INTERROGATING HETEROGENEOUS COMPACTION OF METEORITIC MATERIAL AT THE MESOSCALE USING ANALOG EXPERIMENTS AND NUMERICAL MODELS

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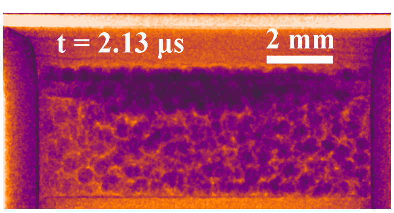
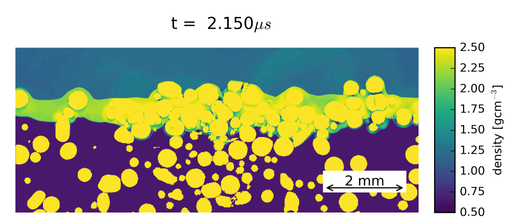
Introduction: It has recently been proposed that highly porous, bimodal primordial aggregates of mm-scale chondrules and fine dust were compacted and lithified into the meteorites we observe today by low velocity (<1 kms^{-1}) collisions between planetesimals in the early solar system [1]. The contrasting properties of the chondrules (spherical solidified melt droplets) and highly porous dust matrix results in extremely heterogeneous shock response during compaction, with variable compaction and >500K temperature differences at the sub mm-scale within the matrix. Understanding this response is an essential step for interpreting the evidence of solar system evolution recorded in meteorites. Here we use a combined experimental and numerical modelling approach to investigate the mesoscale phenomena of this heterogeneous compaction in analog primitive solar system materials.

Experiments & Modeling: Experiments, performed at the ESRF, captured x-ray images during shock compaction of an analog meteoritic chondrule-matrix mix. Analog mixtures comprised 30 vol.% spherical monodisperse Soda-Lime glass beads (chondrules) [2] and 70 vol.% Sipernat silica powder (matrix; grain size $\approx 7\mu$m, $\approx 70\%$ porosity) [3]. Two glass bead (chondrule) diameters were used: 200 μm diameter and 450 μm. The experimental geometry comprised a 2mm $\times$ 10mm flyer (Copper or Polycarbonate), a 2mm $\times$ 10mm Polycarbonate cover plate and a 4mm $\times$ 10mm particle bed with a bulk porosity of 50%. The flyer was attached to the end of a 25 mm long Polycarbonate sabot and the impact velocity was $\approx$ 600ms^{-1}. The experiments were numerically modelled with the 2D shock physics code, iSALE [4]. The simulations replicated the experimental geometry and used the Mie-Grüneisen equation of state for all materials. Porosity in the sipernat matrix was modelled using the the $\epsilon - \alpha$ porosity model [4]. All materials were treated as elastic-perfectly plastic, with a constant yield strength, except for the Sipernat matrix, which was modelled with the Drucker-Prager strength model.

Results & Conclusions: Preliminary simulations using a random, uniform particle arrangement show qualitative agreement between experiments and simulations in shock position at various times. However tomography scans of the experimental targets show significantly non-uniform particle arrangements. Further simulations made use of tomography scans by importing 'slices' of the particle bed's geometry for use as initial conditions. These simulations similarly agree with experiment (Fig. 1a,1b) and allow us to quantify how much of an effect the non-uniformity of the particle distribution affects the bulk response. Analysis of the shocked material in each of the simulations showed that the bulk shock pressure was approximately 0.4 GPa with a standard deviation of ~0.2 GPa and the matrix was compacted to around 2 times its original density. These numbers are comparable to those in recent proposals [1] providing evidence that the experimental work is applicable to such research. This is consistent with previous mesoscale simulations of meteoritic material compaction [1], suggesting that the experiments are useful mechanical analogs for interrogating meteorite compaction processes.



(a) Radiograph image from the experiments with larger chondrules, at $\approx 2.13\mu s$. The colormap is a visualisation tool: although it does not represent a physical quantity it highlights contrasts in mass density.



(b) The equivalent iSALE simulation, using a copper flyer and grain size of $\approx 400\mu m$. The shock is present at a comparable location to 1a

Acknowledgements: We gratefully acknowledge the iSALE developers (www.isale-code.de) and the ESRF for their providing of the facilities necessary to perform the experimental work. JGD is supported by EPSRC studentship funding; GSC are supported by STFC grant ST/N000803/1.

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