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TITLE

TECHNIQUES FOR GAS GUN STUDIES OF SHOCK WAVE ATTENUATION IN SNOW

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TECHNIQUES FOR GAS GUN STUDIES OF SHOCK WAVE ATTENUATION IN SNOW

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1. INTRODUCTION

Shock compression of snow is of interest for its direct applications to such fields as planetary science and arctic and military engineering. The only existing data obtained with reliable experimental techniques are those of Bakanova *et al.*[1] Experiments by Napadensky[2] and Sato and Brown[3] did not meet criteria for plane wave propagation even though the data were reduced using that assumption.

We adopted a technique using stress gauges embedded in gas gun targets of natural snow; such Lagrangian gauges could be used to obtain stress-strain relations for snow by an analysis method first proposed by Fowles and Williams[4] and subsequently refined by Seaman.[5]

We have begun our program with efforts to identify and solve the major experimental difficulties: 1) maintaining uniaxial strain conditions over the gauged target region during shock wave passage; 2) handling and assembling targets of very fragile, naturally bonded snow; 3) embedding stress gauges while creating minimal disturbance to the natural snow structure; and 4) construction of a reliable, accurate stress gauge package that exhibits Lagrangian response in an extremely low-density material. We describe our solutions to these difficulties and discuss data records obtained from preliminary tests.

2. EXPERIMENTAL EQUIPMENT AND METHODS

2.1 Gas Gun

The gas gun used in the tests is a 200 mm diameter, single-stage gas gun operated by the Geophysics Group of Los Alamos National Laboratory. The design enforces planar impact of the flyer with an ideal limit of 0.060 mrad angular deviation, which, with the large diameter, preserves the time resolution of the experiment and ensures that all pressure gauges embedded in a snow sample are in the region of uniaxial flow.

2.2. Sample Preparation

Natural snow, with densities from 100 to 500 kg/m^3, is used to prepare targets. All collected snow is stored in a blast freezer (-35°C) until used in an experiment.

The snow sample target assembly (Figure 1) consists of an inner stack of polymethyl methacrylate (PMMA) rings used to hold the snow and an outer concentric copper cylinder with capping end-plates to provide a vacuum-tight seal. Copper tubing is soldered to the outer cylinder to allow for cooling the sample once the target has been mounted on the gas gun.

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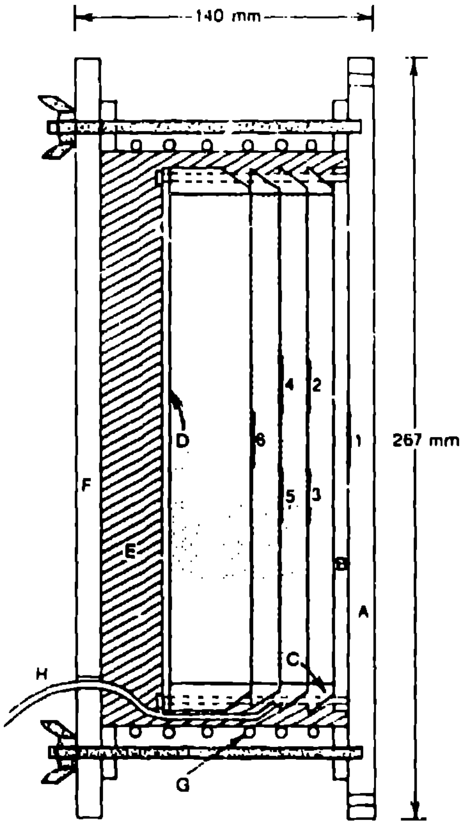

FIGURE 1.
Schematic of snow target assembly consisting of an aluminum buffer plate (A and B), containing a carbon gauge (1), PMMA rings (C) which define the thickness of the snow layers (dotted), a back support of PMMA (D), foam insulation (E), a support plate (F), a cooling coil (G) soldered to a copper cylinder, and gauge and thermocouple leads (H) exiting the rear surface.

The target is assembled with the target axis vertical. The PMMA rings, of thickness equal to the desired gauge spacing in the snow, are used as templates to cut thin wafers of undisturbed snow and to confine them in place on the buffer plate. Three 1.27-cm-thick wafers are installed in order, with stress gauges placed on top of each successive layer (2-6 in Figure 1). Each snow layer is covered with a thin coating of sieved snow to act as a bonding agent and filler. The gauge leads are held in place at the wafer edge by thin metal strips screwed to the PMMA rings. The fourth snow layer is 3.81 cm thick to delay the return of reflected stress waves to the last gauge plane during the test. A thin PMMA plate is used to cap the assembly, completely confining the stack of snow wafers, and a foam plug is placed on top of the PMMA stack. With the back end-plate attached, the target assembly is allowed to equilibrate at the test temperature in the cold room with the resultant resintering of snow layers providing a more uniform and competent sample.

2.3 Instrumentation and Test Procedure

Stress-time records are obtained from 50 ohm carbon-film piezoresistive gauges (Dynasen, Inc., Goleta, CA). Their high sensitivity allows a lower excitation power and less Joule heating of the gauge. The active element for the carbon gauge (0.75 x 1.25 cm) forms a single, continuous, wide strip rather than a grid, as is the case for the more commonly used manganin and ytterbium gauges, and is thus less susceptible to destruction through puncture by individual material grains. The gauges are encapsulated between 0.025-mm-thick layers of kapton, with recording life extended by using a thin layer of electronic-grade mica as armor. We have used a mica-cladding thickness slightly greater than needed to prevent gauge failure, about 0.13 mm on either side of the gauges.

Pulsed Wheatstone bridge power supplies provide 70 volts gauge excitation for 200 μsec. Bridge output signals are recorded digitally using CAMAC-based waveform digitizers with bandwidth of 1 MHz and a sampling rate of 2 MHz (0.5 μsec per point).

We have begun by estimating shock behavior from existing dynamic^3 and static^6 data. We used 5-cm-thick annealed aluminum flyers that give an initial shock duration of about 20 μsec. The target assembly provides enough thermal mass so that mounting of the target can be accomplished and the target chamber pumped out with only minimal rise (1-2°C) in the target temperature, presenting no danger to the snow. The target is mounted with nylon studs and acrylic spacers to the muzzle of the gun, with dry nitrogen gas flushed across the impact surface to prevent condensation during the mounting operation. Refrigeration is applied to the target cooling coil using cold nitrogen gas through access ports in the evacuated target chamber of the gun.

2.4 Shot Records and Data Analysis

Figure 2 shows data from five stress gauges in three gauge planes, for a shot on snow with an initial density of 295 kg/m^3 at a temperature of -9.8°C. The projectile velocity was 161 m/sec, resulting in about 2 GPa impact stress in the target buffer plate. Earlier gauge records show one or two initial spikes, followed by oscillations that settle to a relatively constant plateau, while later records show a significantly longer initial risetime and no large spikes. If the particle velocity in the snow is equal to the impact velocity (an upper limit) the average wave speed results in a Hugoniot state of 9 MPa, in fair agreement with the plateau levels.

We performed two calculations using the finite element code PRONTO[7]. One calculation modeled a 50 mm aluminum flyer with an initial velocity of 170 m/s impacting a target consisting of a 7.4 mm aluminum buffer, 12 mm of snow, 0.75 mm of mica, and 40 mm of snow. In the other, mica was replaced with snow. Both aluminum and mica were modeled as linear elastic media, and snow with a crushable foam constitutive model, based on the steady pressure level seen in Figure 2.

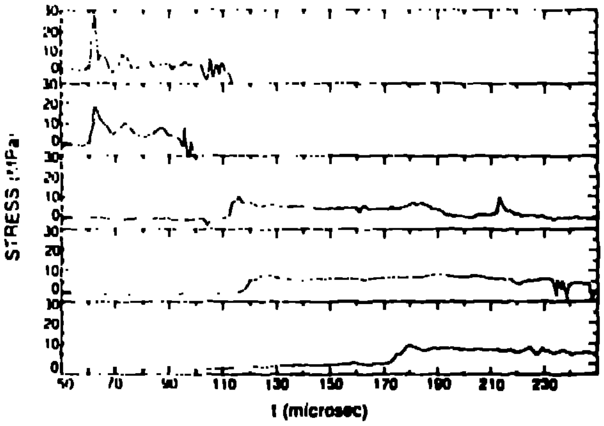

FIGURE 2.

Stress records from gauges embedded in snow.

Results (Figure 3) indicate that spikes seen in the experiments are a result of the mismatch in impedance between snow and mica. In the results from the calculation with no mica (dashed line), the flyer plus buffer act as a piston moving at nearly constant velocity that drives a flat-topped stress pulse into the snow. The small oscillations on top of this wave are caused by ringing in the piston. There is a very slight decrease in the amplitude from one peak to another, because the piston slows down a small amount with each reflection.

The stress history in the center of the mica (solid line) looks qualitatively very similar to that observed in the experiments. The peaks at about 65, 80, and 90 μsec are due to reflections off the gauge and between the gauge and the buffer plate. Note also that the stress drops to zero after several tens of microseconds, just as was observed in the experiment, not due to an overtaking release wave, but rather to separation within the snow/mica laminate.

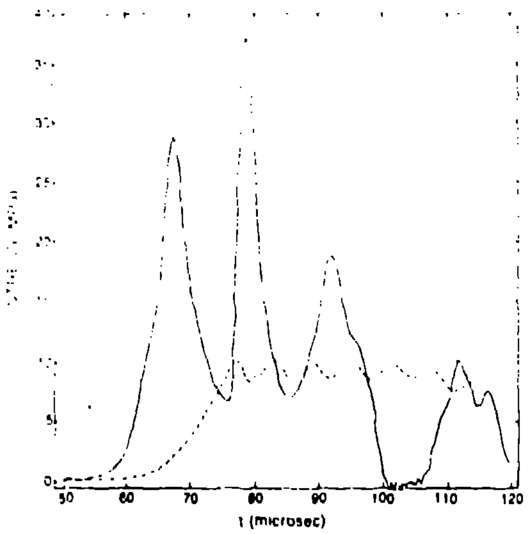

FIGURE 3
Finite element model results for snow experiment.

3. CONCLUSION

We have found appropriate solutions to the problems of transporting and handling naturally bonded snow, constructing layered gas gun targets containing embedded stress gauges, refrigerating the target assembly, and conducting uniaxial strain tests on large diameter targets with very low shock wave velocities. It is clear that the mica-clad carbon stress gauge package we have used, which has proven reliable in dry soil tests[8] is unsuitable when used in snow, where the material density is much lower. The high impedance of the mica package results in significant "ringing" in gauges in the first 15 mm of snow, distorting the response and masking the actual snow behavior. Good Hugoniot data are obtained for shocks which have propagated more than 25 mm.

Studies to resolve this problem, with the aim of obtaining true Lagrangian stress histories, are still under way as of this writing. It is clear that the solution lies in constructing a gauge package of minimal thickness, low density, and with cladding stiffness just sufficient to ensure survival of the gauge element.

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