

EXPERIMENT ON THERMAL FATIGUE OF NEAR-EARTH ASTEROIDS AND LUNAR SURFACES USING REPRESENTATIVE TEMPERATURE CONDITIONS AND SAMPLES. O. Ruesch¹ and M. Patzek¹,

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Introduction: Regolith evolution on airless planetary surfaces needs to be understood at the spatial scale from meters to microns. With such understanding, the preservation of organic matter and volatiles embedded in the regolith can be assessed and the prebiotic chemical evolution of the Solar System can be better resolved. Diurnal temperature variations due to insolation on airless planetary surfaces is a common feature of planetary systems that can play a relevant role in regolith nature and evolution [e.g., 1-5]. In this study we highlight the need for improved understanding of rock breakdown due to temperature excursions and describe a laboratory experiment designed to characterize it. Preliminary results will be presented.

Diurnal temperature excursion effects on mechanical stresses: The stresses resulting from diurnal temperature variations can have a complex spatiotemporal pattern [5,6]. It is helpful to distinguish two types of stresses based on the spatial scale on which they occur. The so-called grain-scale stresses are due to material with spatially heterogeneous thermal expansion coefficients, e.g., contiguous grains with different thermal expansion coefficients. The amplitude of the temperature excursion is a key driver for this process. Other stresses can develop at a macroscopic (thermal skin depth) scale due to the development of strong spatial temperature gradients, e.g., stresses within a block due to daytime surface heating [e.g., 6].

Crack propagation due to these stresses leads to block erosion and, together with meteoroid impacts [e.g., 7], transform a blocky surface into fine regolith. This view of the geological evolution is rather simplistic, however. Recent observations have shown how surfaces of small bodies thought to be covered by cm-scale particles [e.g., 8] are blocky in nature [9,10] and the blocks have unexpectedly low thermal inertia, high porosity and low tensile strength [11]. These findings call for a better understanding of airless surface evolution.

Experimental requirements: [2] have shown how meteorites subjected to thermal cycling (250-440K) develop grain-to-grain thermal fatigue with consequent cracks grow observable in micro computed tomography (micro-CT) scans. Here we take the same approach and develop a new laboratory experiment to

investigate several aspects which were not previously considered:

(1) The different meteoritic components (i.e., chondrules, matrix, metal, sulfides, impact melt clasts and voids) and their distribution influence the preferred formation of cracks between components due to their different thermal conductivities [12,13] and fabric configuration [14]. A sample set representative of the natural petrological and rheological diversity of meteorites needs to be studied.

(2) Only meteorite samples with a low degree of terrestrial weathering are selected since the oxidation of metal can weaken the rock by its volume increase if the primary porosity is low or the abundance of metal is high [15]. Additionally, iron hydroxide may act as a cement filling primary porosity and change the thermal conductivity of the sample.

(3) The amplitude of temperature excursion as well as the absolute temperature range on actual planetary bodies might be important factors because natural samples have specific properties for given temperatures. [16] have shown how some CM2 carbonaceous chondrites have a negative thermal expansion in the range 210-240 K that might lead to enhanced physical disaggregation. To reach such low temperatures, a cryogenic experiment is needed.

(4) Adsorbed water molecules decrease the surface energy and the tensile strength [e.g., 17]. They thus enhance crack propagation [e.g., 18]. A high vacuum chamber (1×10^{-6} mbar) removes most water molecules adsorbed on surface from the atmosphere. Thus, the effects of native OH/H₂O phases from the samples can be studied, if present. A high vacuum chamber also allows the thermal conductivity of porous samples to be primarily controlled by the abundance of cement between grains [19] and avoid unrealistically high thermal conductivity due to gas convection in porous samples.

Experiment design: The experiment is based on an evacuated cryostat cooled with liquid nitrogen. Sample cubes of $\sim 10 \times 10 \times 10$ mm³ are placed on a copper cold finger. To maintain optimal thermal conductivity between the cold finger and the sample a thermal grease is applied. Temperatures are measured on the bottom and the top of the cold finger, and on a monitor sample 10 mm wide (El Hammami, H5; i.e. Fig. 1). A cartridge heater with a maximum power of 100W is installed at the base of the cold finger and is

able to heat the cold finger to a maximum of 475K. The temperature measured inside the monitor sample allow us to ensure successful heat conduction through the samples.

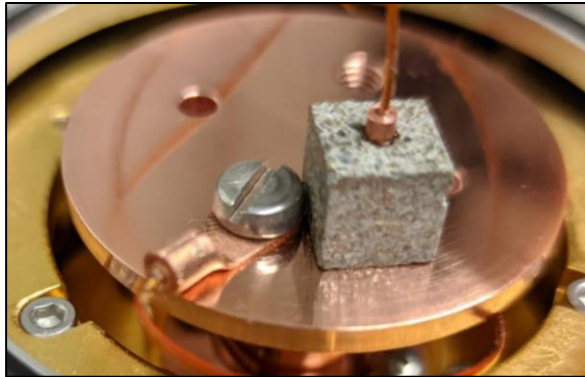


Figure 1. Copper plate with controllable temperatures from 100 K to 400 K. A monitor sample is placed on top of the plate with inserted thermocouple.

Preliminary results: During hardware testing, the terrestrially weathered L4 chondrite Hammadah al Hamra 236 (HaH 236) was subject to thermal cycling between 175 K and 375 K with a ramping rate of 2 K/min during heating and during cooling (conditions found on near-Earth asteroids). Scanning Electron Microscope observations were made after 5 and 10 cycles on the top face of the sample that does not touch the plate.

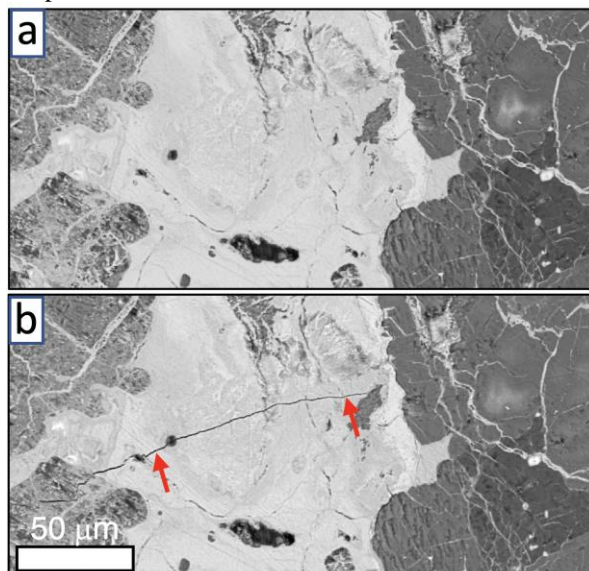


Figure 2. Backscattered electron image of a terrestrially weathered metal grain in the L4 chondrite HaH 236 (light grey) before (a) and after (b) 5 thermal cycles. The newly formed crack (red arrows) extents only within the oxyhydroxide phase that replaced the original metal grain.

After 5 cycles new cracks (few μm wide, $\sim 200 \mu\text{m}$ long) opened within oxyhydroxide phases (Fig. 2). Other minerals were not affected. No further changes were observed after 5 additional cycles, as opposed to the findings of [20] with a L3.6 chondrite, although under different temperatures conditions. The cause of cracking can be thermal fatigue and/or cracking due to loss of adsorbed water molecules from the oxyhydroxide phases. The latter interpretation is supported by report of micropores development in dehydrating particles at the temperatures of our experiment [21]. Although this sample is not representative of asteroids, the finding clearly points to the role of mineralogy in rock breakdown.

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