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Numerical simulation and experiments of precision bar cutting based on high speed and restrained state

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ABSTRACT

According to the disadvantages of conventional bar cutting technology such as low-cutting speed, inferior section quality, high-processing cost and so on, a kind of novel precision bar cutting technology has been proposed. The cutting mechanism has also been analyzed. Finite element numerical simulation of the bar cutting process under different working conditions has been carried out with DEFORM. The stress and strain fields at different cutting speed and the variation curves of the cutting force and appropriate cutting parameters have been obtained. Scanning electron microscopy analysis of the cutting surface showed that the finite-element simulation result is correct and better cutting quality can be obtained with the developed bar cutting technology and equipment based on high speed and restrained state.

1. Introduction

Bar cutting is the first and important procedure in metal-forming processing. The quality of bar cutting has a direct influence on the quality of products and economic benefits. Conventional bar cutting technology has many disadvantages such as worse surface quality, lower productivity and waste of materials, which seriously restrict the development of precision forming technologies. Bar cutting process and deforming of materials in the cutting process is very complicated, and the quality of the cutting surface is affected by many factors such as cutting speed and temperature, restrained state, clearances of dies and types of materials. In recent years, many research on bar cutting technology and devices has been carried out by scholars of different countries, and some achievements has been obtained [1–3]. But up to now, there is still no sufficiently effective cutting technology and machine available in production.

In this paper, a novel advanced high-speed precision bar cutting technology is proposed. The cutting mechanism has been analyzed and a new type of high-speed precision bar cutting machine has been developed. The influence of process parameters on the quality of the cutting surface has been studied with combined methods of finite-element method (FEM) numerical simulation and experimental study. Appropriate cutting parameters and better cutting effects have been obtained.

2. Analysis of the bar cutting mechanism based on high speed and restrained state

During the cutting process, while the materials are in a three directional compression stress state of pure shearing, brittle fracture is liable to occur. Therefore, in this paper, radial clamping method has been adopted, so that the end of the bar and the stock can be clamped at the same time and pure shearing deformation can be realized. The precision bar cutting process based on high speed and restrained state is realized between the cutting die moving at a high speed and the fixed clamping die, as shown in Fig. 1. The moving cutting die driven by the slide moves down at a high speed and cuts the material, the lower clamping die follows down and produces a clamping force F_1 in the upward direction by which the cut material can be clamped. Simultaneously, the upper clamping die produces another clamping force F_2 and the delivered materials can be clamped between the upper clamping die and the fixed cutting die. In the cutting process, the bar material can be divided into three deformation areas, i.e. the violent deformation area I, the plastic deforming area II and the stiffness area III, among which the violent deformation area I is the most important. The stress state of the materials and the deformation process in this area has a direct influence on the quality of the cutting surface.

The cutting process can be divided into three steps [4]: elastic and plastic deforming, crackle generation, fracture expanding and destabilization. According to the theory of fracture mechanics, in conventional precision cutting process, the crackle tip radius in

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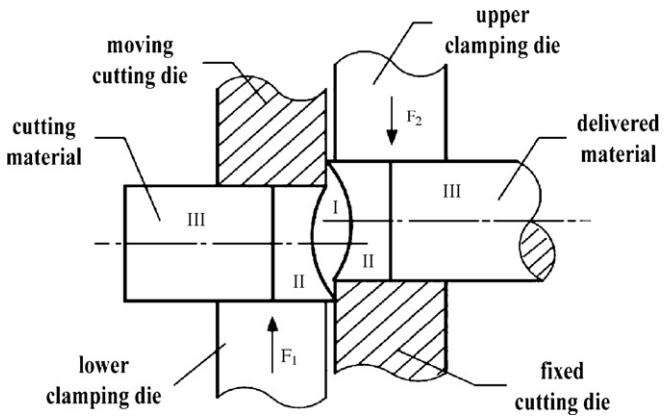

Fig. 1. Principle of the cutting process and deforming of the materials.

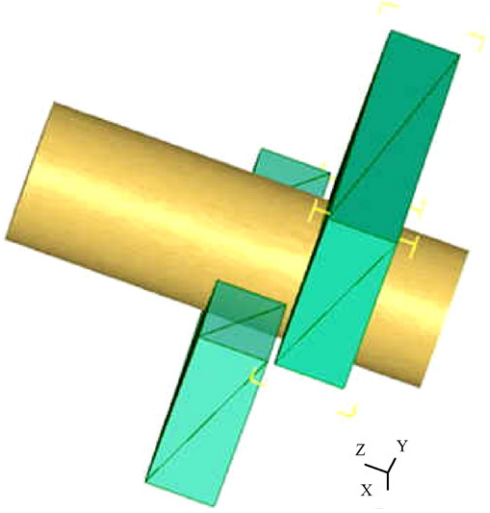

Fig. 2. Simulation model of the cutting process.

plastic area can be expressed as

$$r = \frac{3}{2\pi}\left(\frac{K_{II}}{\sigma_s}\right)^2 \quad (1)$$

while in the process of high-speed precision cutting under restrained state, materials in area I is in a three-dimensional compression stress state. The crackle tip radius can be shown as follows:

$$r = \frac{3}{4\pi}\left(\frac{K_{II}}{\sigma_s}\right)^2 \quad (2)$$

It can be seen form Eqs. (1) and (2) that the radius of plastic area at high speed and restrained state is 50% of that in common cutting process. At the action of the clamping force, the cutting area is in a plane strain state and the resisting force of crackle generation has been reduced. At the same time, with the increasing of the deforming rate, the brittleness of the materials has been improved, cracking can be fully propagated toward the neighbouring area, and tearing phenomena of the cutting centre has been greatly decreased. Therefore, the crackle of the materials in high speed and restrained state cracks smoothly and better quality of the cutting surface can be obtained.

3. Numerical simulation of high-speed bar cutting

The quality of the cutting surface is influenced by many factors such as cutting speed, material temperature, restrained state,

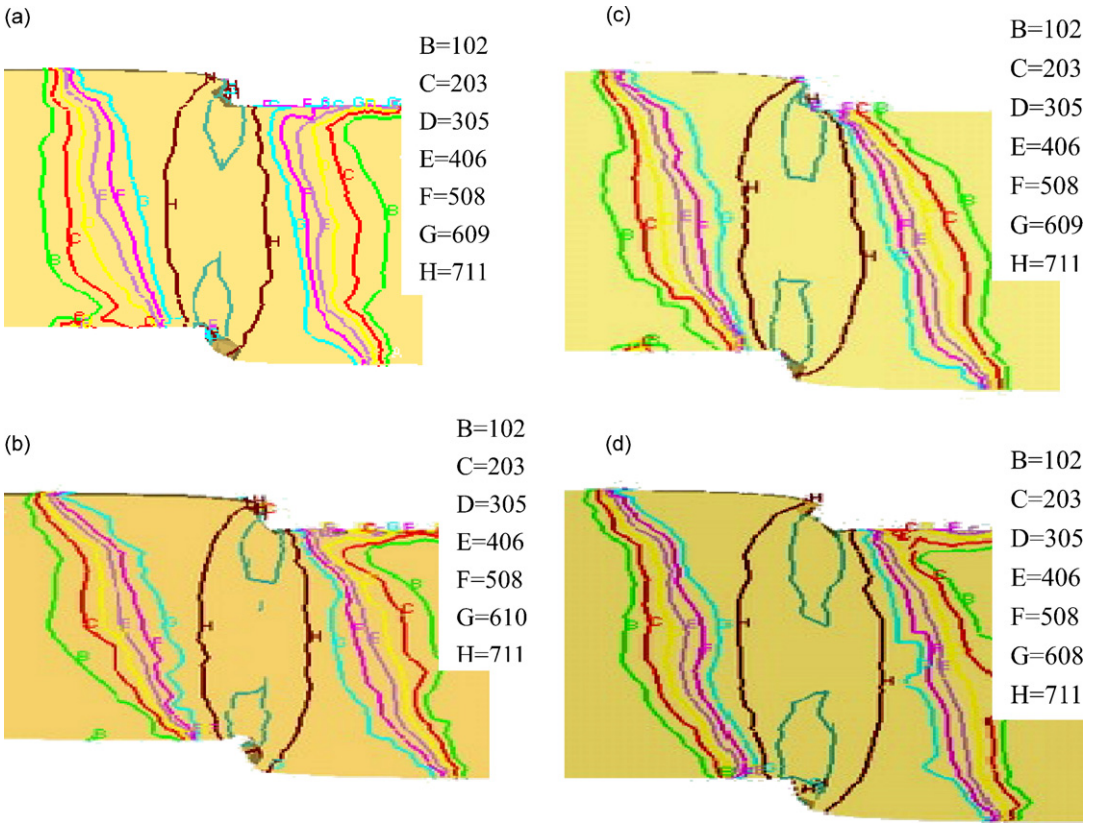

Fig. 3. Equivalent stress field of step 30 at different cutting speed (a) 1 mm/s; (b) 5 mm/s; (c) 7 mm/s and (d) 12 mm/s.