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The effect of target rheology on impact cratering.: case for a wet sand

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We report the results of experiments of impact cratering using wet sand target in order to understand the effect of target rheology. Many craters exist on the surface of planets and satellites, which were formed from meteorite impacts. Various forms of craters are found, such as a bowl-shaped simple crater and a crater with a small central peak. On mars, rampart craters, which are accompanied by distinctive fluidized ejecta, are found. Pit craters are also found on mars and on icy satellites. One cause for the variety of crater morphology is the difference of the surface rheology. There have been experiments using dry granular materials with variable grain size, in order to address the effect of rheology (e.g., Walsh et al, 2003). However experiments using wet granular materials have been limited (e.g., Gault & Greeley, 1978).

Our experiments were performed by releasing a steel ball from a holder so that it fell vertically into a cylindrical container (diameter:180mm, hight:90mm) filled with beach sand (grain size 0.2mm). We use a high-speed camera to record the crater formation process and laser displacement meter to measure crater profiles, from which we obtain the crater diameter and depth. For dry sand target (packing fraction phi=51.3 plus minus 0.1%), we conducted experiments using ball diameters in the range of 10mm-22.2mm and release heights of h=200-1100mm. For wet sand target (packing fraction phi=50 plus minus 2%), we fix ball size (22.2mm) and the release height (h=1100mm) and vary the water saturation(S) from 0 to 80%. We also measure the yield stress of the wet sand using rotating viscometer sheared at 10 rpm.

In dry sand target, we observed a simple crater and a crater with a central peak. Central peak crater formed under a large impact energy. In wet sand target, crater shape changed with S as follows: cone-shaped crater (S=0-3%), cylindrical crater with an outer ring (S=4.1-5.5%), cylindrical crater (S=5.8-72.5%), bowl-shaped crater whose shape is more rounded than the cone-shaped crater (S=74.1-77.4%). Cone-shaped crater formed central peak crater and its diameter decreased as S increased. With stiffening of the wet sand, the crater slope became resistant to collapse and became rougher. For a ringed cylindrical crater, the ring appears when the cylindrical crater begins to form. This phenomenon seems to be related to the increase of the yield stress of the wet sand, which limits the radial extent in which the crater is being excavated. As S increases further, ejecta volume decreases and the ring disappears. For cylindrical craters with small S, the surface is raised after the impact, whereas when S is greater than 62.5 %, the surface becomes depressed after the impact. For a bowl-shaped crater, the excavation occurs and ejecta reappears. The crater diameter changes with S as follows: first it decreases with S, then it becomes constant from S=6-10% to 60-70, after which it increases again. The change of diameter is anticorrelated with the change of the yield stress (sigma y) as a function of S. Stress arising from the inertia of the impacting ball can be estimated from sigma I ~ $(mv^2/R)/pi*R^2$ to be about $1.8*10^5$ [Pa] (m : ball bass, v : terminal velocity, R : ball diameter). The ratio of inertial stress to yield stress (sigma y / sigma I) becomes ~10^{-2} for dry sand, and ~10^{-1} for wet sand. Our experiments suggest that the morphological transiton occurs at around sigma y / sigma I ~10^{-1}.

Keywords: impact cratering, wet sand, rheology, experiment