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Towards a steady forming condition for radial–axial ring rolling

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A R T I C L E I N F O

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A B S T R A C T

Radial-axial ring rolling (RARR) is a typical incremental forming process with high flexibility. It is difficult but essential to establish a successful RARR process and remain its stability by properly designing process variables. This paper is an attempt to develop a steady forming condition under which the RARR process can be established successfully and then proceeds stably with qualified ring rolled parts. For remaining process stability by alleviating dynamic contacts and collisions between the ring and the rolls, constant growth velocity condition (CGVC) of the ring is proposed as a design objective of the process variables. Then a mathematical model of the steady forming condition for RARR is developed based on the CGVC. The model describes both the mathematic correlations and the reasonable ranges of key process variables of RARR, and the application and role of the model are illustrated by a case study in detail. For verifying the steady forming condition for RARR, FE simulations and analyses are carried out through developing reliable 3D-FE models for the entire RARR processes under ABAQUS/Explicit platform. The simulation results show that the designed processes based on the mathematical model of the steady forming condition are successfully operated and have good stability. A value of the growth velocity of the ring, which is close to the median of its reasonable range determined by the steady forming condition, is recommended for the design of the process by taking into account the geometry of the rolled ring, material plastic deformation behavior of the ring and process stability.

1. Introduction

Ring rolling is a near net shape part rolling process widely used to manufacture various quality seamless ring-shaped parts, such as bearing races, ring gears, aero-engine casing, nuclear reactors parts and various connecting flanges, due to the most important advantages of the favorable grain flow and good surface quality of the rolled rings [1,2]. Until now, the ring rolling technology has evolved over 150 years. Allwood et al. [3,4] reviewed the contributions of 174 papers by a thorough survey of work on ring rolling published in the English and Germany languages by 2004. Many studies on the ring rolling technology have been carried out by many researchers through experiment, theoretical analysis or numerical simulation. Johnson et al. [5–7] carried out earlier experimental works on the roll forces, plastic hinge and an experimental single mandrel ring-rolling mill. Hawkyard et al. [8] reported a theoretical prediction for the roll force and torque during ring rolling between plain cylindrical rolls, and examined the prediction accuracy by experimental measurements of roll force and torque. Mamalis et al. [9,10] investigated the cavity formation and spread and flow patterns by rolling plain and profiled (T-shaped) rings experimentally. Lugora and Bramley [11] analyzed the spread in plain ring rolling using Hill's general method of analysis. Hahn and Yang [12,13] reported the UBET analysis for roll torque and deformation patterns of profiled ring rolling. Yan et al. [14] built a mathematical model for planning the feed speed in cold ring rolling. Yang and Kim [15] and Yang et al. [16] simulated the plane strain and T-section profile ring rolling processes by rigid-plastic finite element method. Kim et al. [17] reported a finite element code 'RING' which was developed for the three-dimensional deformation analysis of ring rolling. Davey and Ward [18,19] presented an ALE approach for finite element ring-rolling simulation to save computational cost. Based on the finite element method, Kang and Kobayashi [20] and Joun et al. [21] carried out the studies on preform design in ring rolling using the backward tracing scheme and an axisymmetric forging approach, respectively. Forouzan et al. [22,23] proposed a new method (thermal spokes) to simulate the guide roll effect in FE analysis of the ring rolling process. Moon et al. [24] predicted the polygonal-shaped defects during hot ring rolling using a rigid-viscoplastic finite element method. Casotto et al. [25] presented a thermo-mechanical-metallurgical numerical model to predict geometrical distortions

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