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A Loading Technique for Dynamic Response Studies of Geological Materials

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A LOADING TECHNIQUE FOR DYNAMIC RESPONSE STUDIES OF ENERGETIC MATERIALS

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ABSTRACT

A loading technique to study the dynamic response of [illegible] and explosives. Loading is provided by electrically exploding thin copper mesh patterns with current from a capacitor discharge. Pressure pulses with peak pressures of [illegible] and 0.15-0.2[illegible] ms durations were obtained with this technique. The upper value of peak pressure was limited by the strength of the experimental apparatus and higher pressure generation is possible with a redesign of test hardware.

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INTRODUCTION

The rock tuff is subjected to a wide range of peak pressures and pulse durations during containment experiments at the Nevada Test Site (NTS). Sophisticated computer codes exist which can help design field experiments and perform parametric studies; however, these codes need appropriate equation-of-state data for rational predictions. The dynamic materials properties for tuff in the regime where peak pressures are 1-10 kbar and durations are 50-500 μs are not well known, and there is a need to develop loading techniques to investigate this regime.

Recently, we have conducted investigations[1,2] which measure the impulse and pressure-time pulses from an electrically exploded etched copper mesh pattern.* The purpose of these studies was to develop an impulse simulation technique for radiation-induced material blowoff on layers internal to reentry body shell structures. Impulse intensities up to 6 ktap and peak pressures up to 0.20 kbar were produced, and these levels are adequate for this simulation. In the present study we attempt to increase the impulse and peak pressure by an order of magnitude or greater. A peak pressure of 1.25 kbar was achieved, and higher pressure generation is possible with a redesign of the test hardware.

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*The etched copper mesh patterns were originally developed to produce a simultaneous detonation for high explosives and applications can be found in Refs. 3 and 4.

Pressure Bar Experiments

The copper mesh pattern shown in Fig. 1 is an 18 μm (0.7 mil) thick copper foil bonded to Mylar and etched into a series-parallel mesh of bridgewires by the techniques used to manufacture printed circuits. Individual bridgewires are nominally 0.127 mm (5 mils) wide and 0.51 mm (20 mils) long. The mesh is connected to a 55 μF capacitor bank (two BICC-ES108 capacitors) and the individual bridgewires are electrically exploded by the discharge current.

The experimental setup is illustrated in Figs. 2 and 3. Fig. 2 shows the 76 by 152 mm (3.0 in. by 6.0 in.) rectangular mesh pattern connected to the capacitor bank circuit, and Fig. 3 shows the overall setup. As shown in Fig. 3, a 51 mm (2.0 in.) thick, 0.27 by 0.52 m (10.5 by 20.5 in.) aluminum plate is placed in front of the mesh in order to provide confinement of the gases generated by the exploding bridgewires. The 25.4 mm (1.0 in.) diameter, 1.37 m (54 in.) long pressure bar is inserted into a hole in the rectangular aluminum plate, and the loaded end of the bar is butted against 0.23 mm (9 mils) of Mylar which is glued to the back face of the plate. This thin sheet of Mylar provides the specified pressure bar-copper mesh air gaps and electrically insulates the strain-gaged bar.

Displacement at the free end of the bar was measured with a displacement gage (Kaman Nuclear, KD-1100), and strain-time was measured at 0.305 and 1.22 m (12 and 48 in.) from the loaded end with foil strain gages. For all experiments the two strain traces were nearly identical, and only the trace closer to the loaded end of the bar was used for pressure or impulse diagnostics. All data were recorded with oscilloscopes.

Measurements and Diagnostics

As discussed in Refs. 5 and 6 the axial displacement u at the end of an elastic bar from a short duration pressure pulse is a stairstep-type response produced by the repeated reflections of the longitudinal pressure pulse. A typical displacement-time measurement at the end of the bar is shown in Fig. 4. Impulse per unit bar area is obtained from the formula

$$I = \rho c d/2 \quad , \quad c^2 = E/\rho \qquad (1)$$

which is derived in Ref. 6. In Eq. (1) ρ is the density, c is the bar velocity, E is Young's modulus and d is the displacement magnitude shown in Fig. 4.

As previously mentioned, strain-time is measured at two axial locations, and for all experiments the two traces were nearly identical in shape. Only the trace closer to the loaded end of the bar was used for impulse or pressure diagnostics, and these data are presented in Figs. 5 and 6. The literature[6,7] is rich with analytical solutions and experimental data which address the dispersion of elastic stress pulses which distort pressure bar measurements. However, for this application a reasonably accurate pressure-time measurement for pressure generation from the electrically exploded mesh pattern can be obtained with strain-time measurements. Using Hooke's law and assuming a one-dimensional stress condition in the bar, pressure-time is

$$p(t) = -E\varepsilon(t) \tag{2}$$

where ε is measured positive in tension. Strain response can be converted to pressure-time with Eq. (2) and the data in Figs. 5 and 6. From the work presented in Refs. 6 and 7, two comments on the pressure response data can be made: (1) the high frequency, low amplitude component of response riding on the main pulse with period 12-14 μs comes from the dispersion of the stress pulse and is not related to the pressure from the exploded mesh, and (2) the rise times of the strain pulses are somewhat longer than the rise times of the pressure pulses from the exploded mesh. Impulse values can also be obtained from the integral of the strain-time traces and for this diagnostic

$$I = -E \int_0^{t^*} \varepsilon(t)dt \tag{3}$$

where t^* is the time when the strain magnitude returns to zero.

Results and Discussion

A summary of the experimental data for air gaps of 0.81 mm (32 mils) and 0.30 mm (12 mils) between the copper mesh and pressure bar is given in Tables I and II. The first data column gives the charge voltage for the 55 μF capacitor bank; the next two columns give impulse diagnostics from Eq. (1) and

Eq. (2) with t* = 200 μs; and the last column gives the peak pressure. As previously mentioned, pressure-time can be estimated from Eq. 2 and the data in Figs. 5 and 6. These data indicate that the pressure pulses have a fast rise, decay to a low level at about 100 μs and maintain a low level tail for about 100-200 μs. The overall strain pulse shapes are similar in shape for all the experiments, and only peak pressures are affected by changing the charge voltage or air gap size.

As indicated by the data in Tables I and II, a peak pressure of 1.25 kbar was achieved. An experiment was also attempted at 24 kV with the 0.30 mm (12 mils) air gap. The pressure pulse from this test broke the experimental apparatus, and the resulting strain-time histories were not similar in shape to the data presented in Fig. 6. To eliminate confusion these data are not included. The data in Tables I and II do, however, indicate that higher pressure generation is possible with a redesign of the test hardware.

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TABLE I. DATA FOR THE 0.81 mm (32 MILS) AIR GAP EXPERIMENTS

Test Number	Charge Voltage	$\rho c d/2$	$E\int_0^{t^*} \varepsilon dt$	Peak Pressure
	kV	ktap	ktap	kbar
1	15.2	12.6	13.1	0.35
2	20.1	18.9	19.3	0.82
3	24.0	28.9		1.10

TABLE II. DATA FOR THE 0.30 mm (12 MILS) AIR GAP EXPERIMENTS

Test Number	Charge Voltage	$\rho c d/2$	$E\int_0^{t^*} \varepsilon dt$	Peak Pressure
	kV	ktap	ktap	kbar
1	12.1	17.8	18.0	0.60
2	15.0	28.7	30.2	0.97
3	18.1	42.0	39.7	1.25

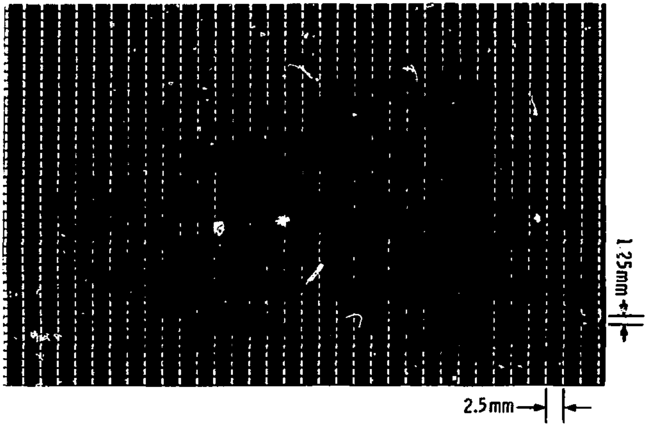


FIG. 1 MESH PATTERN. THE SMALL CONNECTING BLACK LINES ARE THE BRIDGEWIRES.

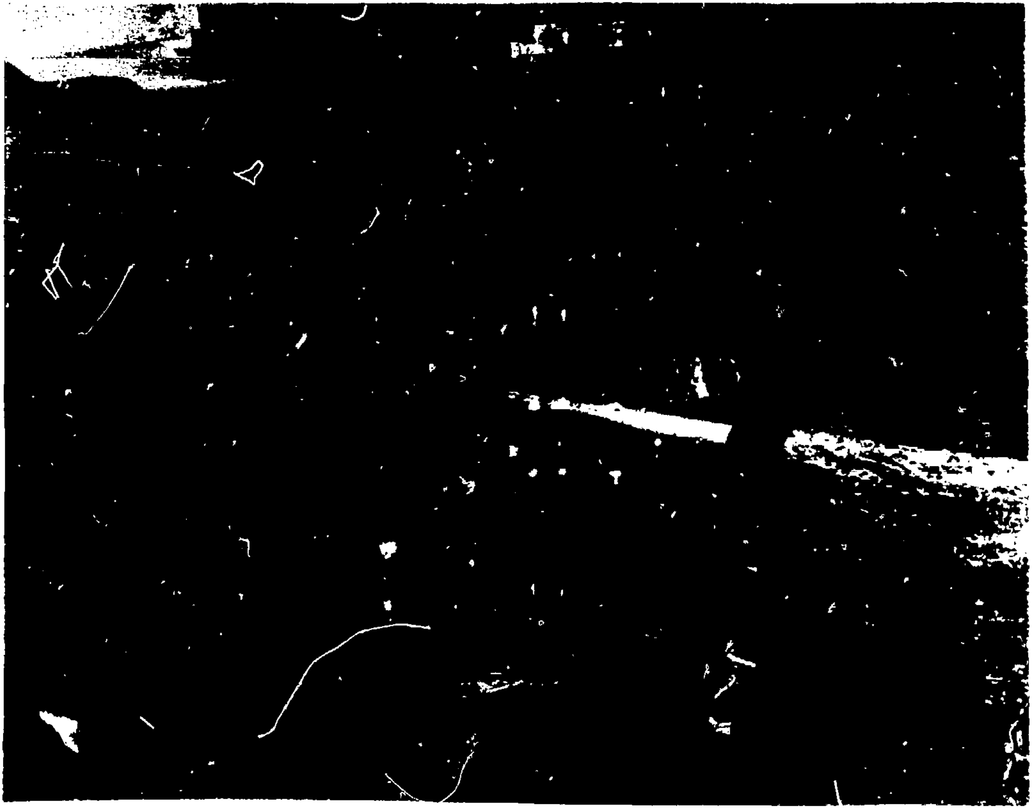
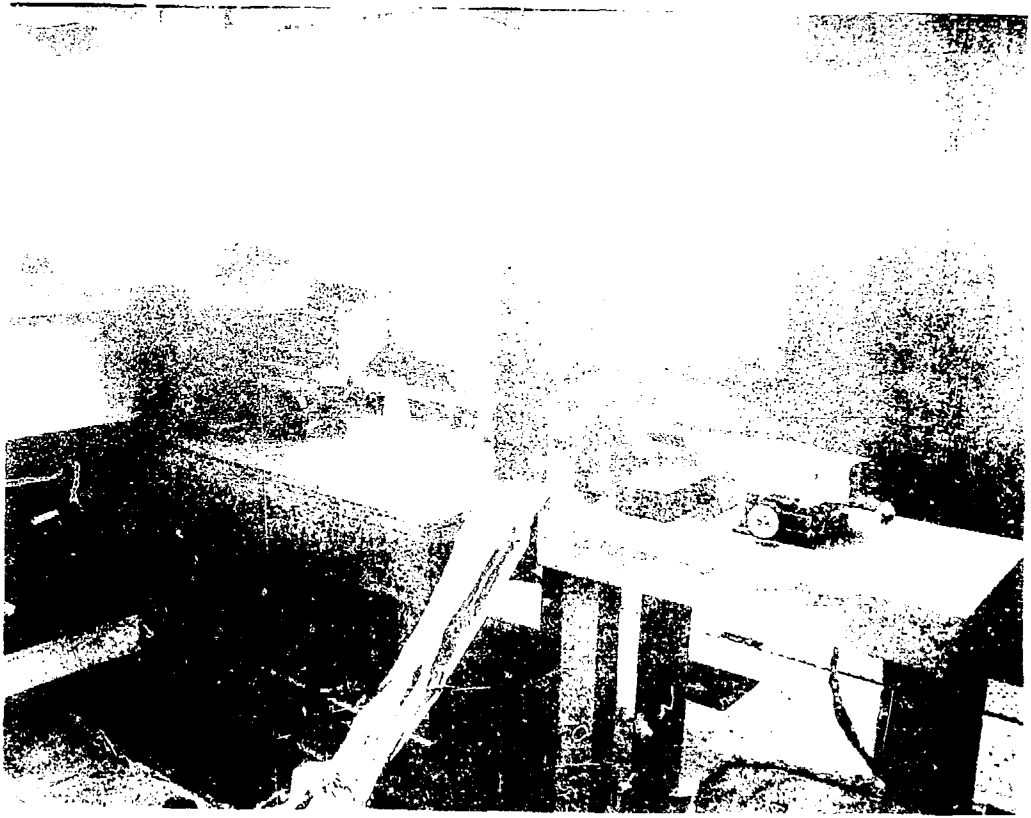
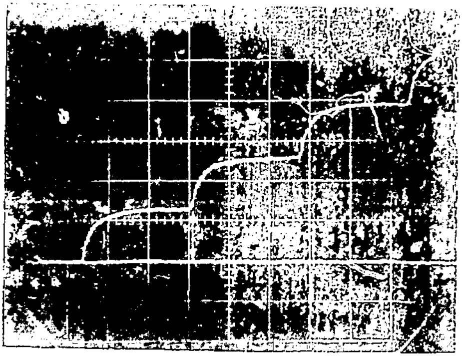
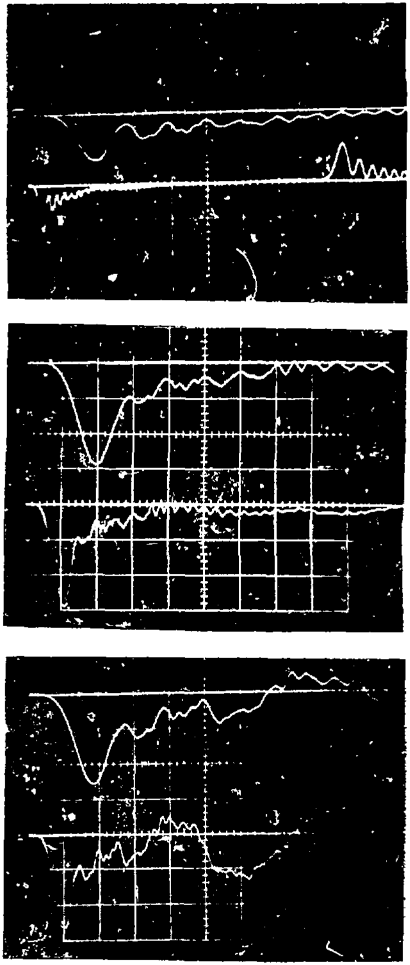


FIG. 2 COPPER MESH CONNECTED TO THE CAPACITOR BANK CIRCUIT







Upper trace: 365 με/Major Div.,
10 μs/Major Div.

Lower trace: 365 με/Major Div.,
50 μs/Major Div.

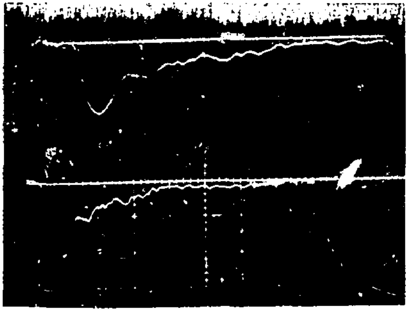
Upper trace: 375 με/Major Div.,
10 μs/Major Div.

Lower trace: 375 με/Major Div.,
20 μs/Major Div.

Upper trace: 600 με/Major Div.,
10 μs/Major Div.

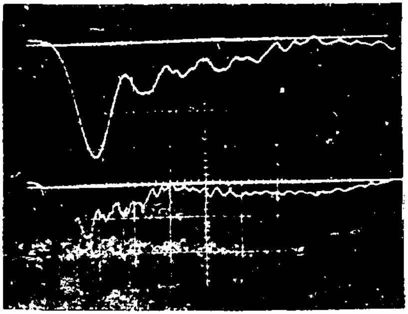
Lower trace: 600 με/Major Div.,
20 μs/Major Div.

FIG. 5 STRAIN-TIME FOR 0.81 mm (32 MILS) AIR GAP
NOTE: ALL TRACES BEGIN AT 50 μs.



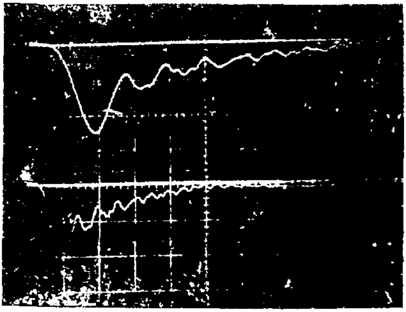
Upper trace: 400 με/Major Div., 10 μs/Major Div.

Lower trace: 400 με/Major Div., 20 μs/Major Div.



Upper trace: 400 με/Major Div., 10 μs/Major Div.

Lower trace: 400 με/Major Div., 20 μs/Major Div.



Upper trace: 667 με/Major Div., 10 μs/Major Div.

Lower trace: 667 με/Major Div., 20 μs/Major Div.

FIG. 6 STRAIN-TIME FOR 0.30 mm (12 MILS) AIR GAP
NOTE: ALL TRACES BEGIN AT 50 μs.

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