CHIN.PHYS.LETT. Vol. 21, No. 4 (2004) 707

Shear Strength Measurements in LY-12 Aluminium Alloy During Shock Loading *

DAI Lan-Hong(戴兰宏)**, YAN Min(阎敏), SHEN Le-Tian(沈乐天)

State Key Laboratory of Nonlinear Mechanics, Institute of Mechanics, Chinese Academy of Sciences, Beijing 100080

(Received 21 November 2003)

Lateral stress of LY-12 aluminium alloy under plate impact shock loading was measured. Based on the measured data, the Hugoniot relation and shear strength were obtained. The result has demonstrated that the shear strength of the tested material increases remarkably with the increasing longitudinal stress. This means that the assumption of constant shear strength usually adopted in shock stress calculation is not suitable for the present material.

PACS: 62.20.−x, 62.50.+p

The shock response of materials has been of great interest in the last several decades.[1,2] One of the most important issues in this field is the determination of the shear strength in shocked materials. This is because shear strength is usually an important factor to govern material resistance to impact, e.g. the ballistic performance.[3] The shock stress generated by a plate impact can be separated into a mean stress P, and a shear strength,

$$\sigma_x = P + \frac{4}{3}\tau, \tag{1}$$

where σ_x is the longitudinal stress to be measured. Thus, from a known impact stress and mean stress, the shear strength is easily calculated. This is in principle a simple process, but the determination of the mean stress P is often based on the assumption that the mean stress can be approximated from low pressure quasi-static measurements. This procedure is not accurate at high pressures due to uncertainties of extrapolating low pressure response. In addition, the thermal effect must be explicitly accounted for when estimating the hydrostatic response by using this method.

A direct measurement of the shear strength can be obtained from the difference between the longitudinal and lateral stresses, σ_x and σ_y in a plate impact experiment,

$$2\tau = \sigma_x - \sigma_y. \tag{2}$$

The advantage of this method is that τ is now determined by experimental means, thus reducing any ambiguity in the final result. This method is used to determine the shear strength of LY-12 aluminium alloy during the one-dimensional strain plane wave loading.

Plate impact experiments were carried out by using a single stage gas gun in length 27 m and bore diameter 101 mm in our laboratory. The planarity of the specimen plate to the flyer was controlled via an adjustable specimen mount to better than 1 mrad. Impact velocities were measured by the sequential shorting of pairs of pins to an accuracy of 0.3%. Longitudinal and lateral stresses were monitored by means of manganin stress gauges which were embedded in the target material, LY-12 aluminium alloy. The plate impact specimens were machined to dimensions 50 mm × 50 mm × 14 mm. The materials of the flyer, front and back covering plates are the same as the target plate, with the thickness of 5 mm, 4 mm, and 10 mm, respectively. The specimen configuration and gauge placements are shown in Fig. 1. The longitudinal and lateral gage data were reduced to stress time using the methods developed by Rosenberg *et al.*[4,5] The particle velocities of the test material behind the shock front were determined by the impedance matching principle.[6]

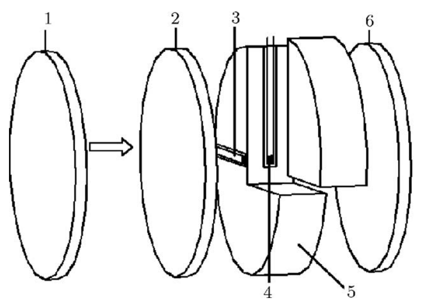

Fig. 1. Specimen configuration and gauge placement: 1. flyer plate; 2. front cover plate; 3. longitudinal gauge; 4. lateral gauge; 5. target plate; 6. back cover plate.

Table 1. Experimental conditions and results.

Impact velocity (m/s)	Longitudinal stress (GPa)	Lateral stress (GPa)	Shear stress (GPa)
76.4	0.555	0.240	0.158
123.1	0.899	0.385	0.257
214.4	1.583	0.788	0.398
258.6	1.920	0.970	0.475
494.1	3.774	2.344	0.715

We present the experimental conditions and results as listed in Table 1. The shock Hugoniot of LY-12 aluminium alloy is reproduced in Fig. 2. It can be seen

* Supported by National Natural Science Foundation of China under Grant No 10232040.
** To whom correspond should be addressed. Email: lhdai@lnm.imech.ac.cn

that the data of the longitudinal stress σ_x and the particle velocity u_p lie on a straight line.

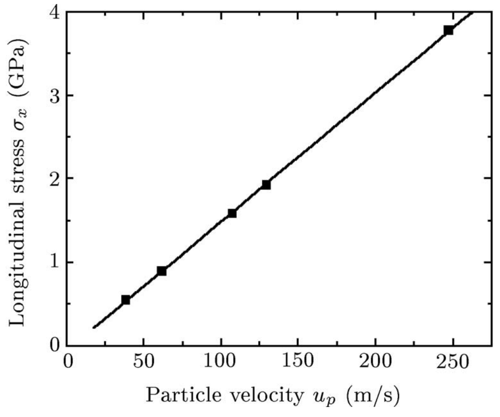

Fig. 2. Hugoniot relation for LY-12 Al alloy.

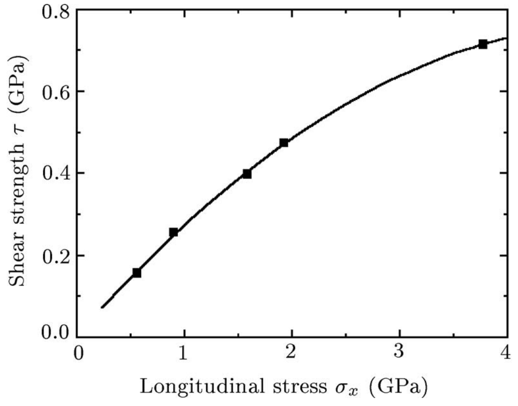

Fig. 3. Variation of shear strength with longitudinal stress for LY-12 Al alloy.

The shear strength has been determined for the tested material using Eq. (2) and the variation with longitudinal stress is shown in Fig. 3. It can be seen that the increase in shear strength with increasing longitudinal stress in the range of 0.5–3.8 GPa is pronounced. This can be most possibly explained by a manifestation of high degree of work hardening for this alloy. Usually, the shear strength during shock loading, which is the offset of Hugoniot from the hydrostat, is assumed to be constant, thus leading to lower calculated value of Hugoniot stress than that measured.[7] Obviously, our present experimental study and some previous works for other materials [8] have demonstrated that this constant shear strength assumption is inaccurate and should be discarded.

In summary, lateral stress measurements have been made in LY-12 aluminium alloy. Based on the measured data, the Hugoniot relation and the variation of shear strength for this alloy have been obtained. The result demonstrates that the shear strength measured during plate impact in the stress range of 0.5–3.8 GPa is shown to increase significantly with longitudinal stress. This means that the assumption of the constant shear strength during shock loading is inaccurate.

References

[1] Geng H Y, Tan H and Wu Q 2002 *Chin. Phys. Lett.* **19** 531
[2] Meng C M et al 2003 *Chin. Phys. Lett.* **20** 1221
[3] Meyer L W 1990 *12th Int. Symp. On Ballistics* (San Antonio, TX) p 419
[4] Rosenberg Z, Yaziv D and Partom Y 1980 *J. Appl. Phys.* **51** 4790
[5] Rosenberg Z and Partom Y 1985 *J. Appl. Phys.* **58** 3072
[6] Meyers M A 1994 *Dynamic Behavior of Materials* (New York: Wiley)
[7] Millett J C, Bourne N K and Jones I P 2001 *J. Appl. Phys.* **89** 2566
[8] Asary J R, Chabildas L C and Dandekar D P 1980 *J. Appl. Phys.* **51** 4774