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PRESSURE LOADING OF ALUMINUM AND
QUARTZ USING SPRAY DEPOSITED
LIGHT-INITIATED HIGH EXPLOSIVE

MASTER

R. A. Benham

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Fig i

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ABSTRACT

A series of experiments was conducted for the purpose of evaluating the impulsive pressure loading generated at a material surface by the detonation of light-initiated high explosive on that surface. The explosive was sprayed and then detonated directly on both carbon and quartz pressure transducers. The output was recorded to allow determination of the characteristics of the pressure loading, as well as to evaluate the variability of this loading.

Key Words: impulse loading, material response

*This work was supported by the United States Department of Energy (DOE).

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PRESSURE LOADING OF ALUMINUM AND
QUARTZ USING SPRAY DEPOSITED
LIGHT-INITIATED HIGH EXPLOSIVE

INTRODUCTION

Light-Initiated High Explosive (LIHE), for several years now, has provided a means for producing nearly simultaneous impulse loads on weapons systems to simulate the structural response generated by hostile nuclear encounters.^{1,2,3,4} In these experiments, the details of the pressure loading was not important so long as the load duration was short with respect to the system's characteristic response time*; i.e., structural behavior was of main interest. Contoured loads on very complex surfaces, including load discontinuities, were easily obtained with this method.

During the early development of the LIHE process, a limited test series was completed to determine the duration and range of pressure loading obtainable. It was concluded at that time that the pressure load duration was from 1 to 2 μ s and that the peak pressures were about one Kbar/Ktap.

Recently, increased interest in combined structural and material response for weapon system development studies have indicated that a better understanding of the LIHE pressure loading was required.

*The characteristic structural response time is the time required for a sound wave to travel one radian around the structures circumference.

This report documents tests in which LIHE-developed pressure pulse shapes were studied. Emphasis was placed on establishing the repeatability and predictability of the currently available pressure loading.* Conclusions are drawn from these test results which establish the pressure loading expected from the standardized LIHE method.** Various methods of pressure pulse shaping are being investigated but will not be addressed here.

The explosive application method, a mathematical pressure model used for calculating the pressure pulse shape, and a discussion of the experimental results are included in this report.

EXPLOSIVE TESTING METHOD

In the LIHE impulse testing method, the explosive silver acetylide-silver nitrate is spray deposited on the surface of the structure to be tested. The surface is then exposed to an intense flash of light which causes the explosive to detonate at many discrete points nearly simultaneously. The facility is described in a previous document² which also describes the basic LIHE process. Other documents^{3,4} describe the loading of various weapon systems and components. An internal document⁵ outlines the formulation-spray process in detail. The many variables that control the process performance are analyzed and/or fixed in an attempt to standardize the method.

The present test series utilized the standardized LIHE process to spray three sets of samples at three different impulse levels on each spray. Pressure pulse shape as a function of impulse was to be determined, as well as was the

* The impulse repeatability and predictability have been established in previous studies.^{1,4}

** The standardized process is defined in a Sandia internal document.⁵

repeatability from spray to spray. The samples, for the most part, consisted of a thick quartz disc pressure gage with a thin film carbon pressure gage ($.51 \text{ cm}^2$ sensitive area) (see Fig. 1) mounted directly over the sensitive area ($.81 \text{ cm}^2$) (see Fig. 2) of the quartz gage. Both gages should experience nearly the same pressure loading (see Fig. 3). Some of the samples had a layer of .0178 mm (.007 inch) aluminum foil attached over the gage front in an attempt to reduce transducer electrical noise pickup from the discharge of the capacitor bank energy which powers the light array causing explosion initiation.

The explosive was remotely sprayed directly on the face of the quartz-carbon gage, which had an exposed area of 5.07 cm^2 including the quartz guard ring. The samples were then taken to the light source where the instrumentation was attached and the explosive detonated. Two samples were sprayed at each impulse level, for each spray set, to obtain process repeatability information. The matrix of tests chosen are the minimum amount required to begin to evaluate the pressure performance data.

Three additional samples were sprayed, one to verify the explosive detonation velocity and two to record the pressure loading with a carbon gage used directly on an aluminum substructure. The quartz gage (Fig. 2) had a maximum accurate recording time of $.884 \text{ } \mu\text{s}$. This time allowed accurate measurements of the rise time and peak levels since the majority of pulses peaked at $.100$ to $.350 \text{ } \mu\text{s}$ after initiation. No attempt was made to determine late time pressures with this stress wave gage. Figure 2 also includes a performance curve for the particular gage for an ideal one-dimensional stress load. The carbon gage theoretically should record pressure faithfully for the entire pulse duration. Substructure fracture or gage element heating during the pressure pulse application may affect the late time (after the peak) gage

output. Carbon gage unloading characteristics are also not fully understood. The carbon gages were fabricated by Dynasen Corporation* and the operation of the gage is described in other documents.^{6,7} The quartz gages were made by Speciality Engineering Associates** and its method of operation is also discussed in other documents.^{8,9}

Since the explosive initiates at many discrete points, both gages will average the pressure loading. It is important that the gage sensitive area is large compared to the pressure initiation perturbation dimensions and that both gages have nearly equal surface area. The gages were chosen to meet these criteria and, as discussed in a later section, the gages were adequate.

The output from the gages was recorded on a transient digitizing recorder with a flexible disc data storage device.*** The data was transferred from the recorder to a desk top calculator. There the data was manipulated to give engineering units by applying the appropriate calibration information. Plots of the data are included in the appendix.

PRESSURE LOADING MODEL

Over the past few years, various observations and measurements have lead to a simplified model of the detonation process which can be used to calculate the average pressure delivered to the surface upon which the explosive is initiated. The model has been documented in past reports.^{10,11,12} Figure 4 shows the basics of the model. The explosive is assumed to initiate simultaneously at many evenly spaced points. A detonation wave expands radially through the explosive from

* Ifleta, CA

** Santa Clara, CA

*** Nicolet Explorer III Oscilloscope

each point until meeting and extinguishing the wave from an adjacent point. The material from the explosion expands away from the loaded surface as a polytropic gas. The average pressure exerted on the surface can be calculated using explosive material properties and the geometry shown in Figure 4. The details of the calculations are given in one of the above-mentioned references.¹¹

For the explosive detonation in these tests, the detonation point density is generally greater than eighty points per square centimeter. A computer program calculates the pressure pulse shape using measured values of the detonation point density (observed after the test from detonation patterns left on the surface), the sprayed explosive areal and mass density, and the explosive detonation velocity. The other required parameters (e.g., explosive products ratio of specific heats and the efficiency of the detonation process) have been empirically established for the standardized LIHE material. The shape of the calculated pressure is shown in Figure 4. The calculated pressure pulse shape will be compared with measurements in a later section to further validate the mathematical model.¹¹

EXPERIMENTAL RESULTS

The tests were conducted between November 6 and November 14, 1979. Nominal impulse levels of 1, 2, and 3 Ktaps were selected. Two preliminary sprays were conducted to establish spraying and data recording procedures for the subsequent tests. Spray groups numbered 3, 4, and 5 produced the data for this test series. Plots of the pressure history for each test are included in the Appendix.

The impulse value for each sample was obtained by relating the areal density of the sprayed explosive to impulse through the facility calibration data.⁵ The local explosive areal densities were obtained by weighing small coupons located around

and sprayed at the same time as the samples. For impulse verification, some of the coupons were placed on a ballistic pendulum where the explosive was detonated. The motion of the pendulum was monitored to determine the impulse delivered by the explosive.

The pressure peaks shown in Table 1 were determined from the hardcopy data included in the Appendix. The carbon data has been corrected for the nonlinear calibration shown in Fig. 1. The gage circuit parameters were measured for each test and the data is on file at the test facility. The quartz data was corrected by the linear sensitivity factor of 1.077 Kbar/V (developed for the quartz material and circuit used).

The peak pressures between the quartz and carbon transducers agree relatively well. The sample rate used for digitizing the data was 50 ns/point. Since the rise time is about 100 to 300 ns long, the exact peak was not captured in each test. When carbon and quartz data are superimposed for a given test, the pressure shape is generally very good until times past the peak. The 10-90 percent rise time data was obtained from the hardcopy data and shows very good agreement between transducers for a given test. Since the detonation process which causes the average pressure loading is not exactly uniform, then there are expected to be small differences in transducer output caused by the small difference in sensitive gage area.

The maximum read time for the quartz gage is .884 μ s (one transit time through the quartz crystal). Since the loading pressure is not exactly planar, then the transducer will give an accurate output for less than the maximum time. The carbon gage should read properly until the stress wave goes through the quartz gage and returns as a tensile wave to the position of the carbon gage. The tensile wave may cause the carbon gage to become partially or totally unbonded and results after about 1.77 μ s after application may be incorrect.

The impulse (area under the pressure data) is plotted next to the pressure trace for each test (see Appendix). It is seen that, in most cases (with the exception of tests 5-6, 5-7), the integrated pressure pulse is considerably below the measured impulse applied during the test. This is partially caused by the limited response time of the transducers--but there are also other possible contributing factors. In many tests, the relief of pressure appears faster from carbon gage data than from quartz data for the stacked configuration. In tests 5-6 and 5-7 where the carbon gage is mounted on aluminum, the transducer output shows the release to be slower and the integrated pressure pulse more closely agrees with the impulse applied (see Fig. 5, test 5-7). Fracturing of the quartz material under the carbon gage may cause some of the rapid pressure release problem (see Fig. 5, test 5-2).

The output from the carbon gages on loading appears reasonably stable at all three impulse levels. The agreement in peak and rise time is good for gages mounted both on quartz and on the aluminum substructure.

The quartz gage shows increasing erratic behavior at higher impulses. At the 1 Ktap range, all gages performed properly. Two gages appear faulty at the 2 Ktap range and four of five appear faulty at the 3 Ktap range. The quartz gage was designed for planar loading. It may be that the irregular loading caused by the discrete detonation process may cause the quartz gage failure at higher pressures. Figure 5 shows the calculated pressure pulse plotted on the carbon data of test 5-7 and carbon and quartz data of test 5-2.

The average of all the peak pressures at the 1 Ktap region is 1.28 Kbar with a standard deviation of .19 Kbar. For the 2 Ktap region, the average pressure is 2.46 Kbar with a standard deviation of .22 Kbar and, for the 3 Ktap region, the average is 2.82 Kbar with a standard deviation of .30 Kbar.

The pressure peaks are plotted in Figure 6. The empirical curve fit derived from the average of individual

Kbar/Ktap ratios at the three impulse values is $P(\text{Kbar}) = I (1.38 - I(.150)) \pm 25$ percent for impulses between 1 and 3 Ktaps. Data at higher pressure levels are currently being obtained and will be reported later.

CONCLUSIONS

A minimum number of experiments have been conducted to describe the pressure loading currently produced by the LIHE test process. Peak pressures are described by the relation $P(\text{Kbar}) = I (1.38 - I(.150)) \pm 25$ percent for impulses between 1 and 3 Ktaps. Rise times (10-90 percent of peak) range from .130 to .300 μs , dependent on the explosive detonation pattern. The carbon gage shows more variance from spray to spray (± 18 percent) than do the quartz gage (± 9 percent) at the lower levels. Variance from spray to spray for the carbon gage at 2 Ktap was ± 8 percent and at 3 Ktaps was ± 15 percent. The variance from spray to spray for the quartz data at 2 Ktap was 18 percent and was not determined at the 3 Ktap level. The model predicts rise times and pulse shapes fairly well for well-behaved gage output, both the carbon and quartz transducers. Some pressure pulse shaping methods are currently being studied and will be reported later.

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READ TIME - AS LONG AS GAGE HOLDS TOGETHER

Figure 1. Carbon Pressure Gage

READ TIME - ONE THICKNESS TRANSIT - $.884 \mu s$

Figure 2. Thick Quartz Pressure Gage

Figure 3. Gage Configuration

Figure 4. Pressure Model

Figure 5. Comparative Test Data

TABLE 1

SUMMARY OF TEST RESULTS

Test Designation (Spray # - Test #)	Impulse (Taps)	Peak Pressure (Kbar)		10-90% Rise Time (μ s)		Comments
		Carbon Gage	Quartz Gage	Carbon Gage	Quartz Gage	
3-4	1085	1.38	1.24	.20	.20	Pulse shape on rise and past peak similar on both carbon and quartz gages
3-5	1150	0.95	1.19	.24	.23	
4-1*	1000	1.45	1.38	.23	.23	
4-2	1000	0.92	1.25	.20	.20	
5-1*	1030	1.22	1.55	.25	.23	
5-2	1050	1.40	1.43	.20	.23	
Average pressure for all low level impulse tests = 1.28 KB with standard deviation = .19 KB						
3-1	2060	2.37	2.23	.13	.25	Carbon gage electrically clipped
3-2	2150	2.55	2.05	.20	.18	
3-3*	2135	--	2.50	--	.19	
4-3*	2100	2.55	3.50**	.19	.18	Perturbation on carbon gage rise 15-90% agrees with quartz
4-4	2100	2.30	2.80	.15	.17	
5-3*	2200	2.65	3.65**	.15	.15	
5-4	2200	2.35	2.24	.35	.20	

Average pressure for all mid-level impulse tests = 2.40 KB with standard deviation = .22 KB

* Gages covered with aluminum foil

**Quartz gage broke during loading. Giving output not consistent with carbon gage output.
Most broken gages had foil on the gage face.

TABLE 1
SUMMARY OF TEST RESULTS (cont.)

Test Designation (Spray # - Test #)	Impulse (Taps)	Peak Pressure (Kbar)		10-90% Rise Time (μ s)		Comments
		Carbon Gage	Quartz Gage	Carbon Gage	Quartz Gage	
3-6	3330	--	--	--	--	Data not recorded
3-7	3200	3.35	2.90	.13	.14	
4-5*	3150	2.83	3.80**	.19	.18	Quartz gage output irratic
4-6	3100	2.95	-- **	.14	--	
5-5*	3100	2.83	2.33**	.18	.33	Carbon gage mounted on aluminum
5-6	3100	2.58	N.A.	.16	N.A.	
5-7	3150	2.88	N.A.	.30	N.A.	Carbon gage mounted on aluminum

Average pressure for all high level impulse tests = 2.82 KB with standard deviation = .30 KB

The pressure data falls within the empirically determined relation $P(KB) = I(1.38 - I(.15))$ +25 percent for $1 < I(Ktap) < 3$ measured equilibrium detonation velocity from Spray #5 - 1164 m/s.

* Gages covered with aluminum foil

** Quartz gage broke during loading. Giving output not consistant with carbon gage output.
Most broken gages had foil on the gage face.

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APPENDIX A

Figure A-1 Carbon Gage Data

Figure A-2 Quartz Gage Data

Figure A-3 Carbon Gage Data

Figure A-4 Carbon Gage Data

Figure A-5 Quartz Gage Data

Figure A-6 Carbon Gage Data

Figure A-7 Quartz Gage Data

Figure A-8 Carbon Gage Data

Figure A-9 Quartz Gage Data

Figure A-10 Carbon Gage Data

Figure A-11 Quartz Gage Data

Figure A-12 Carbon Gage Data

Figure A-13 Quartz Gage Data

Figure A-14 Carbon Gage Data

Figure A-15 Quartz Gage Data

Figure A-16 Carbon Gage Data

Figure A-17 Quartz Gage Data

Figure A-18 Carbon Gage Data

Figure A-19 Quartz Gage Data

Figure A-20 Carbon Gage Data

Figure A-21 Quartz Gage Data

Figure A-22 Carbon Gage Data

Figure A-23. Quartz Gage Data

Figure A-24 Quartz Gage Data

Figure A-25 Carbon Gage Data

Figure A-26 Quartz Gage Data

Figure A-27 Carbon Gage Data

Figure A-28 Quartz Gage Data

Figure A-29 Carbon Gage Data

Figure A-30 Quartz Gage Data

Figure A-31 Carbon Gage Data

Figure A-32 Quartz Gage Data

Figure A-33 Carbon Gage Data

Figure A-34 Quartz Gage Data

Figure A-35 Carbon Data on Aluminum

Figure A-36 Carbon Data on Aluminum

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