results on lead rings.