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UCID - 16438

95,901

LAWRENCE LIVERMORE LABORATORY

University of California/Livermore, California

PARTICIPATION OF LLL IN JSEXP

CALIBRATION OF MP35N ALLOY

(Unclassified)

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15 January 1974

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ABSTRACT

A series of experiments was performed with the LLL 10.16-cm gas gun to determine the equation of state for soda-lime glass for a multi-phase alloy MP35N (35% cobalt, 35% nickel, 20% chromium, 10% molybdenum) and to determine the piezoresistive coefficient of a Manganin gage. Within the range of experimental error, the data for soda-lime glass and for MP35N were similar to previously published Hugoniot data for Pyrex glass and copper, respectively. The coefficient for the Manganin gage is $0.00214 \Omega/\Omega \text{ kbar}$ in the 60 to 90 kbar pressure range.

In addition, several target recovery shots were conducted with MP35N alloy at impact pressures varying between 60 and 450 kbars. These samples were returned to Picatinny Arsenal for microhardness measurements.

INTRODUCTION

At the request of Picatinny Arsenal, a series of experiments was performed at the Lawrence Livermore Laboratory to:

1. Impact samples of MP35N alloy (35% cobalt, 35% nickel, 20% chromium, 10% molybdenum) at pressures between 60 and 450 kbars. After testing, samples were to be returned to Picatinny Arsenal for microhardness measurements and further investigation by Picatinny of the relationship between impact pressure and duration and the change in hardness of the samples.
2. Estimate the Hugoniot response of the MP35N alloy by performing one test at approximately 400 kbars.
3. Investigate the equation of state of soda-lime glass between 50 and 200 kbars.
4. Check the performance of a Picatinny/SRI designed Manganin gage by comparing it with a gage commonly used at LLL.

EXPERIMENTAL PROCEDURE

The LLL 10.16-cm gas gun was used with a vacuum of approximately 10^{-2} torr in all of the described experiments. Various projectile designs were used, depending upon the particular test condition desired. Figure 1 shows the two different sabots used for the MP35N alloy recovery shots. In both the high- and low-velocity tests, a 0.254-cm-thick tungsten flyer was located in the center of a 0.0254-cm-thick tungsten annular flyer. These flyer plates were bonded to a polymethylmethacrylate plate 1.27 cm thick. This arrangement allowed two different pulse widths, nominally 1.0 and 0.1 μ sec, respectively, to be obtained on the same test. Figure 1 also shows a target and holder and some representative recovered targets. Recovery was accomplished by allowing the specimens to enter a plastic foam- and rag-filled catcher tube. Instrumentation on these recovery shots consisted of piezoelectric pins to measure the projectile velocity.

In order to determine the Hugoniot pressure generated in the recovered targets, the equation of state for this alloy in the 60 to 450 kbar range had to be determined. Figure 2 shows the MP35N flyer plate and the OFHC copper target assembly used for this test. Oxygen-free, high-conductivity copper was selected as the target material, because it is well-defined and has a single-wave structure. The piezoelectric pins shown in the holder assembly were used for measuring projectile, target shock, and free surface velocities.

Figures 3, 4, and 5 show the flyer plates and targets used for the soda-lime glass studies. Again, OFHC copper was selected as the target material since the single-wave structure of the copper target would allow relatively straightforward measurement of the peak driving pressure in the double wave encountered in glass. Instrumentation was similar to that used for the MP35N alloy tests.

Figure 6 shows the projectiles used for the gage tests. The Picatinny/SRI Manganin gage is visible in the figure in the center of the target and the two LLL gages on either side. Figures 7 and 8, respectively, show the basic designs of the Picatinny/SRI gage and the LLL gage to which it was compared. The LLL Manganin gages were activated by a Metrophysics piezoresistive gage, pulse power supply (Model 50-75-600). The Picatinny/SRI gages were activated with a Pulsar power supply.

The equations used for the analysis, the material properties data for the specimens tested, and the experimental data are given in Appendices A, B and C, respectively.

RESULTS

Data on all experiments performed are summarized in Table 1. This table includes not only the values which were directly computed from the experimental data but also gives secondary results which depend upon various assumptions discussed in the Appendix. Tests K-Six-1 through K-Six-4 were shots of 0.635-cm-thick soda-lime glass into 0.953-cm-thick OFHC copper. Test K-Six-11 is the Hugoniot test for the MP35N alloy. Both of these series of tests are plotted in Figure 9 with similar data obtained in other experiments.¹ These pressure-vs.-particle-velocity data for the soda-lime glass and MP35N alloy are similar to the published data for Pyrex glass and copper, respectively. Figure 10 gives a plot of shock velocity vs. particle velocity for Pyrex glass. This plot illustrates a phase change which has been discussed by the referenced authors and also includes the soda-lime data obtained in this study which suggests a similar phase change.

Entries for tests K-Six-8 through K-Six-10 list the data for the MP35N alloy recovery shots. All samples tested were returned to Picatinny Arsenal for further study.

K-Six-5 through K-Six-7 were the gage tests. Of the three shots performed, only K-Six-7 was completely successful. With the Manganin gage technique, the stress amplitude is a direct function of the selected piezoresistive constant. In this work, a value of $0.0024\Omega/\Omega$ kbar was used for the piezoresistive constant of the LLL gages. In test K-Six-7 LLL gages recorded a peak stress of 75.9 and 75.6 kbars. If one takes the average of both stresses and applies it to the basic equation

$$P_{kb} = \frac{\Delta R}{R_0} (k)$$

where:

P_{kb} = peak stress, kbars

ΔR = change in resistance, Ω

R_0 = initial resistance, Ω ,

k = piezoresistive constant, Ω/Ω kbar

the piezoresistive constant for the Picatinny/SRI gage becomes 0.00214 Ω/Ω kbar.

Figure 11 shows the gage records obtained from test K-Six-7. These records indicate that the Picatinny/SRI gage output is not as satisfactory in its response to planar impacts as the LLL gage. The planar impacts tend to destroy (i.e., short) the leads before the entire time of interest can be recorded. However, this may not be a serious limitation for the purposes intended, since the Picatinny/SRI gage was designed to monitor the somewhat spherical pressure output of a military detonator which would be expected not to short the leads as quickly.

CONCLUSIONS

The testing program demonstrated that, within the experimental error associated with this test procedure, the equation of state for soda-lime glass is similar to Pyrex glass, the latter having been fully characterized by other experiments (Ref. 1). The pressure-vs.-particle-velocity plots show an excellent correlation between the two materials, and the shock-velocity-vs.-particle-velocity plots suggest a similar phase change in the soda-lime glass as has been seen in Pyrex.

Since the investigation of the equation of state for the MP35N alloy was a secondary aspect of this study, with the primary requirement being to furnish impacted samples to Picatinny, only one test was performed with suitable instrumentation for Hugoniot data. This one test, however, does show a reasonable correlation with the published data for copper. If MP35N alloy does continue to be of interest, more tests should be performed to confirm the suspected similarity to copper.

ACKNOWLEDGEMENTS

We wish to acknowledge the many helpful discussions and suggestions of F. E. Walker and R. J. Wasley of the Lawrence Livermore Laboratory and W. Voreck of Picatinny Arsenal, and the excellent technical efforts of J. Longwith of this Laboratory.

REFERENCES

1. R. G. McQueen, S. P. Marsh, J. W. Taylor, J. N. Fritz, and W. J. Carter, "The Equation of State of Solids from Shock Wave Studies", in High Velocity Impact Phenomena, by Ray Kinslow, ed., Academic Press, New York 1970, pp 293-417.
2. J. T. Rosenberg, Development of a Detonator Output Test. SRI Project PYU 1283, Feb. 1972.

APPENDIX A

Equations

Distribution:

Copies

External

R. F. Walker Picatinny Arsenal Dover, New Jersey 07801	(2)
W. Voreck Picatinny Arsenal Dover, New Jersey 07801	(1)
R. Thorkildsen Office of the Defense Dept. Research & Engineering c/o Engineering Technology Room 3D1089 The Pentagon Washington, D.C. 20301	(1)

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WHERE

ρ_0 = INITIAL TARGET DENSITY

2. FLYER PLATE (SEE FIGURE A-1 & 2)

FIG A-2

THE PROJECTILE (OR FLYER PLATE) VELOCITY (V_P) EXPRESSED IN TERMS OF EXPERIMENTALLY-MEASURED QUANTITIES IS GIVEN BY

$$V_P = \frac{G_1}{t_2 - t_1} \quad (5)$$

WHERE

G_1 = VELOCITY PIN GAP

t_1, t_2 = TIME, PIEZOELECTRIC PINS.

THE PARTICLE VELOCITY IN THE FLYER PLATE MATERIAL (U_{PF}) CAN BE WRITTEN AS

$$U_{PF} = V_P - U_{PT} \quad (6)$$

AT THE TARGET - FLYER PLATE IMPACT PLANE, THE HUGONIDE PRESSURE IN THESE MATERIALS MUST BE EQUAL AND CAN BE WRITTEN AS

$$P_T = P_F = \rho_0 U_{PF} U_{SF} = \rho_0 U_{PT} U_{ST} \quad (7)$$

A-2

WHERE

P_F = HUGONIOT PRESSURE IN FLYER MATL
 U_{SF} = SHOCK VELOCITY IN FLYER MATL
 ρ_{OF} = INITIAL DENSITY OF FLYER MATL

REWRITING EQUATION (7) FOR U_{SF}

$$U_{SF} = \frac{\rho_{OT} U_{PT} U_{ST}}{\rho_{OF} U_{PF}} = \frac{P_T}{\rho_{OF} U_{PF}} \quad (8)$$

APPENDIX B

Specimen Analysis

MATERIALS ENGINEERING
SONICS ULTRASONICS

TEST REPORT

TO: JENS MAHLER

JUNE 12 1973

FROM: D. GREEN

ACCT. NO 6693-10

ULTRASONIC VELOCITY OF NI CR MO ALLOY, NA LIME GLASS ET NO. 407627

SPECIMEN ID	MP-35N	GLASS		
THICKNESS (CM)	1.1253	.309		
GEOMETRY (INCHES)	3/4" DIA	1-1/2" SQ.		
FREQUENCY MHZ (VL)	5.00	15.0		
FREQUENCY MHZ (VS)	5.00	10.0		
LONG. VELOCITY CM/SEC	596212	572727	.0	.0
SHEAR VELOCITY CM/SEC	311074	341537	.0	.0
DENSITY GM/CC	8.615	2.479	.0	.0
POISSON'S RATIO	.3130	.2241	.0	.0
BULK MODULUS K BARS	1950.8	427.6	.0	.0
SHEAR MODULUS K BARS	833.6	289.2	.0	.0
YOUNG'S MODULUS K BARS	2189.1	707.9	.0	.0
THIN ROD VEL. CM/SEC	504089	534386	.0	.0

DATE: MAY 22, 1973

TO: MR. J. MAHLER

FROM: THERMOPHYSICAL MEASUREMENTS LABORATORY, SUPPORT ENGINEERING DIVISION

SUBJECT: DENSITY OF SODA-LIME GLASS; MP-35N ALLOY

TYPE OF TEST: DENSITY (WATER IMMERSION METHOD)

REMARKS:

QUESTIONS OR COMMENTS CONCERNING THE CONTENT OF THIS REPORT ARE INVITED

DATA REVIEWED

Ref. No. 8-187

Job No. 407627

BY REYNOLD JUMP
BLDG. 231 ROOM 1638
EXT. 7185

THERMOPHYSICAL MEASUREMENTS

TEST REPORT

DATE MAY 22, 1973

ACCOUNT NO. 6693-10

TYPE TEST	DENSITY (WATER IMMERSION METHOD)				
SPECIMEN ID.		DENSITY GMS/CC		TEMPERATURE °C	
SODA-LIME GLASS		2.479		21.3	
MP-35N ALLOY		8.615		21.3	

TESTED BY: MARY OWEN

REMARKS: _____

APPENDIX C

Raw Data

Shot Number	FLYER PLATE					Gage Pressure kbars	Calculated Pressure kbars	TARGET				
	Material	V_p mm/us	U_s mm/us	U_p mm/us	Tilt $\frac{min}{mm}$			Material	U_s mm/us	U_{fs} mm/us	U_p mm/us	
K-Six-1	6.25mm Glass	1.16*	4.48	.90	4.1	-	99.7	9.38mm Copper	4.30*	.52*	.26	
K-Six-2	-	-	-	-	-	-	-	-	-	-	-	
K-Six-3	"	1.69*	4.59	1.32	9.7	-	150.4	"	4.61*	.73*	.36	
K-Six-4	"	.52*	5.13	.39	2.2	-	49.2	"	4.12*	.27*	.13	
K-Six-5	Copper	-	-	-	2.6	82.5 86.5	-	Gages	-	-	-	
K-Six-6	Copper	-	-	-	11.4	-	-	Gages	-	-	-	
K-Six-7	Copper	-	-	-	4.5	75.9 75.6	-	Gages	-	-	-	
K-Six-8	Tungsten	.22*	4.40	.07	2.9	-	60.	MP35N	-	-	.14	
K-Six-9	"	.94*	4.40	.32	-	-	272.	"	-	-	.62	
K-Six-10	"	1.41*	4.60	.50	12.4	-	440.	"	-	-	.94	
K-Six-11	MP35N	1.60*	5.38	.81	6.9	-	378.3	Copper	5.23*	1.59*	.80	

Note: * indicates values computed directly from pin data

FIGURE

	K-51X-1	K-51X-3	K-51X-4
U_{scu}	$= \frac{9.665}{11.05 - 8.80}$ $= 4.30$	$\frac{9.718}{11.22 - 9.11}$ 4.61	$\frac{9.725}{6.68 - 4.32}$ 4.12
U_{fscu}	$\frac{.755}{8.80 - 7.34}$ $.52$	$\frac{1.40}{9.11 - 7.19}$ $.73$	$\frac{.395}{4.32 - 2.88}$ $.27$
U_{fscu}	$\frac{1.500}{8.80 - 5.83}$ $.51$	$\frac{2.400}{9.11 - 5.77}$ $.72$	$\frac{.765}{4.32 - 1.34}$ $.26$
$U_{pcu} = \frac{1}{2} U_{fscu}$	$\frac{1}{2} \left(\frac{.52 + .51}{2} \right)$ $.258$	$\frac{1}{2} \left(\frac{.73 + .72}{2} \right)$ $.363$	$\frac{1}{2} \left(\frac{.27 + .26}{2} \right)$ $.133$
V_p	$\frac{1}{2} (1.15 + 1.14)$ 1.155	$\frac{1}{2} (1.70 + 1.67)$ 1.685	$\frac{1}{2} (.52 + .52)$ $.52$
$U_{pg} = V_p - U_{pcu}$	$1.155 - .258$ $.897$	$1.685 - .363$ 1.322	$.52 - .133$ $.387$
$P = \rho U_{pcu} U_{scu}$	$(8.984)(.258)(4.30)$ 99.67	$(8.984)(.363)(4.61)$ 150.42	$(8.979)(.133)(4.12)$ 49.20
$U_{sg} = \frac{P}{\rho U_{pg}}$	$\frac{99.67}{(2.479)(.897)}$ 4.48	$\frac{150.42}{(2.479)(1.322)}$ 4.59	$\frac{49.20}{(2.479)(.387)}$ 5.13
$T_{it} = \frac{3438}{D} \sqrt{\frac{4T}{D}}$	$= \frac{(3438)(1.155)(.10)}{96}$ $= 4.1 \text{ minutes}$	$= \frac{(3438)(1.685)(.16)}{96}$ $= 9.7 \text{ minutes}$	$= \frac{(3438)(.52)(.12)}{96}$ $= 2.2 \text{ minute}$

C-3

	K-SIX - 8	K-SIX - 9	K-SIX - 10
1	7.077	Not Available	4.27
3	6.828		4.29
4	6.819		4.34
6	7.093		4.48
8	7.188		4.40
9	7.160		4.33
V _p FXR	.225		$\frac{115.5}{30.11} = 1.44$
V _p Pins	$\frac{1.00}{4.52} = .22$	.922	$\frac{7.00}{5.04} = 1.39$
Flyer Thickness Circumferential	.0090 inch = .2286 mm	.0100 inch = .254	.0098 inch = .2489
Flyer Thickness Center	.1000 inch = 2.54	.1020 inch = 2.5908	.1000 inch = 2.54

K_r SIX -11

$$u_{scu} = \frac{3.191}{7.12 - 6.51}$$

$$= 5.23$$

$$u_{psc} = \frac{.765}{6.51 - 6.03}$$

$$= 1.59$$

$$u_{pcu} = \frac{1}{2} (1.59)$$

$$= .795$$

$$V_p = \frac{1}{2} (1.59 + 1.61)$$

$$= 1.60$$

$$u_{PAL} = 1.60 - .795$$

$$V_p - u_{pcu} = .805$$

$$P_{cu} = (8.986)(.795)(5.23)$$

$$P u_{pcu} u_{scu} = 373.62$$

$$\frac{u_{SAI}}{P} = \frac{373.62}{(8.615)(.805)}$$

$$P_{AI} u_{PAL} =$$

K-51X-11

Pins

11	3.185	6.50
12	3.195	6.50
13	3.192	6.52
17	3.190	

	3.191	6.51
--	-------	------

1		7.15
3		7.08
4		7.07
6		7.10
8		7.15
9		7.17

		7.12
--	--	------

14	.765	6.03
15	.765	6.04
16	.765	6.02

	.765	6.03
--	------	------

17		
----	--	--

P_{cu}

8.986

V_p pins $\frac{40}{25.77} = 1.55$

V_p Trig $\frac{7.00}{4.39} = 1.59$

V_p FXR $\frac{110.5}{68.624} = 1.61$

FLYER PLATE MOUNTED IN
HIGH VELOCITY SABOT

FLYER PLATE MOUNTED IN
LOW VELOCITY SABOT

TARGET & HOLDER
WITH PINS

RECOVERED TARGET

Figure 1.

**TARGET & HOLDER
WITH PINS**

**FLYER PLATE MOUNTED IN
HIGH VELOCITY SABOT**

Figure 2.

TARGET & HOLDER
WITH PINS

FLYER PLATE MOUNTED IN
HIGH VELOCITY SABOT

TARGET

FLYER PLATE

Figure 3.

TARGET & HOLDER
WITH PINS

FLYER PLATE MOUNTED IN
LOW VELOCITY SABOT

TARGET

FLYER PLATE

Figure 4.

**TARGET & HOLDER
WITH PINS**

**FLYER PLATE MOUNTED IN
LOW VELOCITY SABOT**

Figure 5.

**TARGET & HOLDER
WITH PINS**

**FLYER PLATE MOUNTED IN
HIGH VELOCITY SABOT**

Figure 6.

Fig. 7.
Picatinny/SRI Gage

Manganin Gage Element showing pattern of four-element grid and four leads.

Fig. 8.
LLL Gage.

Encapsulated Manganin 50-Ω twin-lead pressure gage used in these tests. Gages are purchased from Dynasen, Inc. Goleta, Calif.

Figure 9.
 P vs U_p plots for MP35N alloy and soda lime glass compared with copper and pyrex.
 (Ref. 1).

Figure 10.

U_s U_p plot for soda lime glass and pyrex.

- ⊙ Pyrex (Ref. 1.)
- × Soda lime glass.

Shot K-six-7

Flyer: 6.52 mm OFHC Cu

ρ_o : 8.99 g/cc

Impact vel: 0.934 mm/ μ sec

Target: Na-lime glass

ρ_o : 2.479 g/cc

h_{t_1} : 9.4 mm, h_{t_2} : 9.4 mm

75.74 kb

Time 0.5 μ sec/cm

K-six-7 Gage C

LLL Gage A Manganin

0.0004" Manganin

0.001" mica insulator

0.20" piezoresistive grid

LLL Gage B

0.0004" Manganin

0.001" mica insulator

0.20" piezoresistive grid

75.90 kb

Time 0.5 μ sec/cm

K-six-7 Gage A

PA/SRI Gage C Manganin

75.58 kb

Time 0.5 μ sec/cm

K-six-7 Gage B

Figure 11.

Comparison of LLL and PA/SRI Gage Output Traces.