Research Journal of Applied Sciences, Engineering and Technology 5(21): 5046-5050, 2013
DOI:10.19026/rjaset.5.4395
ISSN: 2040-7459; e-ISSN: 2040-7467
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Submitted: September 18, 2012 Accepted: November 08, 2012 Published: May 20, 2013

Research Article

The Dynamic Performance of Copper under Impact Loading

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Abstract: The incident wave and transmission wave varying with the time have been obtained by SHPB experiment. The relationship curve for stress and strain of material copper has also been obtained. The whole process has been numerical simulated by LSDYNA procedure. The results between the experiment and numerical simulation are accordance .It indicates that the dynamic constitutive equations can be researched by SHPB experiment with enough precision. With the primary gas gun, the dynamic properties of copper have been studied under high pressure. Hugoniot curve of metal materials have been obtained, which can be used to study the high-pressure equation of state. The parameters of the state equation have been obtained. The copper is often used to the dynamic test as the standard materials, so the dynamic performance of the copper self is so important.

Keywords: Dynamic, impact, shock wave, state equation copper

INTRODUCTION

In the dynamic test (Tarver *et al*., 1997, 1985; Urtiew *et al*., 1989; Bahl *et al*., 1985), the copper was as the standard materials. The dynamic performance measurement of Materials is the main application of SHPB and agas gun devices. The rate of SHPB test shells are usually 50 m/s below, While the gas gun for high-speed collisions. Using a long barrel, even if the primary gas shells can also be speed up to 1000 m/s or more.

SHPB experiments have been investigated by a number of scholars such as Shi-Sheng (2005) and Fang-Yun *et al*. (2006). The two postulated conditions which SHPB experiment is based on have been discussed .Many experiment techniques improved to test the special engineering materials such as foamed aluminium and concrete (Song and Hu, 2006; Shi-Sheng, 2005; Fang-Yun *et al*., 2006). The primary use of the SHPB experimental technique is the dynamic mechanical property test of materials. The whole process of the experiment are few numerical simulated in the last research with state equations. The whole process has been numerical simulated by LSDYNA procedure in this study. The incident wave and transmission wave varing with the time have been obtained by SHPB experiment. The relationship between the experiment and numerical simulation has been obtained. Earthquake Research Center of Guangzhou University, introduced a gas gun and SHPB equipments. In order to test the projectile velocity and the shock wave speed of the materials, self-made equipment is made to measure the pulse velocity. In this study, self-made pulse velocity equipment is used to the experiments of the gas gun .The impact adiabatic curves of copper have been obtained. The experimental precision is analyzed.

EXPERIMENTS

The incident bar, transmission bar and absorbing bar are all in range of elasticity with the typical SHPB experiment (Fig. 1). The samples tested have been impacted to the range of plastic nature .The state equation can be investigated via the SHPB experiment on the conditions with high load rate.

The stresses on the front face (σ_{s1} (t)) and back face (σ_{s2} (t)) of the sample varying with the time t have been compared by minishing the thickness of the samples and increasing the speeds of incident bar by Wu etc., in SHPB experiment. The investigation indicates that the difference between σ_{s1} (t) and σ_{s2} (t) depends on the thickness of the samples and the speeds of the impact bars. The effective inertias and transmissions have been analysed .There are few difference between the σ_{s1} (t) and σ_{s2} (t) in experiment to assure the homogeneous hypothesis by adopting the thin thickness of sample in this study. It too difficult to use resistance strain gauge to obtain the vivid signals of .The semiconductor strain gauges are used to get the vivid signals of transmission strain-pulse (Fig. 2).The equations ofσs1 (t) andσs2 (t) as:

$$\sigma_{s1}(t) = E\frac{A}{A_S}[\varepsilon_i(t) + \varepsilon_r(t)] \tag{1}$$

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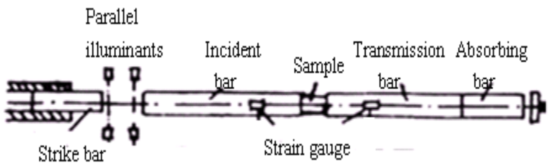

Fig. 1: Typical SHPB experimental device

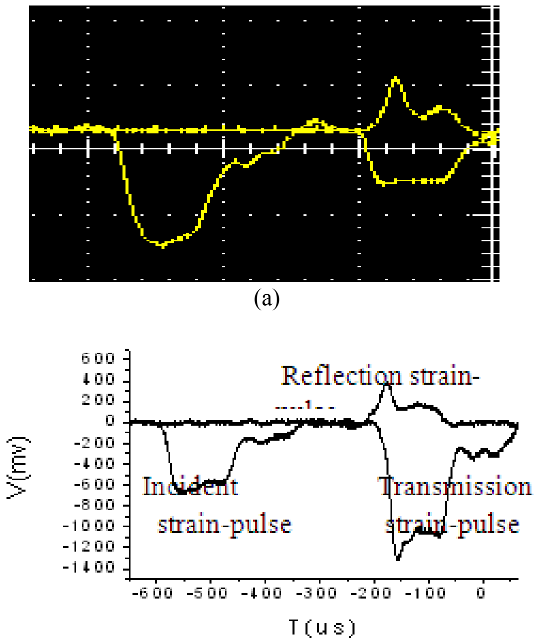

Fig. 2: The typical curves of experiment

$$\sigma_{s2}(t) = E\frac{A}{A_S}\varepsilon_t(t) \tag{2}$$

where,

- E = Young's module of compression bar
- A = Cross-sectional area of compression bar
- A_s = Cross-sectional area of the sample
- $\varepsilon_i(t)$ = The incident strain-pulse
- $\varepsilon_r(t)$ = The reflection strain-pulse
- $\varepsilon_t(t)$ = The transmission strain-pulse

The typical SHPB experiment technique is based on two hypothesis conditions.

One dimension stress wave in bar. Two stresses homogeneous distributes along the sample.

On the first hypothesis condition, average stress σ_{s2} (t) strain ratio ε_s(t) and strain ε_s(t) can be described as:

$$\sigma_s(t) = \frac{A}{2A_S}[\sigma_i(t) + \sigma_r(t) + \sigma_t(t)] \tag{3}$$

$$\varepsilon_s(t) = \frac{c_0}{L}(\int_0^t[\varepsilon_i(t) - \varepsilon_r(t) - \varepsilon_t(t)] \tag{4}$$

$$\dot{\varepsilon}_s(t) = \frac{c_0}{L}[\varepsilon_i(t) - \varepsilon_r(t) - \varepsilon_t(t)] \tag{5}$$

Fig. 3: Sample

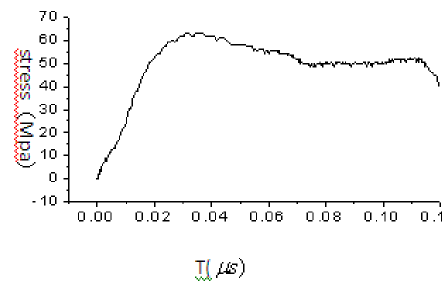

Fig. 4: The relationship curve for stress and strain

where,

- C_0 = Sonic speed
- L = The initial length of the sample

The second hypothesis condition can be described as:

$$\sigma_i + \sigma_r = \sigma_t, \varepsilon_i + \varepsilon_r = \varepsilon_t \tag{6}$$

Simultaneous system of equations:

$$\sigma_s(t) = \frac{EA}{A_s}(\varepsilon_t(t)) = \frac{EA}{A_s}[\varepsilon_i(t) + \varepsilon_r(t)] \tag{7}$$

$$\varepsilon_s(t) = -\frac{2c_0}{L}\int_0^t \varepsilon_r(t)dt = \frac{2c_0}{L}\int_0^t[\varepsilon_i(t) - \varepsilon_t(t)]dt \tag{8}$$

$$\dot{\varepsilon}_s(t) = \frac{2c_0}{L}[\varepsilon_i(t) - \varepsilon_t(t)] = -\frac{2c_0}{L}(\varepsilon_r(t)) \tag{9}$$

The dynamic mechanigal property can be obtained from equations (7), (8) with two known parameters of incident strain-pulse, reflection strain-pulse, transmission strain-pulse. Variable quantity time t is expurgated to get the dynamic cruve of stress and strain (Fig. 4) with high loading ratio. It is obvious that it is difficult to assure the homogeneous distributes hypothesis on high loading ratio conditions. The thin thickness must be adopted to assure the homogeneous distributes (10 mm thickness is adopted in the experiment) which has been proved by wu etc. Also, the homogeneous distributes can be checked by comparing the difference of σ_{s1} (t) and σ_{s2} (t).The typical experiment curve (Fig. 2) of copper (Fig. 3) and dynamic curve of stress and strain (Fig. 4) under high loading ratio are obtained in this study.

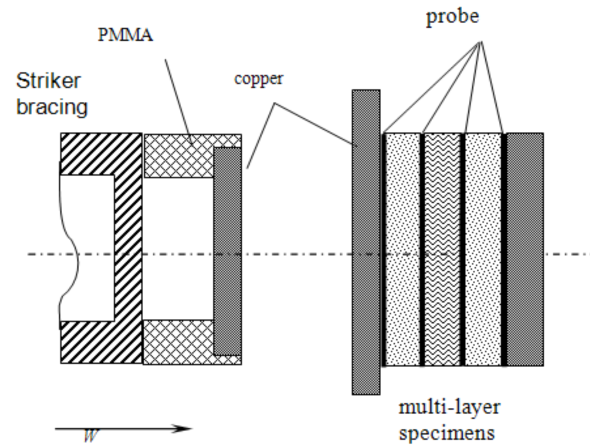

Fig. 5: Schematic diagram of the experiment

Symmetrical impact technology is used in the experiment, multi-layer specimen of copper is really just adopted a 37 thickness of 1cm. The probe measured the location of two time difference, so D = s/t. With the experimental results compared with the standard Hugoniot curve, the experimental error can be obtained. Schematic diagram of the experiment shown in Fig. 5.

The experiments were done on a light-gas gun. The product ID is GZDX-100-00.The light-gas gun caliber is 100 mm. The product type is the dynamic loading equipment. The valve can be open less than or equal 2 ms, the barrel length is 5.6 m, the projectile velocity range of 20 ~ 800m/s. The pilot installation and the installation is the following diagram:

Due to non-symmetric collisions, data processing is inconvenient and the curacy is not as symmetrical impact. The impact experiments are often adopted as symmetrical impact, that is, the speed of flyer each entry received after the shock wave particle velocity as follows:

$$U = 1/2u$$

where,
U = The mass-velocity
u = The projectile velocity

According to a flyer u and shock wave velocity D (two-position displacement and the difference of time to decide), most dense medium speed of shock wave velocity D and particle U is a linear relationship:

$$D = a + bU$$

Fitted through the discrete points can obtain the a and b values. The shock wave pressure P and particle velocity U has the following relationship:

$$P = \rho DU = \rho(a + bU)U$$

So the P-U Hugoniot curve can be obtained.

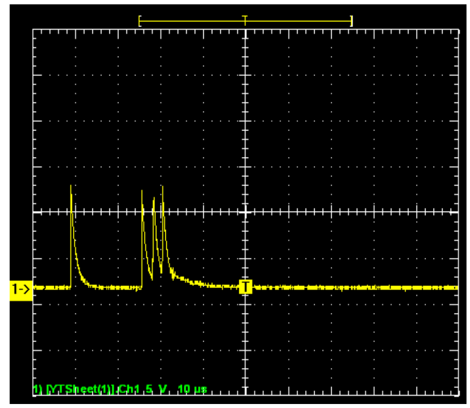

Fig. 6: The typical experimental record

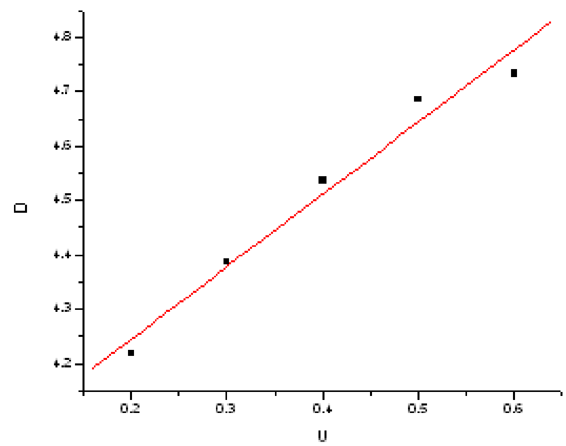

Fig. 7: D – U curve fitted

The typical experimental record is in the following diagram (Fig. 6).

Using actual u measurements to get the D1, compared with the D obtained with standard of A = 3.94 B = 1.489. Using the same methods to measure the different speed of impact, the different margin of errors are all obtained. The results show that the measure has a good accuracy. Fitting of the experiment, the D – μ are shown in Fig. 7.

D-U substituted into the mass conservation equation:

$$\rho_1(D_1 - u) = \rho_2(D_2 - u)$$

Are:

$$P = \frac{a^2(v_0 - v)}{(b-1)^2 v^2 [b/(b-1) - v_0/v]^2}$$

The P – μ curves can be calculated. Where μ is the body strain:

$$\mu = \frac{\rho}{\rho_0} - 1$$

Fig. 8: The model of finite element

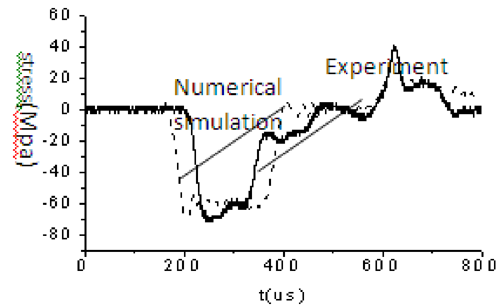

Fig. 9: The curves of incident wave and reflected wave

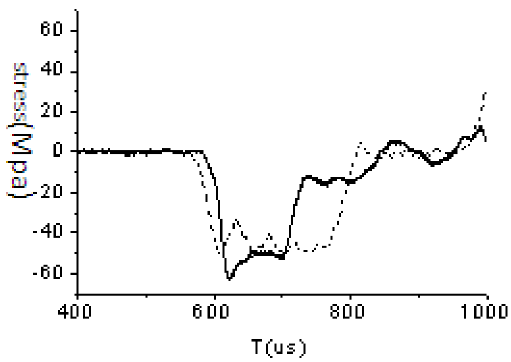

Fig. 10: The curves of transmission wave

The capacity of material change law usually use the polynomial form of Grüneisen equation which is state equation to describe its specific form:

$$P = A_1\mu + A_2\mu^2 + A_3\mu^3$$

Where A_1,A_2,A_3 are the fitting coefficients.
Fitting the equation can get the parameters:

$$A_1 = 62.23719 A_2 = -20.13218 A_3 = -27.7715$$

NUMERICAL SIMULATION

The state equations and constitutive equations of the medium are all selected in the numerical simulation .The precision of the numerical simulation depends on the validity and precision of the substance described.

The copper is defined with MAT_ ELASTIC _ PLASTIC_HYDRO_SPALL material. The pressure is defined as:

$$P = -\frac{1}{3}\sigma_{ij}\delta_{ij} \tag{10}$$

The Gruneisen state equation with cubic shock velocity-particle defines pressure for compressed material as:

$$p = \frac{\rho_0 C^2 \mu[1 + (1 - \frac{\gamma_0}{2})\mu - \frac{a}{2}\mu^2]}{[1 - (S_1 - 1)\mu + S_2\frac{\mu^2}{\mu + 1} - S_3\frac{\mu^3}{(\mu + 1)^2}]^2} + (\gamma_0 + a\mu)E \tag{11}$$

And for expanded material as:

$$p = \rho_0 C^2 \mu + (\gamma_0 + a\mu)E \tag{12}$$

where, C is intercept of u_s - u_P curve, S_1,S_2 and S_3 are the coefficients of the slope of the u_s - u_P curve, γ_0 is the Gruneisen gamma, α is the first order volume correction to γ_0 and $\mu = \rho / \rho_0 - 1$.

The whole process has been numerical simulated by ANSYS/LS-DYNA970 procedure. Qurter of the geometrical models are adoped in the model building because of the symmetrical character. Calculational time is saved. Constraits are applied to the plane of symmetry. SOLIDE164 elements are adoped with all the parts. The geometrical models are defined below (Fig. 8). The parameters of compress bar are ρ = 7850kg/m^3, E = 210GPα, u = 0.3. The results between the experiment and numerical simulation are accordance (Fig. 9 and 10). It indicates that the dynamic constitutive equations can be researched by SHPB experiment with enough precision.

CONCLUSION

- The incident wave and transmission wave varying with the time have been obtained by SHPB experiment. The curve of dynamic sress and strain of material copper has also been obtained in this study.
- The high-pressure state equation of copper is founded. The parameters of the state equation have been obtained.
- The whole process has been numerical simulated by LSDYNA procedure on three dimensions. The results between the experiment and numerical simulation are accordance .It is a new path to investigate the dynamic mechanigal property of materials. The results of measure and numerical simulation indicate that the semiconductor strain gauges can be used to get the vivid signals of the weak transmission strain-pulse.

ACKNOWLEDGMENT

This study was supported by the National Natural Science Foundation of China under Grant no. 51078094.

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