Quasi-static and Dynamic Compaction of the JSC-1A Lunar Regolith Simulant

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The behavior of regolith under compaction is important for the study of planetary evolution, impact cratering, and other topics. Here we present the initial results of quasi-static compression tests, explosively driven flier plate experiments, and numerical models of compaction in samples of the JSC-1A Lunar regolith simulant.

Methods

We have completed quasi-static and high pressure explosive flier plate experiments on the JSC-1A simulant.

JSC-1A regolith simulant We chose to study the JSC-1A simulant because it is more similar to regoliths found on the moon and many asteroids than material models in current use for numerical modeling of impact processes, while still being easy to obtain. These equations of state have been sufficient while other sources of uncertainty dominated the total uncertainties on the numerical models, but increased computing power and better understanding of the objects in question make new models useful to the numerical modelers.

The JSC-1A lunar mare regolith simulant is a processed basaltic volcanic ash from the San Francisco volcano field near Flagstaff, Arizona, produced by the Orbitech corporation for use in geotechnical research. The strength properties of JSC-1A were measured by Alshibli et al. (2009)[1], and a geochemical analysis was conducted by Hill et al. (2007) [2].

Quasi-static Compaction The quasi-static compaction tests were conducted at LANL with the help of D. J. Alexander and D. A. Fredenburg. Powder compaction was performed using a screw-driven electromechanical test frame (Instron model 4483, 150-kN-capacity frame with a 150-kN-capacity load cell) with a computer-controlled data acquisition and test control system. The powder was compressed at a constant crosshead velocity of 0.00222 mm/s (0.00525 in./min.) to a maximum load of 129 kN (29,000 lb), and then unloaded with the same velocity. During the test, the computer automatically recorded time, load, and crosshead displacement at 0.35 s intervals. Two 2.3 g portions of JSC-1A were poured into 2.5-cm-diameter stainless steel dies and smoothed to be approximately level within the dies. A 2.5-cm-diameter stainless steel punch was used to compress the sample in the die under ambient laboratory conditions.

Dynamic Compaction Experiments The conical explosive charge (labeled 1 in Fig. 1 (a)) at the top is detonated, and drives a blast wave through the explosives, a 2.5-cm stainless steel plate (2), and another 1.25-cm disk of 9501 explosives (3). These layers condition the blast wave to be approximately planar when it strikes and drives the 1.3-cm thick aluminum flier plate (4) down into the three sample cells held by the aluminum and poly(methyl methylacrylate) (PMMA) baseplate (5, only one sample shown), which are under vacuum. The sample for this experiment was 2.621-mm-thick, with a mass of 5.819 g, and a density of 1.5 g/cm^3, this is approximately tap density for JSC-1A. It was held in a sample cell that consisted of a 2.072 mm copper buffer above, an aluminum cartridge, and a 21.467-mm-thick PMMA window below. The flier plate velocity, the timing and velocity of blast wave breakout from the sample holder and the front and back of the sample cartridge are measured using photon doppler velocimetry (PDV)[3].

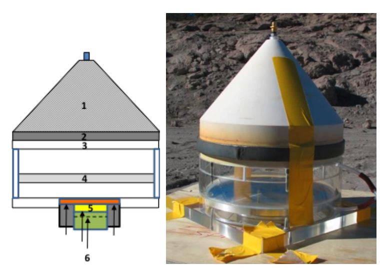

Figure 1: The experiment setup (left), and the apparatus just before firing (right).

Results

In the quasi-static experiments, the compressive load and compressive extension are recorded. The pressure applied to the sample is the compressive load divided by the sample area. The sample's specific volume is the area times the sample thickness, which is derived from the compressive extension normalized to a compliance test done by compressing an otherwise empty cell under standard laboratory conditions. A quasi-static $P-V$ curve can be derived from these quantities, shown in Fig. 2. The compaction curve can then be used in hydrocode models of the dynamical experiments, described below. Detailed compaction curve fits to the quasi-static compaction data will be presented at the meeting.

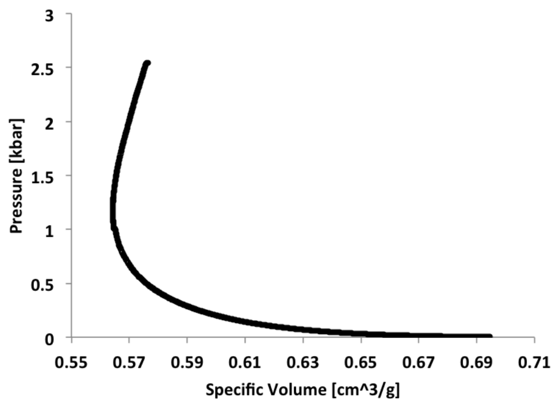

Figure 2: Quasi-static $P - V$ curve for JSC-1A.

In the dynamic experiment, the simulant sample cell was monitored by four PDV probes. Two probes recorded the time that the shock broke out of the baseplate into the sample on opposite sides of the cell. The difference in shock breakout at the two baseplate probes, was $\Delta t = 0.266$ μs, indicating the shock front had very little tilt relative to the plane of the sample face. Two probes measured velocity at opposite side of the sample, at the center of the sample cartridge and off-set from the center by $\Delta r = 4.5$ mm. The shock broke out of the baseplate at $t = 69.8465$ μs, and broke out of the sample at $t = 71.0214$ μs, indicating a sample crossing-time of $\Delta t = 1.175$ μs at the off-center probe, through a sample thickness $\Delta y = 2.621$ mm, giving a shock velocity of $U_s = 2.231$ mm/μs. Using the crossing time measurements, a particle break-out velocity of $U_p = 0.958$ km/s, and the $U_s - U_p$ method detailed in [4], we calculate the shock pressure in the JSC-1A sample to have been 32 kbar. The three hydrocode models predicted peak shock pressures of 32 kbar for the bi-linear ramp model, and 30 kbar for both the one and two exponential $P - \alpha$ models. The sample is then subjected to an increase in particle velocity and pressure from the impedance mismatch ring-up. The hydrocode models predict that the sample is subjected to pressures around 50 kb, and achieves densities near or greater than crystalline density.

The numerical models show some agreement with the data during the compaction of the sample, and predict reasonable initial shock pressures. The bi-linear inverted ramp model is mathematically simpler to fit to existing compaction data, but the $P - \alpha$ models include a more careful treatment of thermodynamics, which is important when the target materials enter parts of the EOS

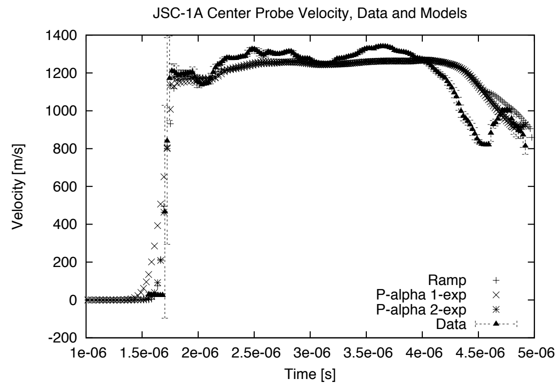

Figure 3: Comparison of 2-D hydrocode model results with different fits to quasi-static compaction data to JSC-1A experimental data, interface velocity over time at the center of the sample.

space close to a phase transition. The SESAME equation of state for basalt with compaction models fit to previous experimental data provide good fits to the initial experimental results for shock compaction of JSC-1A regolith simulant. As the modeled samples decompressed, they released according to the EOS tables. The models did not provide as good a fit to the observed release of the regolith simulant from high pressure.

Future Work

We will conduct lower velocity gas gun experiments to fill in the low-pressure shock regime, with the intent of determining $U_s - U_p$ points and C_0 and S coefficients of the Hugoniot relation for a JSC-1A equation of state.

References

[1] Alshibli, K. A. and Hasan, A. *J. of Geotech. and Geoenv. Eng.* **135**(5), 673–679 (2009). [2] Hill, E. and et al. *J. of Geophys. Res.* **112**(E02006) (2007). [3] Jensen, B. J. and et al. *J. Appl. Phys.* **101**(1), 013523 (2007). [4] Meyers, M. *Dynamic behavior of materials*. A Wiley-interscience publication. Wiley, (1994).