IMPACT EXPERIMENTS IN LOW-TEMPERATURE ICE

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Introduction With the discovery of the large population of impact craters on the surfaces of Jupiter's and Saturn's icy satellites, the role of impact cratering in ice targets at temperatures of 85 $\pm$ 10 K and 70 $\pm$ 10 K, corresponding to those existing on these planets, respectively, has become of prime importance for the understanding of the evolution of these satellites. An important aspect of cratering on icy planets is determining the largest crater which objects can sustain without planetary disruption, as well as the effect of the ultimate strength of the impacted body on the shape of the crater which can be formed for large scale events. In impact experiments on glass spheres [1], basalt cubes [2], and on basalt- and ice spheres [3], the critical specific kinetic energy ke (ke = kinetic energy of projectile / target mass) upon which the targets completely ruptured was found to lie at 10^7, 6 X 10^6, and 3 x 10^5 ergs/g, for glass, basalt, and ice, respectively.

Measurements of the ultimate unconfined compressive strength of ice at small strain rates yielded a significant increase of strength with decreasing temperatures from 12 to 67 bars for temperatures from 273 to 223 K [4]. Whether or not these results are applicable to very large strain rates, typical for an impact event, as well as whether this trend persists down to temperatures applicable to the surface conditions of Jupiter's and Saturn's satellites (see above), has not been determined. We performed impact experiments on cubic ice targets of different temperatures, aimed to determine the critical specific kinetic energy of ice as a function of temperature, in order to shed some light on the question of impact cratering on icy planets.

Experimental Procedure The targets were prepared following the technique described by [5]. The cubic blocks of appr. 19 cm size were built up in plastic containers, layer by layer, each layer consisting of crushed ice and water, thus preventing the formation of single crystals and the incorporation of large bubbles. The blocks were then stored in a freezer at temperatures of about 205 K for several hours. For lower temperature ice, subliming, solid CO_2 of 194.5 K and boiling liquid nitrogen of 77 K were used as cooling agents. The ice blocks were weighed and temperatures were measured immediately before the shooting, by means of two thermocouples, placed at different positions in the block. The target was then placed in front of a sealed barrel of a 20 mm gun, inside a steel tank. The target blocks were impacted a few minutes after removal from the coolant, which provided only insignificant warming of the block. We used pure Lexan projectiles (Lexan is a poly-carbonate with a density of 1.196 g/ccm). Immediately after the impact, the fragmented target block was photographed and a number of representative samples, from different positions in the tank were taken for further analysis.

Results As yet, three experiments have been completed. For all three experiments the targets were impacted with velocities of 1 km/s, target temperatures lay at 257 K, 205 K, and 81 K, respectively. Impact velocity (1 km/s), projectile mass (6.1 g), and target masses M_T between 5.4 and 6 kg yielded specific kinetic energies ke in the range of 5.3 x 10^6 and 5.9 x 10^6 ergs/g. These values lie close to the critical values of glass- and basalt targets and well above the critical value of ice as given by [3]. Consequently, all of the targets in our experiments were completely ruptured.

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the resulting fragments can be divided into three size groups. Group I with fragment sizes in the mm to sub-cm range (snow to small fragments), group II with sizes in the range between sub-cm to 2 cm (small, irregular boulders), and group III with sizes between 2 cm and a maximum of around 8 cm (irregular boulders). The relative amount of fragments in each size group varied from 5-25%, 60-75%, and 10-25% for group I, II, and III, resp. The fragments were usually concentrated on either side of the tank, i.e. close to the impact point and away from the impact point, on the back wall of the tank, respectively. It was seen, that the number of larger fragments increased with increasing distance from the point of impact. Figure 1 gives the weight distribution of fragments for all three experiments. The sampled fragments generally belong to the third size group. As can be seen, the relative distribution of fragment weights m_f for the three target temperatures is essentially the same with the bulk of the fragments having weights between 5 and 25 g. However, the increase in the absolute number of fragments with decreasing temperature as shown in Fig. 1 is not a sampling error but is due to the fact that the number of fragments belonging to size group III increased with decreasing temperature.

Figure 2 gives the cumulative number of fragments of our experiments as well as those for a basaltic target as given by [2]. The cumulative numbers are given as function of the ratio of fragment mass m_f to target mass M_T. As can be seen, relative fragment sizes for a basaltic target are larger by one to two orders of magnitude as compared to ice targets for impacts of comparable strength, i.e. comparable value of ke. This indicates that the mechanical properties of ice of even very low temperature differs significantly from those of rocks.

In order to investigate the shapes of the resulting fragments, we measured three different parameters a, b, and c. These are defined according to the description given by [6] as the length of the long, intermediate, and short axis of semi-parallel surfaces on each fragment, respectively. Figure 3 gives the ratio of b/a as a function of c/a for most of the sampled fragments from the 257 K and 81 K targets. The mean values for b/a and c/a for both targets are very similar, i.e. 0.75 and 0.49 and 0.74 and 0.56 for the 257 K and 81 K ice, respectively, and are in accordance with the ratios reported for a basaltic target (0.73 and 0.50 for b/a and c/a, resp.)[6]. However, from a close inspection of Fig. 3 it can be seen that more of the 257 K fragments tend to be platy as compared to the 81 K fragments which are more spheric .

In conclusion, it was found that the critical specific kinetic energy for ice targets of temperatures down to 81 K lies well below 5×10^6 ergs/g. The relative abundance of large fragments, resulting from total rupture of an ice target increases with decreasing temperature but even at 81 K it is about 10^2 lower than that of indurated basalt.

References

[1] Gault, D. E. and J. A. Wedekind (1969) J. Geophys. Res., 74, 6780-6794.
[2] Fujiwara, A., G. Kamimoto, A. Tsukamoto (1977) Icarus, 31, 277-288.
[3] Hartmann, W. K. (1978) Icarus, 33, 50-61.
[4] Butkovich, T. R. (1959) Quart. Colo. Sch. Mines, 54, 349-360.
[5] Croft, S. K., S. W. Kieffer, and T. J. Ahrens (1979) J. Geophys. Res., 84, 8023-8032.
[6] Fujiwara, A., G. Kamimoto, and A. Tsukamoto (1977) unpublished.

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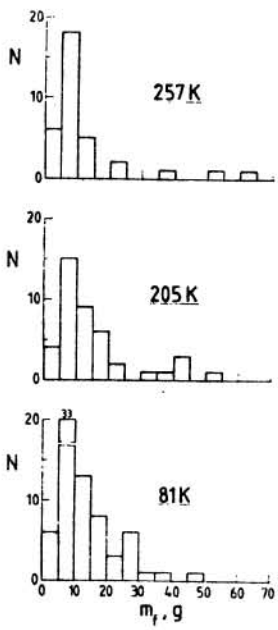

Figure 1: Weight distribution of fragments of 2 to 8 cm size for completely ruptured ice targets of varying temperature. See text for further details.

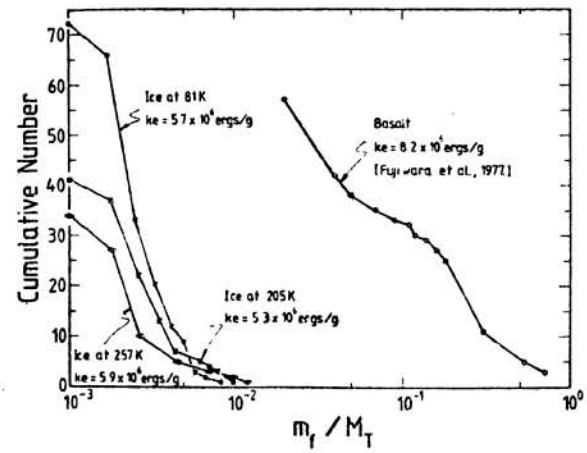

Figure 2: Cumulative number of fragments from completely ruptured basalt- and ice targets of varying temperature as function of the ratio of fragment weight m_f and target mass M_T. ke gives the specific kinetic energies of the projectiles.

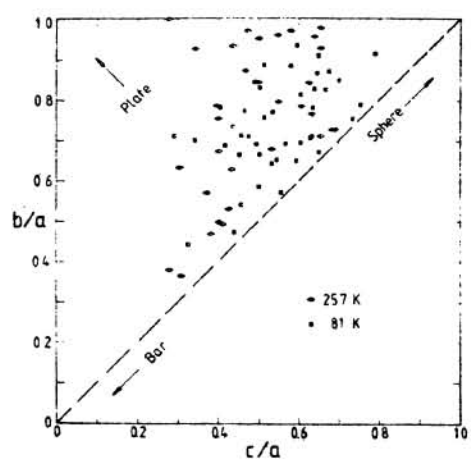

Figure 3: Ratios of shape factors b/a as a function of c/a for fragments of completely ruptured ice targets of varying temperature. Fragments are in the size range between 2 and 8 cm. a, b, and c are the length of the long, intermediate, and short axis, respectively, measured on semi-parallel surfaces of each fragment. For further details see [6] and text.

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