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Set-up of radial–axial ring-rolling process: Process worksheet and ring geometry expansion prediction

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ABSTRACT

This papers aims to give an answer to the problem of set-up for a cylindrical ring rolling process, giving the possibility to determine stable kinematic conditions for the key variables of the process (such as mandrel feeding speed, main roll rotational speed, etc.) and also to estimate the dimension of the initial blank used to obtain the desired final ring, minimising scrap material.

The set-up of a manufacturing process is usually a tedious and time-consuming activity, which is largely based on the experience of the process planner. Every process presents a typical process parameters window where the set up can be arranged by the planner according to the limits due to the available machine (working volume, geometry of the tools, maximum loads, etc.) as well as to the properties of the manufactured component (material, structure, forming temperature, rheology, etc.). The general target for the planner is to produce the component, which satisfies the specifications of the designer, with the shortest time cycle and with the available machines and tools. The process planner tries to perform this commitment adopting a trial and error procedure, where he modifies the process parameters and initial blank geometry in order to find a feasible setup of the process. If this approach is directly applied in the production plant, it results to be extremely expensive, time consuming and can generate a large quantity of scrap parts. The adoption of a numerical approach based on FE simulation can be helpful because it removes the trial and error experimentation from the real production plant to its virtualization inside a CAE environment.

In the case of ring rolling process the virtualization of the process is not so straightforward due to intrinsic complexity of the kinematics of the rolling mill where different tools should be moved with different laws and the plastic deformation of the ring occurs in a really 3D volume, which cannot be reduced to a simplified model as axial symmetric, plane strain or plane stress. For these reasons, the FE model is complex in terms of kinematics of the tools and discretisation of the ring volume (mesh). Moreover, this numerical problem pertains to the high not linear problems where coupled thermo-mechanical analysis is required. In this case, the computational effort increases considerably and results in a computational time of few days in a 4-cores computer for one simulation.

Collecting rules suggested by the literature and by the practice, introducing some improvements in the model of the ring rolling process and organising them in a worksheet it is possible to provide to the process planner an analytical-numerical tool where he can check rapidly different setups of the process in terms of kinematics of the rolling mill, evolution of the ring geometry, required forces, etc. The present paper focused on the first two targets remarked just above.

The choice of a constant mandrel feeding speed, as suggested in the literature, aiming to satisfy both initial and final ring dimensions, is too strict and in some practical cases cannot be accomplished. Hence, the authors suggest choosing a linear variable motion law for the feeding mandrel speed between the initial and the final condition in order to satisfy all the requirements necessary for the stability of the process.

In addition to that, an analytical method is proposed in order to forecast the evolution of the kinematic key parameters during the ring rolling, including the forecast of the number of rounds necessary for the complete forming of the ring. The analytical procedure has been tested through FE simulations which have confirmed the estimations of the theoretical model, showing that the theoretical frame is suitable for the design of a rolling process for small, medium and large rings.

The purpose is to give a full set of equations for setting up and controlling the ring-rolling process and to foresee the evolution of the main geometrical variables of the ring during its expansion. The

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proposed worksheet offers process planners and engineers a useful starting-point from which to reduce the required amount of FE simulation needed to forecast the process and to simulate it using a previously screened range for all key process parameters.

1. Introduction

Radial–axial ring rolling (RARR) is a metal-forming process for manufacturing seamless annular forgings, which are accurately dimensioned and have circumferential grain flow [1]. This technology has wide applications in machinery, metallurgy, aerospace, etc. because of its low cycle time, high-energy efficiency, low material waste and favourable grain orientation [5]. A schematic illustration of a radial–axial ring-rolling mill is shown in Fig. 1.

The RARR process is characterised by complex coupled thermo-mechanical deformation behaviour that must be taken into consideration and that strongly influences the forming quality. The thickness and height of the initial blank are plastically deformed and reduced, at the same time but in opposite sections, resulting in a reduction of the ring section area and consequent enlargement of the ring diameter. Regarding the procedure through which to determine blank dimension, Qian et al. [11,12] developed an algorithm for the determination of the dimensions of the blank, but this procedure presents difficulties in the definition of the ratio between final cross section and initial cross section of the ring, which is a fundamental parameter for the determination of the initial annular blank. Moreover Zhou et al. [13] investigated the thermo-mechanical coupling in radial–axial ring rolling process regarding strain distribution and temperature. Zhou et al. [10] also compared the results of FE simulation with experimental data, showing good accordance; however, a mathematical algorithm able to forecast ring geometry evolution without the need of FE simulation seems not available in the literature.

As indicated by Hua and Zhao [2], the extreme parameter in ring rolling can be derived from the extreme drafts, which also affect the extreme feeding speed. Mandrel feeding speed and upper axial roll-feeding speed should satisfy the relation suggested by Keeton, who defined a hyperbolic relationship between the height and the thickness of the ring [3].

Hua and Zhao [2] first determined rules for identifying the range of acceptable parameters required to avoid instability in the process by adopting a kinematic approach. Yan et al. [4] subsequently presented a method for planning the feed speed of the mandrel in the case of simple radial ring rolling without any reduction of the height, neglecting the feeding speed of the upper axial roll. Moreover, Zhou et al. [6] defined a way to calculate the range for both mandrel and upper axial roll feeding speed but, in order to simplify the problem by choosing a constant feeding speed of the mandrel, they restricted the range of suitable velocities and adopted a mandrel feeding speed included in the interval between the maximum of the minimum values and the minimum of the maximum values, kept constant during the whole ring-rolling process. Their suggestion is a conservative one and for some ring geometry configurations, it cannot be satisfied, as is subsequently explained in this paper.

Considering thickness draft, two conditions must be taken into consideration during the whole ring-rolling process. The first is related to the maximum achievable draft, over which the ring stops the rotation, because of slip between the main roll and the mandrel; in this case, the friction is not high enough to pull the material through the roll gap. The second is given by the minimum draft required for plastic deformation along the whole thickness, in order to ensure ring expansion. The same considerations can be observed for the upper axial roll-feeding speed, which must respect the same kind of conditions applied to the reduction of height in order to avoid interruption of ring rotation and to guarantee plastic deformation along the whole height of the ring.

In this paper, the range of acceptable parameters is defined for both radial and axial movements at the beginning and at the end of the ring-rolling process; the mandrel feeding speed is a linearly varying parameter between a value that satisfies the initial configuration and a value that satisfies the final one. Adopting Keeton's rule [3], the initial and final speed for the upper axial roll are calculated and compared with the corresponding ranges at the beginning and at the end of the process.

If the calculated values are within the defined ranges, the adopted solution can be considered as suitable. If not, a new set for mandrel speed should be defined and verified. From a kinematic perspective this solution is feasible, but should be checked in terms of required forces and torques as well as defects such as spreading, fishtail effect, etc. To this end, the FE simulation of the ring-rolling process is a straightforward approach to verifying the process design as well as optimising it, as shown in [9], but the required computational effort is high, and therefore a reduction of the ranges for input parameters for the FE simulation will result in a reduction of the time taken to reach the optimal final solution.

Moreover, in this paper, the geometric evolution of the ring is not estimated in terms of diameter and thickness averaged during one ring rotation but rather considers a finite number of intervals into which the ring is divided and where the main key variables are estimated. Nevertheless, the algorithm takes into consideration separately the deformation in thickness and the deformation in height: because of the intrinsic configuration of the ring-rolling mill, these deformations occur, at each instant of the process, in two different sections of the ring separated by 180°. The electronic worksheet operates in real time and allows exploration of different combinations of kinematic process parameters, providing the process designer with a preliminary estimation of ring geometry evolution and the duration of the rolling process. Based on these results, the FE model can be rapidly set up and the FE simulation can be executed in order to check forces, torques or forming defects. Small, medium and large ring simulations have been carried out with the software Simufact.Forming 12 in order to

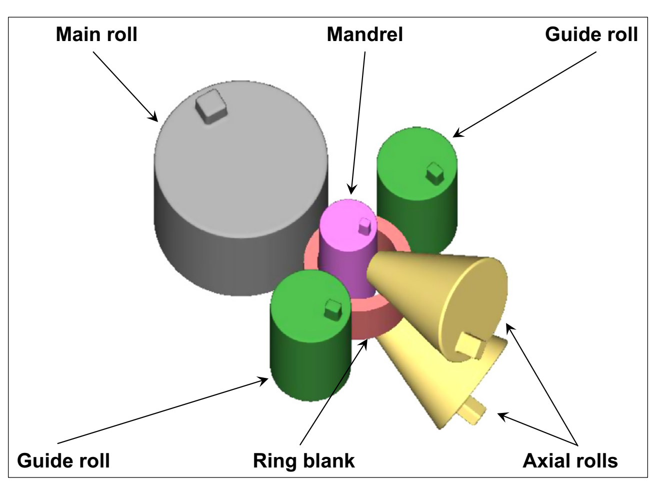

Fig. 1. Schematic illustration of radial–axial ring-rolling mill.