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September 17 2021

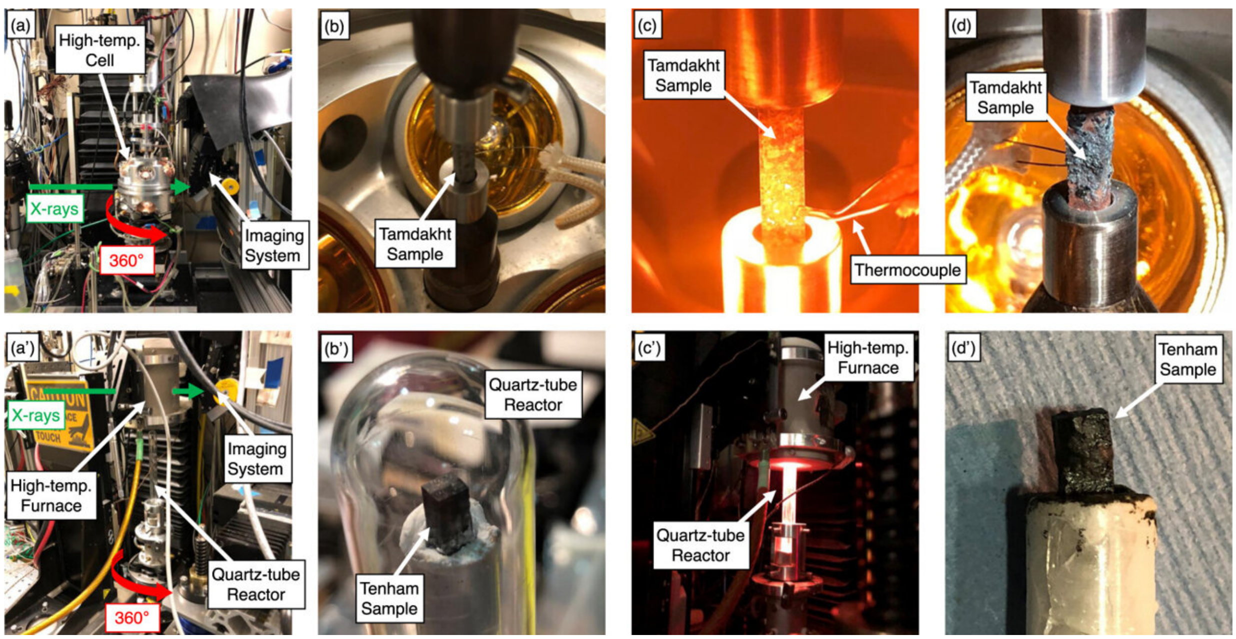

Figure 1. Setup for μ-CT experiments of the Tamdakht (top) and Tenham (bottom) meteorite samples. Credit: DOI: 10.3847/PSJ/ac1749

Researchers at the University of Illinois Urbana-Champaign watched fragments of two meteors as they ramped up the heat from room temperature to the temperature it reaches as it enters Earth's atmosphere and made a significant discovery. The vaporized iron sulfide leaves behind voids, making the material more porous. This information will help when predicting the weight of a meteor, its likelihood to break apart, and the subsequent damage assessment if it should land.

"We extracted samples from the interiors that had not already been exposed to the high heat of the entry environment," said Francesco Panerai, professor in the Department of Aerospace Engineering at UIUC. "We wanted to understand how the microstructure of a meteorite changes as it travels through the atmosphere."

Panerai and collaborators at NASA Ames Research Center used an X-ray microtomography technique that allowed them to observe the samples in place as they were heated up to 2,200 degrees Fahrenheit and create images in three dimensions. The experiments were performed using the synchrotron Advanced Light Source at Lawrence Berkeley National Laboratory.

"The iron sulfide inside the meteorite vaporized as it heated. Some of the grains actually disappeared leaving large voids in the material," Panerai said. "We were surprised by this observation. The ability to look at the interior of the meteorite in 3D, while being heated, led us to discover a progressive increase of material porosity with heating. After that, we took cross sections of the material and looked at the chemical composition to understand the phase that had been modified by the heating, changing its porosity.

"This discovery provides evidence that meteorite materials become porous and permeable, which we speculate will have an effect on its strength and propensity for fragmentation."

NASA selected Tamdakht as case study, a meteorite that landed in a Moroccan desert a few years ago. But the team of researchers wanted to corroborate what they'd seen so they repeated experiments on Tenham to see if a meteorite with different composition would behave in the same way. Both specimens were from a similar class of meteorite called chondrites, the most common among the meteorite finds that are made up of iron and nickel, which are high-density elements.

"Both became porous, but the porosity that develops depends upon the content of the sulfides," Panerai said. "One of the two had higher iron sulfides, which is what evaporates. We found that the vaporizing of iron sulfides happens at mild entry temperatures. This is something that would happen, not at the external fusion crust of the meteorite where the temperature is a lot higher, but just underneath the surface."

The study was motivated by the potential threat meteorites pose humans—the clearest example being the Chelyabinsk meteor that blasted the Earth's atmosphere over Russia in 2013 and resulted in about 1,500 people being injured from indirect effects such as broken glass from the shock wave. After that incident, NASA created the Asteroid Threat Assessment Program to provide scientific tools that can help decision makers understand potential meteorite threats to the population.

"Most of the cosmic material burns away as it enters. The atmosphere protects us," Panerai said. "But there are significant sized meteorites that can be harmful. For these larger objects that have a non-zero probability of hitting us, we need to have tools to predict what damage they would do if they would hit Earth. Based on these tools, we can predict how it enters the atmosphere, its size, how it behaves as it goes through the atmosphere, etc. so decision makers can take counter measures."

Panerai said the Asteroid Threat Assessment Program is currently developing models to show how meteorites behave and models require a lot of data. "We used machine learning for the data analysis because the amount of data to analyze is huge and we need efficient techniques.

"We are also using tools refined over the years for the design of hypersonic entry vehicle and transferring this knowledge to the study of meteoroids, the only hypersonic systems in nature, which is very exciting. This provides NASA with critical data on the microstructure and morphology of how a common meteorite behaves during heating, so that those features can be integrated in those models."

More information: Francesco Panerai et al, Morphological Evolution of Ordinary Chondrite Microstructure during Heating: Implications for Atmospheric Entry, *The Planetary Science Journal* (2021). DOI: 10.3847/PSJ/ac1749

Provided by University of Illinois at Urbana-Champaign