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Effect of the geometric shapes of specimens on impact tensile tests

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Abstract: The geometric shapes of specimens are important in impact tensile tests because geometric shapes determine the stress states of the specimens, and precise geometric shapes can obtain proper material properties without non-material factors. The aim of this study was to investigate the 1D form of the stress by changing the length-to-diameter (*L*/*D*) ratios of specimens. The experiments were carried out on a split Hopkinson tensile bar (SHTB)—rotating disk indirect bar-bar tensile impact apparatus. The *L*/*D* ratios of the LY12CZ specimens used in the test ranged from 1 to 5. Results show that the specimens can be used to obtain exact parameters of materials under the proposed conditions when the *L*/*D* ratio is greater than 2. This is because the longer length will reduce or eliminate the effects of the interfaces.

Key words: Impact tensile, Split Hopkinson tensile bar (SHTB), Length-to-diameter (*L*/*D*) ratios
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1 Introduction

Split Hopkinson tensile bars (SHTBs) are widely used to study the strain rate related tensile properties of materials. Various tensile impact apparatuses have been developed (Nicholas, 1981; Harding and Welsh, 1983; Staab and Gilat, 1991; Xia *et al.*, 1991; Haugou *et al.*, 2006; Raisch and Möginger, 2010). Each kind of apparatus has its own geometric specimen to meet the needs of a variety of materials, such as metals (Wang *et al.*, 2004), composites (Naik *et al.*, 2010), or polymers (Raisch and Möginger, 2010). The geometric shapes of the specimens of various apparatuses differ from each other, and can be classified into two categories: flat dumbbell connected by glue, or cylindrical dumbbell connected by glue or by screw thread.

Generally speaking, all the data obtained from the tests are structure responses. In a given condition, some of the data are material properties. The stress state of the specimen at every moment determines whether the data are material properties. For a given material, the stress state of the specimen is dependent only on the loading condition and geometric characteristics of the specimen. The geometric shapes of specimens are important for the tests, because precise geometric shapes can reduce or eliminate the effects of non-material factors (such as structural effects) from the test data. For SHTB tests, the design of the specimen is based on two principles. The first is that the stress in the specimen is uniform along its length, which requires the specimen to be short enough to neglect the stress wave's propagation. The second is that the stress is 1D, and this demands that the specimen is long enough to reduce the effect of the interface. To meet the demands of these two principles, the specimen must have an appropriate length for different geometric shapes.

Wang and Xia (1996; 2000) and Wang *et al.* (1999) studied the flat dumbbell specimen using a numeric method, and proposed a way to design specimens, but gave no concrete sizes. Staab and Gilat (1991) studied a cylindrical specimen glued by a screw thread in experiments, and concluded that the data were steady when the length-to-diameter (*L*/*D*) ratios were greater than 1.60.

However, the steady data may not reflect material properties, because any steady experimental system can produce steady data and the data may include some errors or structural factors. Most previous studies including Wang and Xia (1996; 2000), Wang *et al.* (1999) and Staab and Gilat (1991) focused on the uniformity principle and concentrated less on the 1D principle. For a tensile specimen, the stress state cannot totally be 1D because of the connecting interfaces. Researchers have tried to reduce the effect of the 3D stress on the test data by studying the size of the specimen. To investigate the effect of the second principle on experimental data, the geometric shapes of specimens with different *L*/*D* ratios were studied by experiment in this paper. The material of the specimen was LY12CZ.

2 Materials and methods

2.1 LY12CZ

LY12CZ is a kind of aluminum alloy, which is widely used in industry. The chemical composition is shown in Table 1. The mechanical properties of LY12CZ have been widely studied (Nicholas, 1981; Gao, 1994; Xu, 2002). The properties of LY12CZ are rate-independent, and the yield stress is about 330 MPa. So the change in test data depends only on the specimen size.

2.2 Split Hopkinson tensile bar equipment

The SHTB is a piece of equipment that can be used to study the dynamical tensile properties of materials. The equipment used in this study (Wang *et al.*, 1999) (Fig. 1) included hammers on a rotating-disk, a block, a short metal bar, a specimen, an input bar and an output bar. The incident wave induced by the fracture of the short metal bar transmits through the input bar, and arrives at the specimen, where it generates two waves: the reflected wave, which travels back to the input bar, and the transmitted wave, which runs across the specimen and spreads through the output bar. The waves can be detected by strain gauges on the bars. Under the action of these three waves, the specimen will produce deformation. The incident wave and the reflected wave are recorded by the strain gauge on the input bar, and the transmitted wave is recorded by another strain gauge. The strain gauge was a resistance strain gauge with a gauge factor of 2.17.

The equipment is based on the theory of 1D-stress-waves with the following hypothesis: the stress of the specimen is uniform and 1D. From the theory, the specimen stress, with the strain and the strain rate of the specimen, can be obtained from the strains of the bars:

$$\sigma(\tau) = \frac{EA}{A_2}\varepsilon_t(\tau), \tag{1}$$

$$\varepsilon(\tau) = \frac{2C_0}{l}\int_0^\tau [\varepsilon_i(\xi) - \varepsilon_t(\xi)]\mathrm{d}\xi, \tag{2}$$

$$\dot{\varepsilon}(\tau) = \frac{2C_0}{l}[\varepsilon_i(\tau) - \varepsilon_t(\tau)], \tag{3}$$

where σ, $\varepsilon(\tau)$ and $\dot{\varepsilon}(\tau)$ are the stress, the strain and the strain rate of the specimen, respectively, ε_i and ε_t are the strain of the incident wave and the transmitted

Table 1 Chemical composition of LY12cz (%, w/w)

Ti	Si	Mn	Mg	Fe	Cr	Zn	Ti+Zr	Al	Cu
≤0.15	≤0.50	0.30–0.90	1.2–1.8	0.000–0.500	≤0.10	≤0.25	≤0.20	Remnant	3.8–4.9

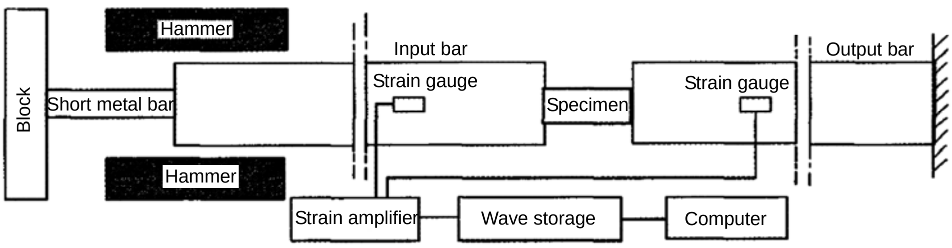

Fig. 1 Schematic diagram of split Hopkinson tensile bars

wave, respectively, A_2 and l are the cross-sectional area and the length of the specimen, respectively, and E, A and C_0 are the elastic modulus, the cross-sectional area and the stress wave velocity of the bars, respectively.

2.3 Specimen

The specimen was a cylindrical dumbbell (Fig. 2) connected by a screw thread. During the tests, only the length (L) was changed to study its influence on the test data. The L/D ratios were 5, 2.67, 2 and 1 with different lengths.

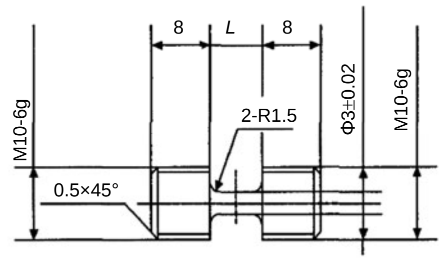

Fig. 2 Sketch map of specimen (unit: mm)

3 Results

3.1 Original waves

The original waves obtained by the strain gauges are shown in Fig. 3. The breadth of the incident wave was 368 μs, and the rising time of the incident wave was 68 μs. During the rising time, the stress wave came and went 5 times when the L/D was 5, because the specimen's elastic stress wave velocity was about 5 km/s. So the stress along the length became uniform. Thus, the specimen with the longest length in this study satisfied the first principle which demands that the length is sufficiently short. We then investigated whether the specimen met the second principle with the change in the L/D ratio.

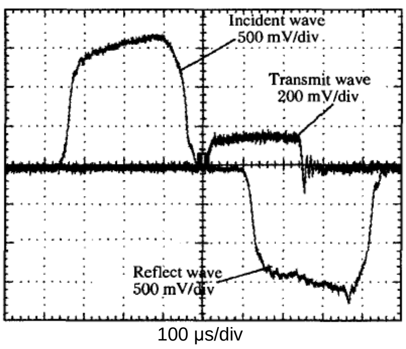

Fig. 3 Original waves obtained by the strain gauges

3.2 Stress-strain curves and strain rate-time curves

Stress-strain curves and strain rate-time curves are shown in Fig. 4. To study the dispersion degree and reduce the test errors, every strain rate experiment consisted of three tests. For every L/D ratio, experiments with two strain rates were carried out to study whether the test data were rate-dependent.

Figs. 4a–4d show that the yield stress was about 330 MPa regardless of the variation in the strain rates, and the elastic modulus was rate-independent when ratios were 5 and 2.67. When ratios were 2 and 1, the yield stress was greater than 330 MPa, and the elastic modulus was rate-dependent.

4 Discussion

From the experiments, it can be concluded that the data are material data without the effects of non-material factors when $L/D>2$. This conclusion is based on the following results: first, the initial yield stress of every strain rate is 330 MPa, which is consistent with the data of previous studies (Nicholas, 1981; Gao, 1994; Xu, 2002). Second, the curves of different strain rates match well (Fig. 5), which shows that the data is geometrical and rate-independent.

When the L/D ratio was 2, the data were stable and well matched, but they were not material data (Fig. 4e). This is because the initial yield stress is 400 MPa, which is greater than that of previous studies (330 MPa, Fig. 5). Thus, stable data may not be material data.

When the L/D ratio was 1 (Fig. 4c), the stress-strain curves were not well matched because of affection between the specimen and the connecting interfaces. With the shorter length, the stress state along the length of the specimen became more 3D. The affection was greater when the L/D ratio was smaller. The same affection acted on the strain-rate curves. Thus, the larger L/D ratio was more stable for the material tests.

5 Conclusions

Based on the theory of 1D stress waves, the following conclusions can be drawn:

1. The criteria for material tests were satisfied

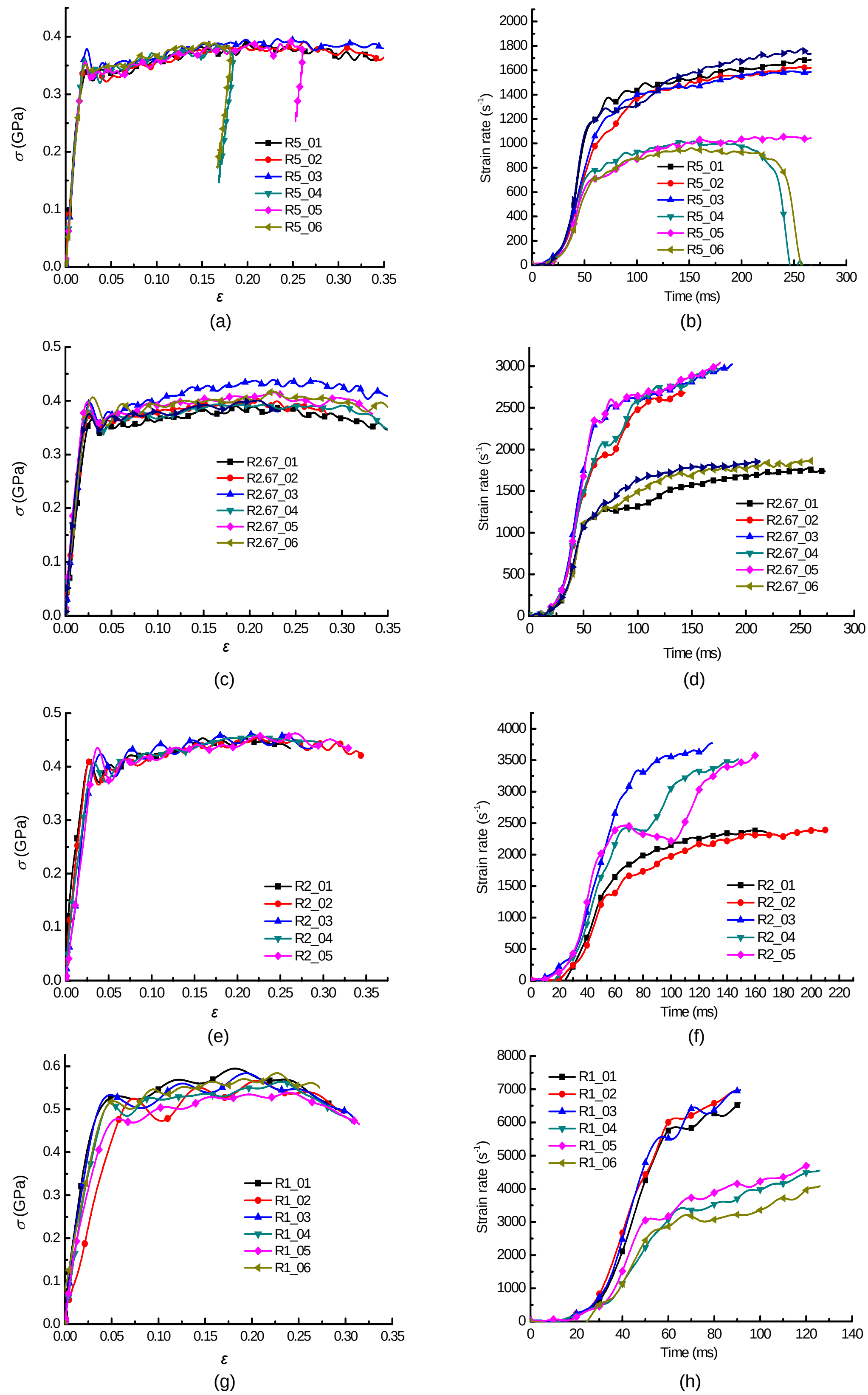

Fig 4 Stress-strain and strain rate-time curves of the specimen for different *L*/*D* ratios

(a), (c), (e), and (g) are stress-strain curves of *L*/*D*=5, 2.67, 2, 1, respectively; (b), (d), (f), and (h) are stress rate-time curves of *L*/*D*=5, 2.67, 2, 1, respectively. In RA_BB, A denotes the *L*/*D* ratio, and BB denotes the specimen number

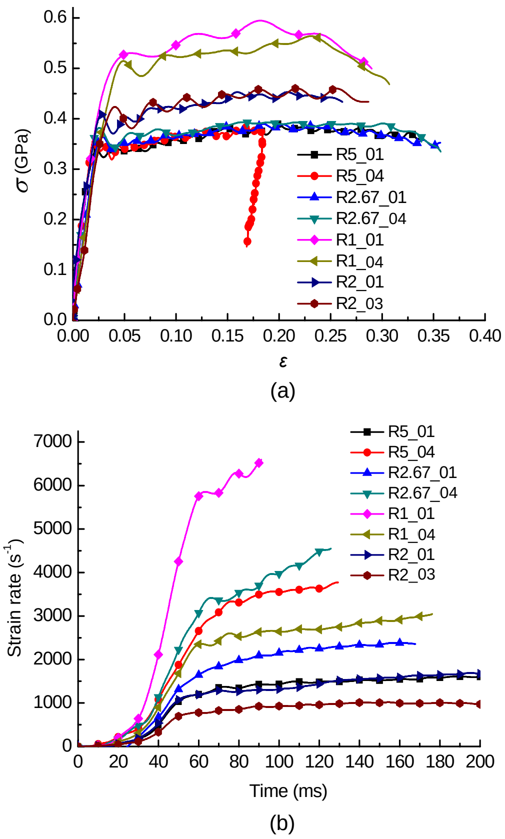

Fig. 5 Stress strain curves of the specimen for different *L*/*D* ratios (a) and strain rates (b)

when the *L*/*D* ratio was ≥2.67, but precise material data could not be obtained when the *L*/*D* ratio was ≤2. This is because when the *L*/*D* ratio is smaller, the 1D character of the specimen stress is weaker, and therefore unable to meet the demands of the SHTB test.

2. During the design of a specimen, the 1D character of specimen stress must be emphasized as well as the uniformity of specimen stress.

3. Stable data may not have material properties.

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