International Journal of Mechanical Sciences 76 (2013) 144–151

Contents lists available at ScienceDirect

International Journal of Mechanical Sciences

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

Investigation on the influences of clearance and notch-sensitivity on a new type of metal-bar non-chip fine-cropping system

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ARTICLE INFO

Article history:
Received 3 August 2013
Received in revised form
5 September 2013
Accepted 13 September 2013
Available online 2 October 2013

Keywords:
Non-chip fine-cropping
Clearance
Ductile damage
Stress triaxiality
Equivalent critical fracture strain

ABSTRACT

The aim of the present paper is to study the influences of the clearance and the notch-sensitivity on a new type of metal-bar non-chip fine-cropping system by combining the ductile damage initiation criterion, the fatigue crack propagation path analysis and the micrograph fractography observation. The single factor test method and the orthogonal test method are both applied to the numerical simulations and the corresponding non-chip fine-cropping experiments. The comparative numerical results show that the ductile damage initiation criterion is obviously influenced by the clearance and the notch geometric parameters. The corresponding cropping experiments are carried out and achieve a good agreement with the simulation results. And some other interesting results, which are useful for practical fine-cropping, are also obtained.

1. Introduction

Metal-bar fine-cropping process, which separates the workpiece into segmented accurate billets and products by large cold plastic deformation, is the first and one of the most important metal cold forming procedures in manufacturing industries [1,2]. The traditional cropping methods (e.g. common shearing, sawing and cutting), which are still widely employed in manufacturing industries for their convenience, more or less have some deficiencies such as low material utilization rate, short tool life, bad cross-section quality, and low productivity [3,4].

It is well known that the plastic strain is the quantitative applied to evaluate the magnitude of the deformation. Besides, many researchers [9–12] discovered that the ductile damage of metal strongly depends on the stress triaxiality η. Rice and Tracey [9] firstly theoretically applied the stress triaxiality into the ductile enlargement of voids. Mirza et al. [10] studied the qualitative relationship between the equivalent critical fracture strain ε_f and η in high positive stress triaxiality region by using the experiments and the numerical simulations. Bao et al. [11,12] extended the range of η $(-1/3-0.95)$ through series of experiments.

However, there are a limited number of literatures concerning the metal-bar fine-cropping process although the fine-cropping method has been continuously researched. Chan er al. [6] reviewed and studied the shearing behavior between fine-blanking and bar-cropping by experimental comparisons. They compared some characteristic parameters (e.g. surface finish, hardness distribution, clearance and portion of fracture) based on a cross-section quality measurement system called 'Figures of Merit' firstly proposed by Organ and Mellor [7]. Zhang et al. [5] proposed a new type of low-stress fine-cropping system with variable frequency vibration and studied the influence on the ratio of the maximum tension stress to the maximum shear stress on the bar clamping position. After then, Tang et al. [8] improved the vibration cropping system and proposed a novel type of fine-cropping system by using the rotary striking action. However, the cropping process is still a time-consuming process though the fine-cropping method can guarantee a better cross-section quality than the traditional ones. Furthermore, in order to obtain a shorter final cropping time, further investigations of the fundamental mechanism should be carried out.

The present paper presents an investigation on the influences of the clearance and the notch-sensitivity during the non-chip fine-cropping process. A simplified model is established on the commercial finite-element (FE) code ABAQUS/explicit platform [13]. The influences of the clearance and the notch-sensitivity are studied in detail by combining the ductile damage initiation criterion (DUCTCRT), the equivalent plastic strain (PEEQ), the stress triaxiality η, two new comparative parameters (the damaged rate ω_D and the mean damage D_{mean}), the fatigue crack propagation path analysis and the micrograph fractography observation. Finally, the corresponding non-chip fine-cropping experiments are carried out to verify the numerical simulation results. And some interesting results and other comparisons are obtained.

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0020-7403/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.ijmecsci.2013.09.019

2. The working principle of the new fine-cropping machine

The schematic diagram of the working principle of the new fine-cropping system and the definition of the geometric parameters are shown in Fig. 1(a)–(c). C1 and C2 are respectively the clearance between the metal bar and the clamping die and the clearance between the metal bar and the bar sleeve. L and D are the length and the diameter of the cropped-billet. L1 is the distance between the right edge of the clamping die and the V-shaped circular groove bottom. L2 is the distance between the left edge of the bar sleeve and the V-shaped circular groove bottom. H is the length of the bar sleeve. R, θ and h are the fillet radius, the flare-angle and the depth of the V-shaped circular groove, respectively.

The original notion of the new cropping system comes from the reciprocating bending breakage of the iron wire and the mechanical radial-forging machine. The new cropping system mainly consists of four parts, namely the hydraulic power unit, the actuator part, the clamping device and the electrical control system. While a slotted metal bar is fed into the clamping die and fixed in the metal bar fixed position as shown in Fig. 1(c), the clamping die clamps the slotted bar. The hydraulic power unit operates and supplies a steady flow of high pressure oil to the actuator part through the hydraulic pipe and the piston cylinder in and out repeatedly. Then, the actuator part, which is composed of six piston cylinders and six cropping hammers, operates in a certain order according to the switch of the corresponding electromagnetic valve controlled by the electrical control system. The electrical control system, which mainly consists of a programmable logic controller and an industrial personal computer, controls the whole cropping system. Simultaneously, the circumferential equivalent displacement load, which is produced by the contact impact between the cropping hammer and the bar sleeve, is simply represented in Fig. 1 (a) by using six parallel arrows. The bar sleeve is back to the in situ by the hyper-elastic polyurethane sleeve after every impact. With the continuous supply of oil, the material in the vicinity of the V-shaped circular groove comes into different stress states while the stress wave transmits over the groove. The criterion for damage initiation is met when the cumulative equivalent plastic strain reaches the critical fracture strain. The damage propagates steadily along the cross-section until the ligament reaches the critical carrying capacity. Finally, the final instant-rupture takes place and the metal-bar is cropped thoroughly.

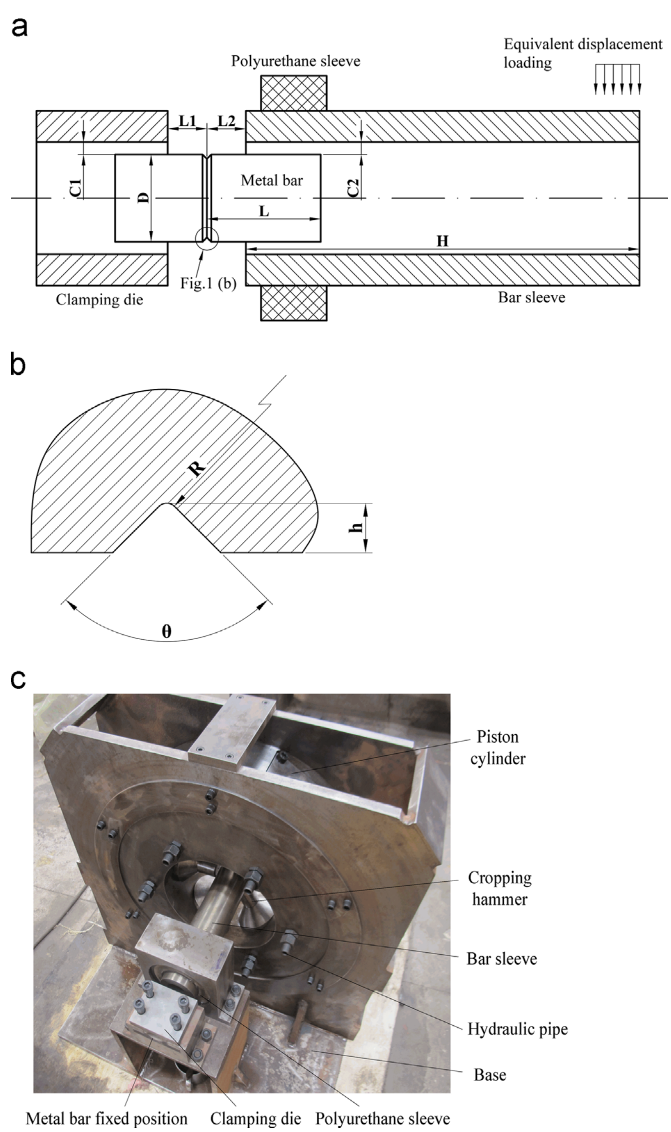

Fig. 1. The schematic diagram of the working principle of the new cropping system and the definition of the geometric parameters: (a) the clamping device of the new cropping machine (b) the partial enlarged drawing of the V-shaped groove and (c) the close-up photo of the cropping system.

3. The finite-element model of the new cropping system

3.1. Definition of the stress state and ductile fracture

Most of the phenomenological fracture models assume that the equivalent critical fracture strain ε_f is a function of the stress state (i.e. stress triaxiality η). The stress triaxiality η, which has been widely used in ductile fracture area, is a kind of quantitative representation of stress state [9,14–17]. The expression is defined by

$$\eta = -\frac{p}{q} \tag{1}$$

where p and q are respectively the pressure stress (mean stress) and the von Mises equivalent stress, in which

$$p = -\frac{(\sigma_1+\sigma_2+\sigma_3)}{3} \tag{2}$$

$$q = \sqrt{\frac{1}{2}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_1-\sigma_3)^2\right]} \tag{3}$$

where, $\sigma_i (i=1,2,3)$ is the principle stress. Generally, for a linear load path, the function $\varepsilon_f(\eta)$ can be used directly as a ductile fracture criterion. However, there are few linear load paths in practical applications. For a nonlinear load path, an integral ductile fracture criterion is necessary. The criterion for ductile fracture initiation is met when the following expression is satisfied

$$D = \int_{\mathrm{PEEQ}} \frac{d\varepsilon_{eq}|_{\eta_t}}{\varepsilon_f|_{\eta_t}} = 1 \tag{4}$$

where D is a state variable increases monotonically with the plastic deformation. $d\varepsilon_{eq}|_{\eta_t}$ and $\varepsilon_f|_{\eta_t}$ represent the increment of the equivalent plastic strain and the equivalent critical fracture strain at η_t.

3.2. Details of the FE simulation model

According to the working principle of the new cropping system, a three-dimensional FE model is established on the commercial FE code ABAQUS/Explicit platform. The global mesh generation of the simulation model is shown in Fig. 2(a). In order to improve the