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A Dynamic Model for Simulation of Hot Radial Forging Process

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Abstract

A comprehensive dynamic process model has been developed to investigate features of the inherently transient hot radial forging process, taking account of complex process kinematics, thermo-elastoplastic material behaviour and microstructural evolution. As an input to this model, a fully systematic thermomechanical testing matrix was carried out on a Gleeble 3800 including temperature (20-1100 °C), strain (up to a true strain of 1) and strain rates (from 0.1 to >50 s^{-1}). The proposed model can accurately capture vibration characteristics due to the high frequency short strokes during radial forging, which have been found to have a strong effect on material flow, forging load. Numerical analyses were performed to investigate the effect of different axial spring stiffnesses on forging load, strain distribution in the workpiece, and maximum axial feeding rate. It has been found that forging load increases significantly with increasing stiffness of the axial spring. The axial spring stiffness was also found to have a strong effect on determination of axial feeding rate and reduction ratio of workpiece by limiting the axial vibration amplitude of workpiece under the maximum compression of spring coil to avoid hard stop of workpiece in the axial direction during forging. It has been found that the spring stiffness does not have a strong effect on the strain distribution in the work piece. For practical application, the proposed model is applied to simulate the manufacturing process of a hollow transmission shaft using a GFM SKK10/R machine. Simulation results based on a 3 dimensional framework provide a detailed insight of material flow, residual stress and grain size evolution during the multiple pass radial forging process and the results are compared with available experimental measurements. The results provide valuable insights for process design.

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1. Introduction

Radial forging is an open-die forging process utilizing radially moving dies for reducing the diameters of ingots, bar, rods, and tubes for production of tubular components with different internal and external profiles. The process is fully automated and has good reliability to produce high integrity forgings with tight tolerance, smooth surface, improved mechanical properties at relatively high production rates and low cost. These bring extensive application potentials in aerospace, automotive, and oil and gas industries. Establishing the radial forging procedure is still an expensive and time consuming process based on trial and error, since a number of parameters such as workpiece temperature, rotational speed, feed rate, die geometry, oscillation speed and amplitude etc. need to be determined and optimised to meet stringent requirement of structure and mechanical properties. Recent development on process modelling on radial forging using finite element analysis has been proven to be an accurate approach to improve understanding of the process[1–3].

The challenge of modelling and simulation of the radial forging process is the large number of short and high frequency strokes around the work pieces, which makes the simulation of radial forging process excessively time consuming. With the assumption of predominant radial and axial material flow during the process, radial forging simulation were usually performed in simplified axisymmetric two-dimensional (2D) analysis. The simplified axisymmetric model allows parametric study of effects of different process parameters on material flow [3], and strain heterogeneity [4]. However these 2D models do not fully account for the rotational feed of the billet, and circumferential effect of the forging process. To fully understand the various aspects of hot radial forging process, a 3D model needs to be developed. A symmetric 3D model was developed by Ghaei and Movahhedy [5] to investigate the die design for the radial forging process neglecting the rotational feed of billet. Rong et al. [6] and Chen et al. [7] developed a coupled thermomechanical full 3D FE model to consider the circumferential effect in radial forging process, however simulation was performed only for a short period of actual process time due to the excessively long computation time, which is difficult to reflect the all the characteristics of radial forging process. Another challenge in modelling and simulation of the radial forging` process is the complex process kinematics due to the inherently high frequency of vibration. In previous modelling approaches, a prescribed time dependent velocity or displacement boundary conditions for the gripper cannot capture the correct vibration characteristics of the actual process.

In the present work, a comprehensive 3D dynamic model is proposed to address the above challenges. The main contribution of this paper is to take account of full process kinematics of radial forging by including the axial spring in the process model and investigate the dynamic vibration effect on various aspects of radial forging. Another contribution is the attempt made to predict grain size evolution in 3D radial forging simulation.

Nomenclature

A	die oscillation amplitude (mm)	l	die displacement in radial direction (mm)
D_0	initial grain size (µm)	R	universal gas constant (JK^{-1}mol^{-1})
D_d	recrystallized grain size (µm)	T	absolute temperature (K)
f	die oscillation frequency (Hz)	v	die axial feeding rate (mm/s)
k	axial spring stiffness (N/mm)	α	die angle (degree)

2. Modelling Approach

A schematic of the radial forging process is shown in Fig. 1. The workpiece is fixed by a gripper and deformed by 4 radially oscillating dies through high frequency short-strokes. After each stroke, the gripper rotates for a specific angle to obtain a good surface finish of workpiece. To prevent twisting of the workpiece, a high oscillating system is applied to the gripper to interrupt rotation during stoke. After each stroke the workpiece is fed axially towards the hammer die at a specific rate. To stabilize the hammer/workpiece interaction an axial spring bar is connected to the gripper, which allows the workpiece to move in axial direction during stokes. This coordinative