12
8-4-95 JS①

UCRL-ID-119252

The Shock Hugoniot of Glass Microballoons

R. Simpson
F. Helm

December 1994

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

This report has been reproduced
directly from the best available copy.

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information
P.O. Box 62, Oak Ridge, TN 37831
Prices available from (615) 576-8401, FTS 626-8401

Available to the public from the
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Rd.,
Springfield, VA 22161

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

The Shock Hugoniot of Glass Microballoons

R.L. Simpson and F.H. Helm

Energetic Materials Center
Lawrence Livermore National Laboratory
Livermore, CA 94550

Summary

Shock Hugoniot measurements were made on glass microballoons. Input pressures ranging from 0.37-3.9 GPa produced compression from 860-690%. The Hugoniot curves were found to be anomalous in that the density shocked to decreases with increasing pressure.

Introduction

Four shock loading measurements were made on glass microballoons to determine the Hugoniot behavior. The glass microballoons were manufactured by the 3M Company (St. Paul, MN). Table 1 lists the properties of the microballoons determined by H. Gregg.

Table 1. 3M H50 microballoon properties. Analyses done by H. Gregg, LLNL.

Bulk density	0.247±0.01 g/cc	Median size	34.1 µm
Tap density	0.347±0.01 g/cc	Water (to 350°C) (to 750°C) (to 910°C)	635±45 ppm 1430±125 ppm 2350±200 ppm
Specific gravity	0.517±0.01 g/cc	Organics	0.28±0.3 ppm
Surface area	0.331±0.003 m ² /g	Major constituents	Si, Al, Ca, Na, B, P
Size distribution	2.5-80 µm	Minor constituents	Mg, Zr, Fe, K, Li, Ba, Pb, Ti, Sn, Ga, Mn, Sr, Cu

Shock Loading

Shock waves were generated using a 100 mm smooth bore powder gun. The experimental configuration used is shown in Fig. 1. A flyer plate is driven into an impact plate. The resulting shock wave is then propagated into the microballoons. Barium titanate piezoelectric pins were used to measure the time of arrival of the shock front at different depths in the sample. Time resolution was 5 ns per pin. The shock velocity in a sample of microballoons was calculated by fitting a line to 15 pin signals. Projectile tilt was accounted for in the analysis.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

Figure 1. Shock loading configuration.

The maximum velocity attainable with the flyers was 2.5 mm/μs. To generate high pressures with this velocity limit one experiment (FH-4) was carried out where a stainless steel flyer was used to load an aluminum impact plate which then released into the sample. The shock diagram for this process is shown in Fig. 2. The steel flyer shocks the aluminum impact plate to State 1. The aluminum then releases to State 2.

Once the shock velocity is measured in the microballoons the Rankine-Hugoniot equations are solved to calculate a state on the Hugoniot. In the case of the steel flyer loading the aluminum impact plate the Rankine-Hugoniot equations are used twice. The Hugoniot state is first calculated at the steel-aluminum interface. Next, the calculated particle velocity is doubled and this value is used as the velocity of an equivalent aluminum flyer that impacts the microballoons directly. That is, State 2 in Fig. 2 is determined by doubling the particle velocity at the steel-aluminum interface and finding the intersection of the microballoon Hugoniot with the reflection of the aluminum Hugoniot. At the Al-microballoon interface conservation of momentum can be written as

$$P = \rho_{0Al} U_{sAl} (2 u_{pss/Al} - u_{pAl/\mu B}) \quad (1)$$

where

$$U_{sAl} = C_{0Al} + S_{Al} u_{pAl/\mu B} \quad (2)$$

and

$$P = \rho_{0\mu B} U_{s\mu B} u_{pAl/\mu B} \quad (3)$$

Equations (1-3) can be solved to determine the Hugoniot of the microballoons.

Figure 2. Hugoniot construction of a steel flyer impacting aluminum and the aluminum releasing into the microballoons. The steel flyer impacts an aluminum plate at a velocity V_f shocking it to State 1. The shock transits the impact plate and loads the microballoons to State 2.

Table 2 lists the Hugoniot values for steel and aluminum used in the data analysis. The Hugoniot data measured in this work are summarized in Table 3. In Fig. 3 the data are plotted as U_s vs. u_p and P vs. V/V_0 . The U_s - u_p data can be described precisely as a straight line. Figure 2b shows the anomalous P - V/V_0 behavior. That is, the higher the shock pressure the lower the density of the final state. This is due to the thermal portion of the compression energy being large with very porous materials.¹

Table 2. Hugoniot values for flyer and buffer plate used in calculations.

Material	ρ_0 (g/cc)	C_0 (mm/ μ s)	S	γ
6061-T6 Aluminum	2.703	5.35	1.34	2.00
304 Stainless steel	7.890	4.565	1.495	2.17

Table 3. Shock Hugoniot data for 3M H50 microballoons.

Experiment	V_f^a (mm/ μ s)	ρ_o^a (g/cc)	u_p (mm/ μ s)	U_s^a (mm/ μ s)	P (GPa)	V (cc/g)	V/V _o	ρ (g/cc)
FH-2	1.0244 ^b	0.325	0.9992	1.1305	0.3671	0.3574	0.1162	2.798
FH-1	1.682 ^b	0.325	1.616	1.853	0.9731	0.3939	0.1280	2.539
FH-3	2.485 ^b	0.325	2.347	2.7116	2.068	0.4140	0.13454	2.4156
FH-4	3.448 ^c	0.325	3.196	3.7364	3.881	0.4450	0.1446	2.247

^a Measured.

^b 6061-T6 Aluminum flyer.

^c 304 Stainless steel impacting 6061-T6 aluminum. Aluminum releases into the microballoons.

(a)

(b)

Figure 3. The Hugoniot of 3M H50 microballoons.

Conclusions

The Hugoniot of 0.325 g/cc 3M H50 glass microballoons is linear in U_s vs. u_p for shock strengths ranging from 0.37-3.9 GPa. The intersection of the U_s vs. u_p curve is near zero suggesting at shock pressures below 0.37 there is a decrease in the slope of U_s vs. u_p to allow for a positive non-zero sound speed.

Higher shock strengths in the microballoons were found to produce lower final densities. This is due to the partitioning of a large fraction of the shock compression energy into a thermal component in this porous media.

Reference

1. Y. B. Zel'dovich, Y. P. Raizer, *Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena*. W. D. Hayes, R. F. Probstein, Eds., Academic Press, New York, 1967, pp. 712-716.