REGOLITH FORMATION ON AIRLESS BODIES. K. Hazeli[1], J. Wilkerson[2], C. El Mir[1], M. Delbo[3] and K. T. Ramesh[1]. [1]Johns Hopkins University, Hopkins Extreme Materials Institute, 3400N Charles Street, Malone Hall Suite 140, Baltimore, MD 21218 (hazeli@jhu.edu). [2]Mechanical Engineering, University of Texas at San Antonio, TX 78249. [3]Laboratoire Lagrange, UNS-CNRS, Observatoire de la Coˆ te d'Azur, Boulevard de l'Observatoire- Nice Cedex , France.

Observations and Motivation: Early asteroid evolution models predicted a negligible regolith layer on small rocky asteroids with diameters in the order of tens of km [1]. However, close-up high resolution images (~6 mm/pixel) taken by the Hayabusa spacecraft from altitudes of 80 to 63 m above the surface of asteroid 25143 Itokawa revealed a dense regolith field with grain sizes ranging from millimeters to centimeters [2]. Dombard et al. [3] associated the formation of debris aprons to mechanical abrasion during sliding events, micrometeorite spallation and thermally induced disaggregation. Recently, Delbo et al. [4] reported that thermal fragmentation induced by the diurnal temperature variations breaks up rocks larger than a few centimeters more quickly than do micrometeorite impacts, suggesting that thermal fragmentation may be a key factor in the process of regolith generation and surface rejuvenation of small airless bodies.

Therefore, to identify and quantify the suggested mechanisms, it is crucial to determine the physical and mechanical properties of asteroids and lunar rock components. In addition, development of a realistic thermomechanical model to predict rock comminution demands experimental characterization of the thermal and mechanical properties of meteorites constituents' phases, which are poorly known. Furthermore, such quantification could potentially provide insights into some of the major processes associated with the evolution of the solar system.

Material and Methodology: Thermomechanical characterization was performed on an L6 ordinary chondrite (GRO 85209) that was found in the Grosvenor Mountains, Antarctica, and provided by the Smithsonian museum. The hybrid experimental system used in this investigation consisted of thermal cycling of the meteorite material with simultaneous measurement of the thermal field and displacement fields using thermal cameras and high-resolution optical cameras, and computation of the local strain fields in situ during the thermal cycling. The meteorite was thermally cycled between 35 ^{O}C and 155°C for up to 60 cycles.

In these experiments, the thermal cycling was performed using a programmable hot plate. The current report presents the result for a heating segment. The temperature rate is chosen to be 2 ^{O}C/min. This temperature rate is assumed to be representative of typical (some) NEA surfaces [4]. Fig. 1a shows the temperature profile during heating. The temperature field was measured using a previously calibrated FLIR A325 thermal camera that obtained 16-bit 320x240 images at 60 Hz.

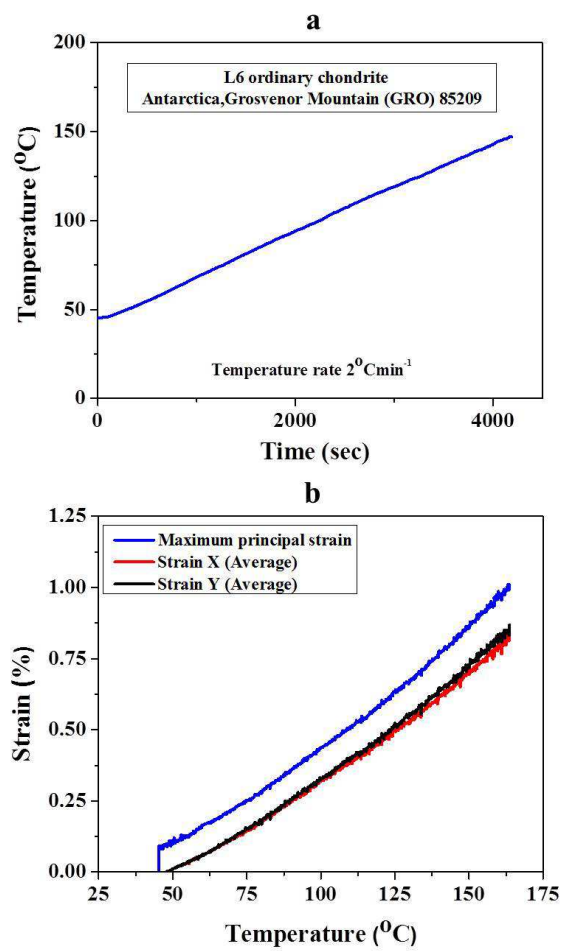

Fig. 1 (a) Average temperature field as a function of time, and (b) corresponding strain components.

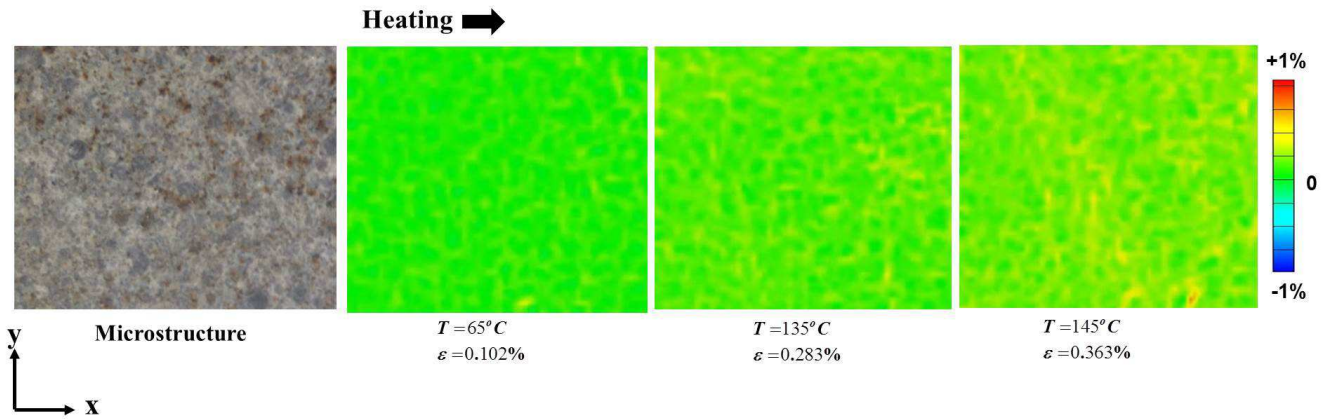

Fig. 2 Image illustrating the meteorite microstructure and its associated full-field strain map at different temperatures. The strain map develops in a heterogeneous pattern as a result of the different CTE values of each individual constituent.

A series of optical images were simultaneously recorded in order to monitor the local displacements due to the thermally-induced expansion. The image sequences were subsequently used to measure the full-field strain map and to quantify different components of strain by implementing digital image correlation techniques (DIC [5]), see Fig. 1b and Fig. 2. Imaging was conducted using a 5-megapixel GOM camera. For the targeted field of view the measurement sensitivity was 8 microns/pixel. The recorded digital images were post-processed using the commercially available ARAMIS DIC software. The facet and step size was set to be 30×30 pixels and 12 pixels respectively.

Preliminary Results: Fig. 1b shows the computed average strain along the conventional X and Y directions (Fig. 2). The X and Y components of strain were used to calculate the maximum principal strain, shown in Fig. 1b as an average over the surface area examined. (Note that the principal strain values are in a rotated reference frame where the shear components are zero). Substantial shear strains are developed within the sample. The presence of shear strain within the material even for through-the-thickness heating phase highlights the importance of the local microstructural heterogeneities to the global strain response. It is observed that the maximum principal strain evolves heterogeneously with temperature and develops localization at higher temperatures. Fig. 2 presents the optical microstructure of the tested meteorite along with the corresponding *in situ* full-field maximum principal strain maps at various temperatures. It is important to note that temperature changes can induce considerable strain in the microstructure. Fig. 2 suggests that the dissimilarity of the CTE values of the constituent leads to strain heterogeneity.

As a result of the localized stress field associated with the CTE differences among neighboring phases, these heterogeneities are expected to act as nucleation sites for thermally-induced cracks and promotes subsequent crack growth. Therefore, an experimental quantification of the different CTE values in the meteorite's natural constituent phases is needed, as well as a characterization of the extent of crack initiation and propagation due to diurnal temperature cycling. This will allow the development of more informed thermal fragmentation models. Such models are crucial in extending the experimental data to longer time and length scales and thus enabling a more complete understanding of the regolith generation processes on asteroids and other airless bodies. Currently, the authors are in the process of analyzing the sensitivity of meteorite samples to both crack initiation and propagation during heating and subsequent cooling.

Summary: The current report presents initial experimental results on the identification and quantification of the role of thermally-induced cracking in regolith formation. The hybrid experimental set-up combining DIC method and infrared thermography permitted the quantification of the local and global strain evolution as a function of temperature. Results suggested that the localized strain field associated with the CTE differences among neighboring phases give rises to stress interactions, which could ultimately drive microstructural cracks.

References: [1] Housen K. R. et al. (1982), Annu. Rev. Earth Planet. Sci., 5056-5070. [2] Yano H. et al. (2006), Science, 1350-1353. [3] Dombard A. J. (2010), Icarus, 713-721. [4] Delbo M. et al. (2014), Nature, 233-236. [5] Sutton M. A. Springer, New York, doi, 2009.