EPSC Abstracts
Vol. 8, EPSC2013-1000, 2013
European Planetary Science Congress 2013

The Compaction of Brittle Particulates at High Strain-Rate: Experiments and Numerical Simulations

W.D. Neal (1,2) and G.S. Collins (2,3)
(1) Institute of Shock Physics, Imperial College London, UK (2) Applied Modelling and Computational Group, Imperial College London, UK (3) Impacts and Astromaterials Research Centre, Dept. Earth Science and Eng, Imperial College London, UK (w.neal09@imperial.ac.uk, g.collins@imperial.ac.uk)

Abstract

Shock compaction experiments were conducted on samples of soda-lime glass microspheres to longitudinal stresses up to 2.8 GPa. States along the shock compaction curve were inferred from shock (U_s) and particle velocity (u_p) measurements. This data was used to generate $\varepsilon - \alpha$ [2] compaction model parameters. Simulations of the experimental configuration were completed using iSALE 2D. The model accurately predicted shock-velocity but failed to represent the complex wave structure observed in the experiments. The linearity of the empirical model is not well suited for representing particulate systems where the strongly non-linear U_s-u_p relationships dominate the compaction process.

1. Introduction

Macro-scale hydrocodes typically use the P-α [1] or $\varepsilon{-}\alpha$ [2] to empirically represent the shock compaction of porous or particulate materials. Both models assume linear pressure-density behaviour up to an elastic threshold followed by a non-linear densification during the majority of the porosity removal. These models were initially designed to represent ductile, metallic foams and their suitability in brittle particulate materials has yet to be fully explored. As part of an ongoing investigation to use silica as analogues for primitive porous solar system solids, it is essential to generate a reliable macro-scale model for these brittle particulates.

2. Experiments

This study chose to use samples of soda-lime glass microspheres (ρ_0=1.50±0.02 g cm^{-3}) due to their regular shape and consistent bulk porosity. A single-stage light-gas gun was used to conduct a series of plate impact experiments on the samples ranging from 230-1080 ms^{-1}. The samples were supported within a Poly(methyl methacrylate) (PMMA) cell. Longitudinal stress gauges were embedded in the PMMA walls upstream and downstream of the particulate bed to measure the incident and transmitted shock pulses (see figure 1). The upstream wall of the cell was impacted with a flyer plate, the velocity of which was measured by a sequence of shorting pins to within 1%.

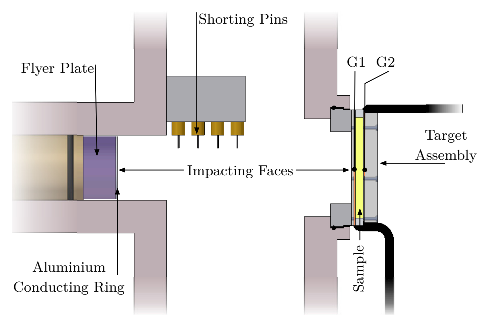

Figure 1: Impact: a flyer plate impacts the target assembly. Longitudinal stress gauges, G1 and G2, measure stress and wave transit time through sample.

The transit time between measured wave profiles was adjusted to account for the effects of the cell walls and used to determine the sample shock-velocity (U_s). The impact velocity (V_i) was used with the Rankine-Hugoniot jump conditions to infer the densification within the sample.

Quasi-static compaction data was taken from [3]. This data was measured at speeds of 20 μm s^{-1}.

3. Simulations

The shock-compaction data was used to generate $\varepsilon - \alpha$ model parameters for implementation into an in-house hydrocode, iSALE 2D. Figure 2 shows the fit to the data.

The experimental configuration was modelled with a Lagrangian mesh resolution of 10 μm which equated to 40 cells along the longitudinal direction of the sample material. The model assumed axial symmetry and captured the radial release effects present in the experiments. A strain-rate independent Von-Mises strength model was used to represent the PMMA cell. Tracer particles were placed in the PMMA to represent the longitudinal stress gauges.

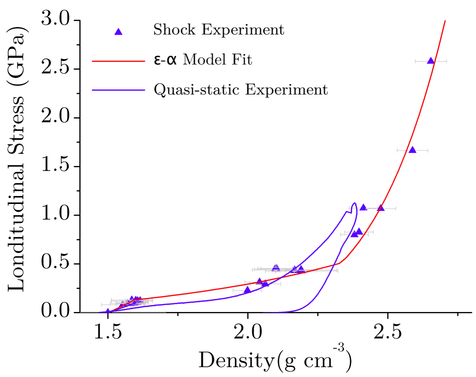

Figure 2: Epsilon-alpha compaction model fit to experimental data used for iSALE simulations.

4. Results

The results from a simulation at circa. 400 ms^{-1} are shown in figure 3. The simulation predicts the velocity of the transmitted wave well although the linearity of the elastic compaction fit causes the wave to have smaller rise time than the experiments.

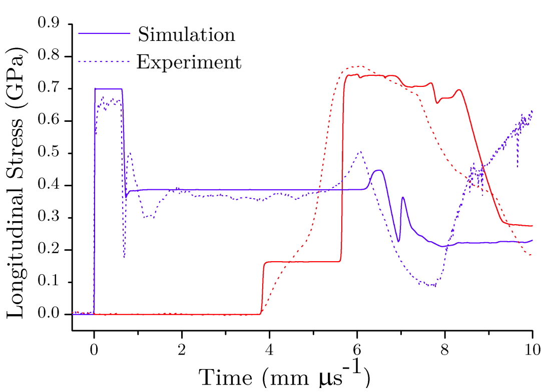

Figure 3: Incident (*blue*) and transmitted (*red*) gauge data from experiments (*dotted*) and simulations using iSALE (*solid*).

The magnitudes of the wave profiles show excellent agreement. The series of releases and re-shocks present in the early stages of the incident gauge are not captured by the model. This is likely due to the very low shock-impedance of the particulate material at zero-pressure.

The initial linearity of the model is a poor assumption as shown by the quasi-static data in figure 2. Although this data was measured at a different rate, it does provide an estimate of the low stress compaction states that the shock data lacks.

5. Conclusions

This work indicates that the traditional empirical compaction models can correctly predict wave velocity and magnitude but do not sufficiently predict the intricate behaviours of particulate materials undergoing shock compaction. In particular, the non-linearities in wave speed with respect to pressure are too complex for a simple linear model.

Acknowledgements

This work was funded by the Atomic Weapons Establishment and the Natural Environment Research Council, Fellowship Grant NE/E013589/1. The authors are grateful for the support of Alan Dawes and Jeremy Millet. We also gratefully acknowledge the developers of iSALE-2D, including Gareth Collins, Kai Wünnemann, Dirk Elbeshausen, Boris Ivanov and Jay Melosh.

References

[1] Herrman. Constitutive Equation for the Dynamic Compaction of Ductile Porous Materials. Journal of Applied Physics (1969) vol. 40 (6) pp. 2490-2500

[2] Wünnemann et al. A strain-based porosity model for use in hydrocode simulations of impacts and implications for transient crater growth in porous targets. Icarus (2006) vol. 180 (2) pp. 514-527

[3] Neal. The Role of Particle Size in the Shock Compaction of Brittle Granular Materials, Imperial College London, 2013.