Journal of Materials Processing Technology 213 (2013) 1258–1267

Contents lists available at SciVerse ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

An advanced manufacturing method for thick-wall and deep-groove ring—Combined ring rolling

Dongsheng Qian, Zhiqiang Zhang, Lin Hua*

School of Materials Science and Engineering, Wuhan University of Technology, Wuhan 430070, China

ARTICLE INFO

Article history:
Received 27 March 2012
Received in revised form 22 January 2013
Accepted 27 January 2013
Available online 4 February 2013

Keywords:
Manufacturing
Ring
Combined ring rolling
Plastic forming
FE simulation

ABSTRACT

Ring parts like duplicate gear, double-side flange and high pressure value body, are widely used in engineering machinery, which have the common geometrical characteristic of thick-wall, small-hole and deep-groove on the surface. The conventional manufacturing technology for this kind of ring is simple forging with cutting, which has the disadvantageous of high energy and material consumption, low material productivity and poor performance. In this paper, a new manufacturing method for this kind of ring named combined ring rolling (CRR) is firstly proposed based on the minimum resistance principle in metal plastic forming and its forming principle is introduced. Then, the reasonable ranges for key forming parameters of CRR are determined, the FE modeling and simulation analysis and experiment study for the CRR process with a double-side flange ring are performed. By this work, the CRR technique is testified feasible, and the basic thermo-mechanical deformation rules in CRR process are revealed based on simulation with the valid FE model proved by the experiment.

1. Introduction

Ring is the basic mechanical component, which has wide application in many industry fields such as machine tool, automobile, railway, energy and aviation. As a rotary forming technology, ring rolling is an advanced manufacturing technique for various seamless rings like bearing ring, flange ring and gear ring, which can obtain high performance ring with accurate geometry and good microstructure by continuous local plastic deformation. Aiming ring rolling technique, many studies have been performed on the aspects of theory, technology, mold and equipment using various methods like analytical analysis (Lugora and Bramley, 1987) and experimental test (Johnson and Needham, 1968). Sufficient information on ring rolling technology and previous researches can be observed in the reviews carried out by Allwood et al. (2005a,b) which present a thorough survey of work on ring rolling published by 2004, including the evolution of design of ring rolling equipment, the methods used to investigate the process, the gained insights and developments in the control and operation of the process. Especially for application of ring rolled products and equipment configurations, these two papers made the systematic description, which was instructional and helpful to develop other novel rolling configurations.

Different finite element modeling methods have been explored to research the rolling process. Joun et al. (1998) presented an axisymmetric rigid–viscoplastic finite element method to predict the deformation of material in ring rolling. A hybrid mesh technique was used by Lim et al. (1998) with an elastic–plastic finite-element method to simulate ring rolling. Utsunomiya et al. (2002) investigated the cold ring rolling process by a conventional implicit elastic–plastic finite element method on a non-steady-state scheme. Song et al. (2002) established a coupled thermo-mechanical 2D FE model of the deformation processes occurring during the hot rolling of IN718 rings. Yea et al. (2003) predicted spread, pressure distribution and roll force in ring rolling process using a commercial rigid-plastic FEM. Wang et al. (2006) realized the elastic–plastic dynamic approach instead of the static implicit approach is adopted to solve the hot ring rolling process so as to greatly improve computational efficiency.

Regarding the control of technological parameters during ring rolling process, some studies have been researched on many aspects. Szabo and Dittrich (1996) described a state-of-the-art manufacturing systems for the production of seamless-rolled rings. Forouzan et al. (2003a,b) proposed thermal spokes method to simulate the guide roll effect in FE analysis of the ring rolling process. Guo and Yang (2006) found the effect of size of forming rolls on cold ring rolling investigated by 3D dynamic explicit FEM. Li et al. (2008) explored the hydraulic adjustment mechanism in 3D-FE ring rolling model and proposed the key technological parameter design of the hydraulic ram. Yang et al. (2008) studied size effects of rectangular-section blanks on the uniformity of strain and

* Corresponding author. Tel.: +86 27 87168391; fax: +86 27 87168391.
E-mail address: bestcx@yahoo.com.cn (L. Hua).

0924-0136/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jmatprotec.2013.01.024

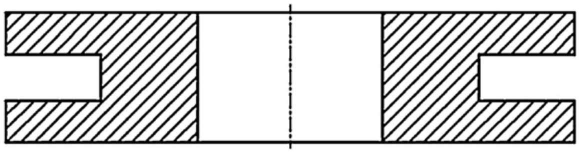

Fig. 1. Small bore ring with thick wall and deep groove.

temperature distributions during hot ring rolling of titanium alloy large rings. These works have revealed the forming mechanism and deformation rules of ring rolling effectively, and promoted the development and application of ring rolling technique.

Some studies have been done aiming at profile ring rolling. Allwood et al. (2005a) summarized the range of profiles and cross-section including radial profiles, thin section rings and thick section rings, but radial profiles with thick section was not introduced. Mamalis et al. (1975) found that for certain values of feed-rate, groove and shape factor, a specific form of cavity formation arises when rolling T-shaped rings at large reductions of ring wall thickness. Yang et al. (1991) simulated the open pass profile ring rolling of a T-shaped section from an initially rectangular cross-section using 3D rigid-plastic FEM. Hahn and Yang (1994) proposed the upper-bound elemental technique (UBET) for prediction of the torque and the deformation pattern during the ring-rolling of rings having arbitrarily shaped profiles. Davey and Ward (2002) developed a model comprising the finite element flow formulation, an ALE update strategy, and a novel iterative solution scheme called the successive preconditioned conjugate gradient method to analyze the profiled ring rolling. The rolling process of profile ring with a round groove located asymmetrically on the outside was analyzed by Kim et al. (2007) using FEM of MSC.SuperForm and experiment. Hua et al. (2009) established a FE model of plastic penetration in L-section profile cold ring rolling to research the expanding rules of plastic zone in roll gap.

Through comprehensive analysis of the research results and investigation on the actual production, it can be known that, ring rolling technique is more suitable for manufacturing the rings with simple cross-section shape and thin wall, as they are easy to be formed in ring rolling process. While, for some rings with complex section shapes, its effect is unfavorable. This is because the difference between the metal circumferential flow and radial flow in ring rolling process always results in the inconformity between the diameter enlarging and the profile forming, thus the required diameter dimension and cross-section shape cannot be obtained simultaneously.

The ring shown in Fig. 1 has following geometrical characteristic: thick wall, small bore and deep groove on surface. The ring parts like duplicate gear, double-side flange, high pressure value body which are widely used in engineering machinery have the similar geometry feature as above ring, which can be described as the thick-wall and deep-groove ring. At present, this kind of ring is manufactured by simple forging and cutting. Take a double-side flange for example, in its manufacturing process, the hammer forging is firstly used to simply form the surface groove, then, much cutting is used to obtain the required cross-section, as shown in Fig. 2. High energy and material consumption, low material productivity and poor performance exist in the conventional manufacturing technologies of these rings. In the engineering design, this kind of ring should be avoided unless it can be manufactured simply and effectively. So, it is necessary to develop a new advanced manufacturing technology to manufacture the thick-wall and deep-groove ring.

Allwood (2007) presented a “periodic table” of 102 “elemental” ring rolling machines. It can be seen that the constraint type of above ring is similar to number 71 in I-0. However, this ring does not suit to be manufactured by general ring rolling because its deep groove cannot shape when its diameter reaching to the certain size. For general ring rolling, the rolling ratio can be described as follows:

$$\lambda = \frac{H_0}{H} \tag{1}$$

where λ is the rolling ratio of general ring rolling, H_0 and H are the radial thickness of the blank and rolled ring, respectively, as shown in Fig. 2.

In order to establish the stable rolling process, the following rolling condition must be satisfied (Hua et al., 2001):

$$\Delta h \le \Delta h_{\max} = \frac{2\beta^2 R_1}{(1+R_1/R_2)^2}\left(1+\frac{R_1}{R_2}+\frac{R_1}{R_t}-\frac{R_1}{r_t}\right) \tag{2}$$

$$\Delta h \ge \Delta h_{\min} = 6.55\times 10^{-3} R_1\left(\frac{R_t}{R_1}-\frac{r_t}{R_1}\right)^2\left(1+\frac{R_1}{R_2}+\frac{R_1}{R_t}-\frac{R_1}{r_t}\right) \tag{3}$$

where Δh is the feed amount per revolution, $\Delta h_{\max}$ and $\Delta h_{\min}$ are the maximum and minimum values of Δh, respectively, β is the friction angle between the rolls and ring, R_1 and R_2 are the radii of the maximum size of the main roll and mandrel, respectively, R_t and r_t are the external and inner radius of the rolling ring, respectively.

It can be known that the established condition for Eqs. (2) and (3) is that,

$$\Delta h_{\max} \ge \Delta h_{\min} \tag{4}$$

According to Eqs. (1) and (4), by derivation, it can be obtained:

$$\lambda \le \frac{17.5\beta R_1}{(1+R_1/R_2)H} \tag{5}$$

From Eq. (5), it can also be known that for rolling with thick-wall and deep-groove ring, the rolling ratio should be small in order to satisfy the rolling condition, because the larger the rolling ratio, the greater the thickness of ring blank, and the rolling condition may not be satisfied.

By analysis, the problem for rolling with thick-wall and deep-groove ring can be found that because the metal flow along circumferential direction is dominant in ring rolling process, thus the diameter enlarging is faster than the groove shaping, and the deep groove cannot be formed completely with the small rolling ratio when the required diameter dimension is obtained. So, controlling of the metal circumferential flow is the key for rolling with thick-wall and deep-groove ring.

In this paper, a new manufacturing method for the thick-wall and deep-groove ring named combined ring rolling (CRR) is firstly proposed. The reasonable ranges for key forming parameters, FE

Fig. 2. Conventional manufacturing process of these rings.