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Experimental research and numerical simulation of the dynamic cylinder upsetting

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ABSTRACT

In order to study the dynamic effects under impulsive load, experimental and numerical investigations on the dynamic upsetting process of lead cylinder were conducted. Experiments were carried out on a drop hammer impact test machine. The results show that the dynamic effects on the forming load is related to the hammer velocity, radius–height ratio of specimen and drop mass. The forming load increases with the increase of the hammer velocity or radius-to-height ratio. The fluctuation of load–displacement curve becomes obvious with the increase of the hammer velocity and drop mass. The deformation processes were simulated by the finite element program ANSYS/LS-DYNA. The deformed configuration, velocity vector field and equivalent strain distribution were obtained. The results show that the deformed geometry exhibits mushroom, the material points in the upper region flow faster than that in the lower region, and a strain concentration zone appears in the upper center region.

1. Introduction

Hammer forging is a dynamic deformation process, in which the workpiece is subjected to dynamic impact loading, and the dynamic characteristic of the deformation is obvious due to high hammer velocity [1,2]. According to the dynamic theory of solid, the material behavior under dynamic loading is different from that under static or quasi-static loading. The strain rate effect, inertial effect and stress wave propagation effect have an important effect on the metal deformation, which makes the analysis of dynamic deformation complex [3,4].

In order to investigate the deformation behavior of metal under high velocity impact, many researchers have studied the dynamic upsetting process using experimental and analytical methods. The results showed that the hammer velocity has a significant effect on the forming load, pressure distribution, etc. [5–8], and all of these effects were commonly termed the “dynamic effects” [9]. Tirosh adopted the upper bound and lower bound methods to research the sources and influencing factors of the dynamic effects. The obtained results showed that the degree of dynamic effects on the deformation process depended on the five important factors: characteristic velocity, characteristic acceleration, geometry factor of specimen, mass density and yield stress of material. For the cylindrical upsetting process, characteristic velocity and acceleration were die velocity and acceleration, respectively, and geometry factor of specimen was radius–height ratio of cylinder. When the first three factors kept constant, the dynamic effects became significant with the increase of the ratio of mass density to yield stress [5–7].

Owing to the inherent limitations, the experimental and analytical methods cannot give enough information about the deformation process, so the introduction of the finite element method (FEM) is necessary. In the present work, the dynamic cylinder upsetting processes are investigated with the experimental and finite element methods. The effects of hammer velocity, radius–height ratio of specimen and drop mass on the forming load are investigated. The flow rule of material points and the metal deformation law are analyzed by the velocity vector field and equivalent plastic strain distribution.

2. Experimental method and procedure

The dynamic upsetting tests were carried out on an Instron Dynaup 9250 HV drop hammer impact test machine, as shown in Fig. 1. The impactor and hammer ram are integrated as the drop part which can slide up and down freely along the guide rail in the range of 1 m. The drop mass can be varied by addition or removal of different sized weights-over the range of 4.5–46 kg. In order to confine the hammer displacement to control the maximal deformation of the specimen and protect the machine, there are two energy absorber bars at both sides of the anvil, which absorb the redundant kinetic energy after the deformation.

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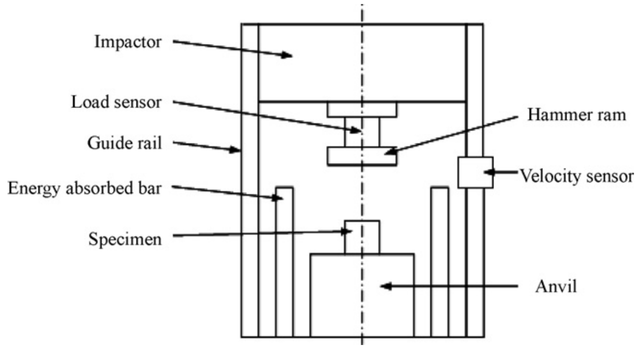

Fig. 1. Schematic diagram of drop hammer impact test machine.

The instantaneous velocity at the moment of impact can be set beforehand or measured by a velocity sensor. The load between the hammer ram and specimen is measured using a piezoelectric sensor. During the deformation, the hammer velocity, hammer displacement and deformation energy of the specimen are obtained through the data acquisition and processing system.

The dynamic effects of lead are obvious, and the material flow of lead specimen under low-velocity impact condition at the room temperature is very similar to that of steel specimen under high-velocity impact condition at the high temperature [9]. Therefore, industrial pure lead (99.994% Pb-1) is chosen as the test material of specimens. Its material property parameters are as follows: mass density is 11.34 g/cm^3, Young's modulus is 17,000 MPa, Poisson's ratio is 0.42.

At the beginning of an experiment, the two contact surfaces of the specimen are lubricated with animal oil. The specimen is placed on the anvil, and the axial centre lines of specimen and hammer ram are coincided. After that, the hammer is raised to a setting height according to the desired impact velocity and then drops down freely. The specimen deforms under drop hammer impact, and the deformation process is continued until the kinetic energy of the hammer is consumed by the deformation energy of specimen and the elastic energy of system components.

During the drop hammer impact test, the value of impact energy is decided by two independent variables of the impact velocity and drop mass. When the specimen dimension and the hammer velocity keep constant, the appropriate drop mass should be selected to make sure that most of the kinetic energy of the hammer is consumed by the deformation of specimen and the vibration of ground base is minimized.

3. Experimental results

3.1. Effect of hammer velocity

In order to study the effect of hammer velocity, dynamic upsetting tests were conducted under different hammer velocities at the ambient temperature. Cylinder specimens with a diameter and height each of 20 mm are used. The drop mass kept constant as 5.1 kg in all tests. And the hammer velocity was selected as 3 m/s, 4 m/s and 5m/s, respectively. The forming load-contact time and hammer displacement-contact time recordings were obtained during the experiments. The forming load–hammer displacement curves were derived from above results, as shown in Fig. 2.

The forming load–hammer displacement curves exhibit saw tooth oscillations, and the oscillation is more obvious at the initial stage. These are caused by the inertia force and stress wave propagation under high impact loading. The inertia force leads to the vibration of the specimen. The stress wave propagation makes the measured load curve oscillation. The large oscillation in the curve at the initial stage of deformation is the inertial peak which results from the inertia effect. With the increase of the hammer velocity, the slope of load–displacement curve and the inertial peak value rise simultaneously.

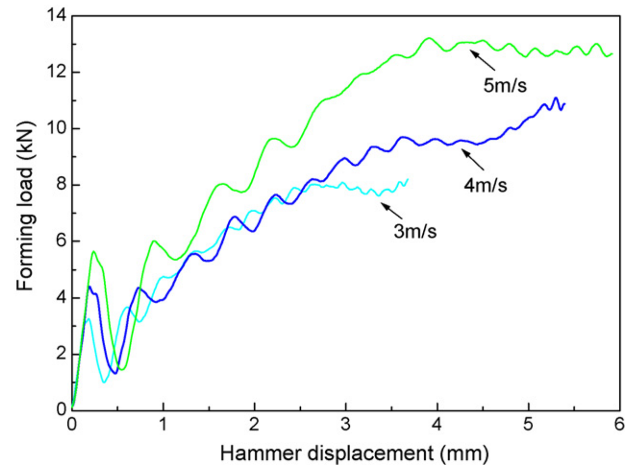

Fig. 2. The forming load–hammer displacement curves under three impact velocities.

3.2. Effect of radius-to-height ratio

In order to study the effect of radius-to-height ratio (R_0/H_0) on the relation curve between the forming load and hammer displacement, cylindrical specimens with a radius of 10 mm and R_0/H_0 ratio of 0.33, 0.5, 0.67 were chosen respectively. The tests were performed under the drop mass of 10.0 kg and the hammer velocity of 3.5 m/s. The results obtained are shown in Fig. 3.

It can be concluded from Fig. 3 that under the same drop mass and hammer velocity, the forming load increases with the increase of R_0/H_0 ratio. This can be explained as follows: the degree of dynamic effects on the forming load is dependent on the instantaneous radius to height ratio (R/H). During the dynamic upsetting of cylinder, the averaged pressure which is applied on the hammer surface can be expressed as follow [5]:

$$\frac{p_{\mathrm{av}}}{\sigma_0} = 1 + \frac{2}{3\sqrt{3}} m \left(\frac{R}{H}\right) + \frac{3}{16}\rho\frac{u_0^2}{\sigma_0}\left(\frac{R}{H}\right)^2 + \frac{1}{8}\rho\frac{R\dot{u}_0}{\sigma_0}\left(\frac{R}{H}\right) \quad (1)$$

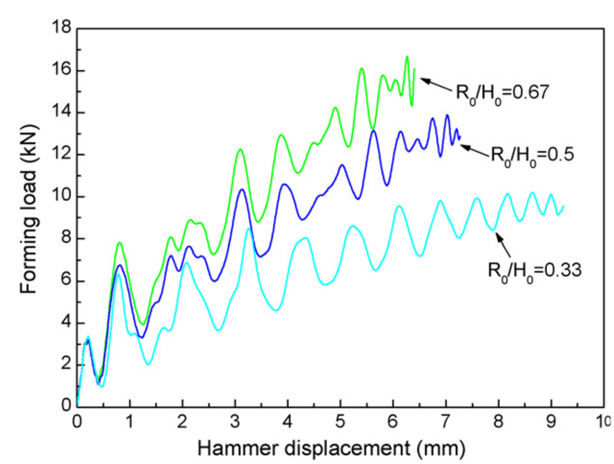

Fig. 3. The forming load–hammer displacement curves under three radius–height ratios.