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The tensile strength of ice and dust aggregates

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Abstract

In order to understand the early formation of planets in the solar system and the activity of comets the tensile strength of astrophysical materials is of major importance. Therefore we currently developed a method to measure the tensile strength of ice and dust aggregates. The measured tensile strength for dust aggregates is depending on the grain size and for water ice it is very low compared to the theoretical predictions, so the specific surface energy has to be an steep function of temperature and very low at 150K.

1. Introduction

The tensile strength describes the maximum mechanical force a material can resist before it breaks. The knowledge of this parameter is important in astrophysics, because it describes the mechanical behaviour. In the formation of planets, the kilometre-sized planetesimals were formed by collisions of millimetre-sized aggregates. These were grown out of micrometre-sized particles, also by collisions. Besides other physical parameters, the tensile strength influences the growth of particles. [4].
For comets, the tensile strength is also very important to describe the dust activity [5]. The reason for the activity is the sublimation of icy materials, mainly water ice. The resulting gas pressure can eject aggregates from the surface by momentum transfer, if it is sufficient to overcome the tensile strength of the aggregate packing. In this picture, the presence of millimetre-sized particles in the coma can be explained, but not the existence of smaller micrometre-sized particles. For their existence, the aggregates must be broken by an unknown mechanism, which must provide a disruption stress greater than the tensile strength.
Motivated by this importance, an experiment was designed to measure the tensile strength of ice and dust aggregates.

2. The experiment

For this purpose the Brazilian Disc Test was chosen. This method uses a piston is used to compress a cylindrical sample (disc) until it fails. The maximum force is measured and used to calculate the tensile strength [1]. The experimental setup is shown in figure 1. The tensile strength σ is than calculated by

$$\sigma = \frac{2\,F}{\pi\,l\,d} \tag{1}$$

where F is the maximum force, d the diameter and l the thickness of the disc.
The samples were formed in a press, so that the diameters of all dust and ice samples were the same value. The thickness is determined by the amount of material used and was typically $11 - 26mm$. For the compression of the samples we used always the same pressure to achieve a constant volume filling factor.
To be able to perform measurements with ice the whole experiment was cooled with liquid nitrogen. Because the discs were very fragile and the temperature had to be very low (less than 150K), the experiment were performed directly inside the press without touching or moving the disk. The temperature of all parts in contact with the sample and the air around it were measured to ensure no sintering happens, so the temperature is always under 150K ([2] for details).
The exerted force was measured by a scale underneath the sample and the resulting cracks were observed by a camera.

3. Results

In figure 2, a typical measured curve is shown. In the first 40 seconds, the piston is moving without touching the sample, thus, the scale measures zero force. Therefore the tensile strength calculated with equation 1 is also zero. When the force starts to rise, the piston touches the sample. The maximum force is measured

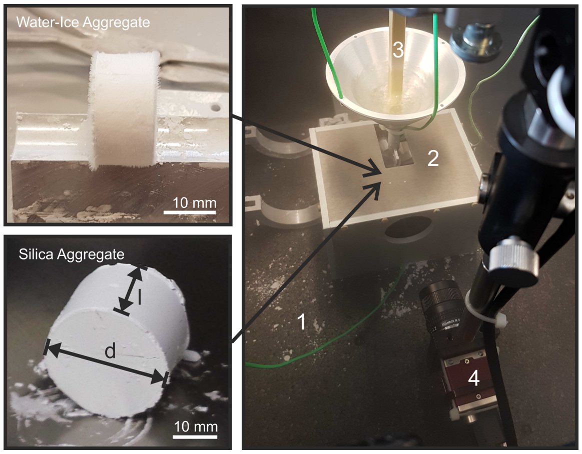

Figure 1: Images of the aggregates (left) and the experimental setup (right) used. Components visible in the image: styrofoam box (1) and metal housing (2) needed for low temperatures, piston (3) controlled by a stepper motor to exert pressure and the camera (4) to observe the crack appearing. The scale required for monitoring the exerted force is positioned underneath the styrofoam box and so not visible in the image [3].

at the point of breakup. After that, the force is depending on the crack, but not important for the tensile strength.
The tensile strength of the dust samples depends on the size of the particles used, so it gets higher with smaller particles.
Due to the extreme fragility of the ice samples the measured tensile strength is very low, even in regard of the bigger particle sizes. The tensile strength is $1.2 \pm 0.6 kPa$ with a volume filling factor of $\Phi = 0.5$. This value is less than the expected tensile strength for dust at this grain size, so the surface energy of water ice at 150K must be much lower than expected, so it is a steep function of temperature.

4. Summary and Conclusions

In this work the principal of the Brazilian Disk Test was used to measure the tensile strength of ice and dust samples. Therefore the experiment was modified to enable low temperatures. The results show, that the tensile strength of water ice below 150K is much smaller than expected, so the surface energy must be much smaller at these temperatures than previously assumed. This means for astrophysical models that ice cannot be used as glue for the aggregates in the formation of planets.

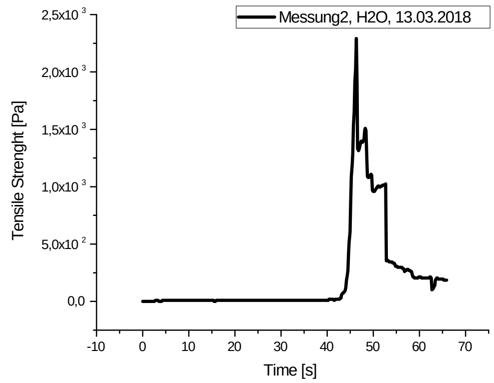

Figure 2: Example for a typical tensile strength measurement of an ice aggregate. With the force measured by the scale, the tensile strength was calculated by using equation 1. The temporal evaluation of the tensile strength is shown. During the experiment the temperatures were always under 150K. The maximal tensile strength measured is used for every sample.

Acknowledgements

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