Effect of thermal cycling on the regolith formation. S.Cohoner[1], D.Britt[2], B.Harthong[1], A.DiDonna[1] and R.Peyroux[1]
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The Hayabusa2 space mission recently returned asteroid regolith samples from the carbonaceous asteroid 162173 Ryugu to Earth. Other samples from the astoid 101955 Bennu which is also a carbonaceous asteroid are on their way to Earth with the OSIRIS-REx mission. Micrometeorite bombardment [1–3] and thermal cracking [4–7] are thought to be the two main processes responsible for the formation of regolith.

In this study we focus on the formation of regolith due to thermal fracturing. Surface temperature can vary significantly during day/night cycles. In fact, the temperature variation of a type C near earth asteroid (NEA) is of the order of 200K [4]. An analogue to carbonaceous meteorites with a CM-like composition, following the preliminary compositional results for 101955 Bennu and 162173 Ryugu was developed in collaboration with the University of Central Florida (UCF) and Deep Space Industries (DSI) [8]. It is now produced by UCF's Exolith Lab will be used to investigate this phenomena.

Water and sodium metasilicate were added to the simulant to act as a binder to form blocks with strength properties similar to CM meteorites. Glass beads of 400 −600μm were added to simulate chondrite inclusions (chondrules, CAIs). A wire saw was used to machine the samples into the appropriate experimental shape. The experiment consists in subjecting the samples to thermal cycles and regularly scan them with X-ray tomography in order to follow the thermal induced crack propagation. We chose a cylindrical shape to have a temperature propagation as homogeneous as possible. The size of the sample has been chosen to be big enough to be a representative volume element and as small as possible to reduce the time of the thermal cycles (11mm of diameter and 20mm height).

The samples were subjected to temperature variations of ΔT=200K. To do so, liquid nitrogen was used to cool down the sample to 77K while the ambient temperature will warm it up. In order to avoid the formation of frost on the sample, which would deteriorate it, the sample was put inside a thin copper tube. In order to fill the empty space between the wall of the tube and the sample and avoid the thermal barrier of the air, aluminum foil was used to wrap the sample and ensure thermal contact between the copper tube and the simulant. This set up protected the sample against the ambient humidity without significantly extending the time required for the thermal cycling. To assure the hermeticity, the tube has been made long enough for the cap to be always outside the liquid nitrogen tank.

Numerical simulations were run to assess the time needed to perform one cycle. Even though these simulations did not take into account all physical phenomena such as the evaporation of the liquid nitrogen in contact with the sample, the results are in agreement with those of the preliminary tests. Sensors linked with an Arduino card were used automatically track the thermal cycles and a Python interface enabled us to see the evolution of the temperature of inside the tube in real time.

X-ray tomography scans have been performed at the initial state and after different amount of cycles in order to follow the formation and the propagation of cracks inside the material. The images were then processed using SPAM, a Python numerical code developed by the 3SR laboratory in Grenoble, France [9].

The first results show the appearance of cracks from the first 70 cycles. These cracks occur in areas close to the sample surface and are localized around inclusions. During the first 140 cycles, there are detachments of inclusion on the surface as well as the propagation of certain large voids which can go as far as opening on the surface (See in Figure 1). After 270 cycles, the propagation of the cracks significantly damaged the material, making it weaker, which led to the rupture of the lower part of our sample (See in Figure 2).

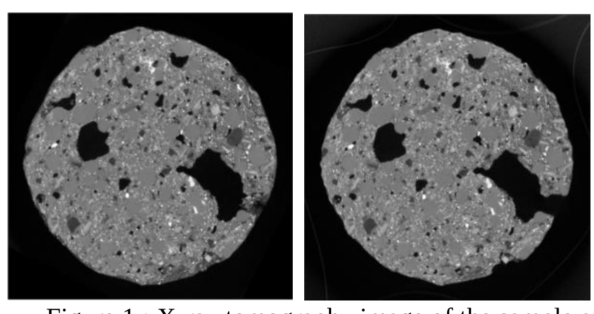

Figure 1 : X-ray tomography image of the sample at the initial state (on the left) and after 140 cycles.(on the right)

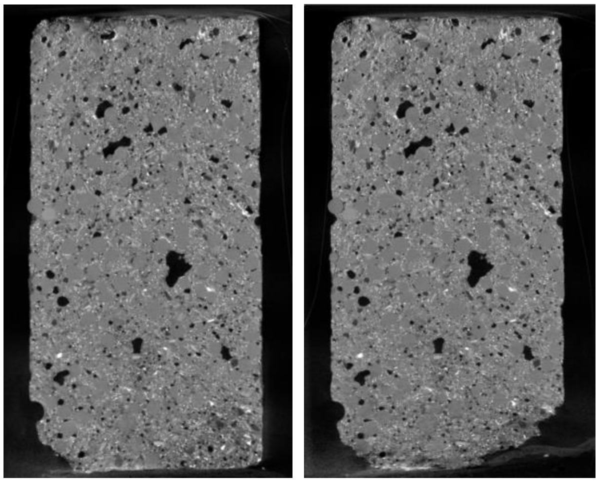

Figure 2 : X-ray tomography image of the sample at the initial state (on the left) and after 400 cycles.(on the right)

References:

[1] J. D. Hogan, C. El Mir, J. B. Plescia, and K. Ramesh, (2015), *Dynamic brittle fragmentation: probing the byproducts of hypervelocity impact in space*, Procedia Engineering 103, 205–212.

[2] T. M. Yamada, K. Ando, T. Morota, and H. Katsuragi, (2016), *“Timescale of asteroid resurfacing by regolith convection resulting from the impact-induced global seismic shaking”*, Icarus 272, 165–177.

[3] C. Avdellidou, C. Schultz, M. Price, M. Cole, A. DiDonna, B. Harthong, M. Delbo, D. Britt, and R. Peyroux, (2019), *“Mechanical properties of very weak carbonaceous asteroid analogues and response to hypervelocity impacts.”*, Icarus.

[4] M. Delbo, G. Libourel, J. Wilkerson, N. Murdoch, P. Michel, K. Ramesh, C. Ganino, C. Verati,and S. Marchi, (2014), *“Thermal fatigue as the origin of regolith on small asteroids”*, Nature 508, 233–236.

[5] K. Hazeli, C. El Mir, S. Papanikolaou, M. Delbo, and K. Ramesh, (2018), *“The origins of asteroidal rock disaggregation: interplay of thermal fatigue and microstructure”*, Icarus 304, 172–182.

[6] C. El Mir, K. Ramesh, and M. Delbo, (2019), *“The efficiency of thermal fatigue in regolith generation on small airless bodies”*, Icarus 333, 356–370.

[7] J. Molaro, K. Walsh, E. Jawin, R.-L. Ballouz, C. Bennett, D. DellaGiustina, D. Golish, C. D. d’Aubigny, B. Rizk, S. Schwartz, et al., (2020), *“In situ evidence of thermally induced rock breakdown widespread on bennu’s surface”*, Nature Communications 11, 1–11.

[8] D. T. Britt, K. M. Cannon, K. Donaldson Hanna, J. Hogancamp, O. Poch, P. Beck, D. Martin, J. Escrig, L. Bonal, and P. T. Metzger, (2019), *“Simulated asteroid materials based on carbonaceous chondrite mineralogies”*, Meteoritics & Planetary Science 54, 2067–2082.