Solid Nitrogen Hardness at Triton Conditions: Testing with the World's Only Instrumented Indenter for Cryogens

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Introduction: Neptune's largest moon, Triton, is a unique body that has a rarified Nitrogen atmosphere.[1] To enable development of future missions to study this captured Kuiper Belt Object such as the Triton Hopper, accurate mechanical property data of solid and gaseous nitrogen at relevant surface and atmospheric conditions are required. The surface of Triton is estimated to be at 1.6 Pa[2] and have a temperature range between 30-40 K.[3,4] This temperature range straddles the nitrogen α to β phase transformation temperature, 35.61 K.[5] There are only three known physical strength measurements for SN_2 reported in the literature.[6–8] Therefore additional data were needed to accurately assess the hardness of SN_2 and determine the requirements for extracting it for use.

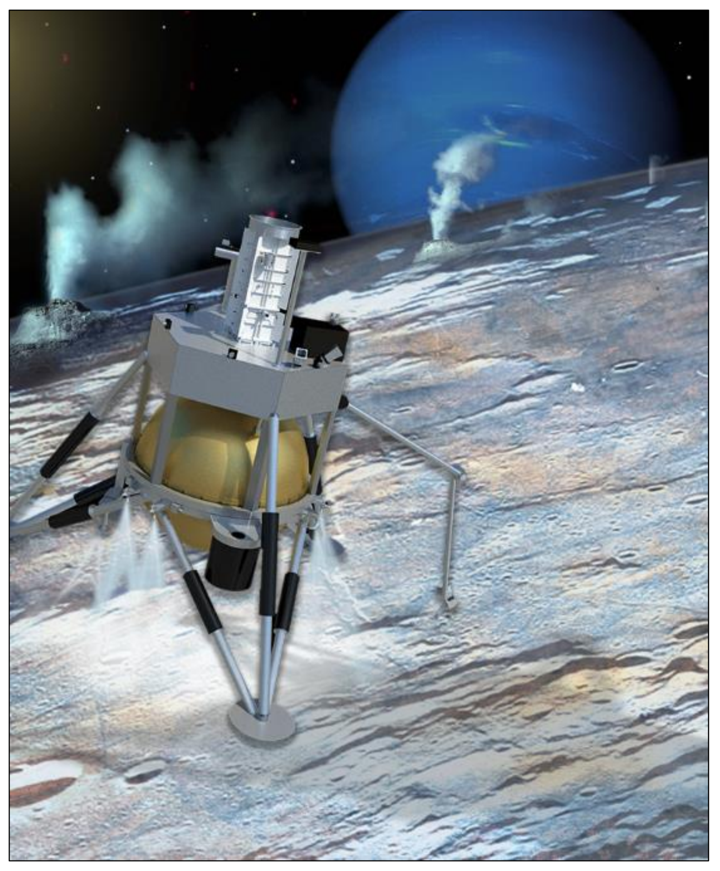

Figure 1. Rendering of the Hopper navigating Triton's surface.

Methods: An instrumented indentation tester was developed to interface with a custom-built cryostat. The stainless steel vacuum chamber is evacuated by a Leybold DB8 rotary vain vacuum pump in line with an Agilent Tv 81m turbomolecular pump. Cooling is provided by a Cryomech PT405 pulse-tube cryocooler.

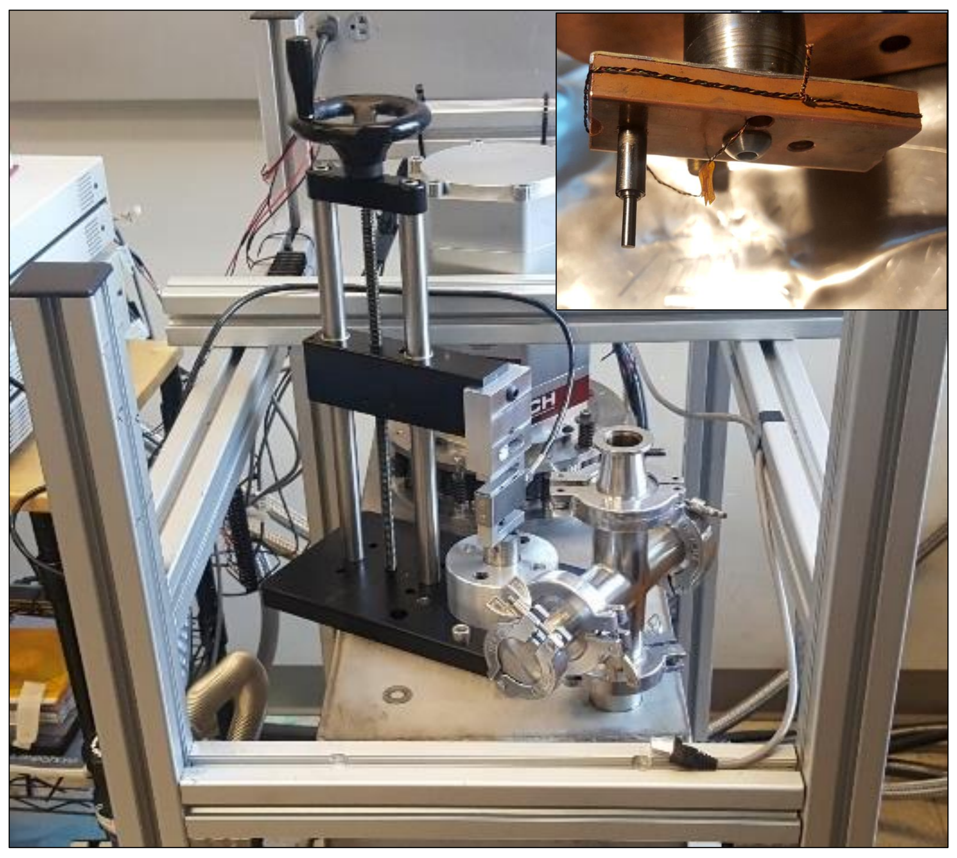

Figure 2. Photograph of the tester.

The system uses a commercially available 45 kg screw-driven load frame. A custom microcontroller system provides vertical motion control via a stepper motor and force measurement is via an S-beam load-cell. Inside the specimen chamber, a copper cross-bar is mounted to the end of the indenter shaft and the titanium indenter probe is threaded into the cross-bar. Offsetting the indenter from centerline enables multiple indents per sample without the need to reheat to liquid between tests. Reheating is necessary to provide an undeformed flat surface to indent. Thermal equilibrium was achieved by bringing the indenter into contact with the specimen. During all testing the crossbar temperature was measured at approximately 1.5 K above the sample temperature. The device is shown in Fig. 2 and illustrated in Fig. 3. A flat punch indenter geometry was used because this made surface detection via analysis of the force vs. displacement data straightforward and because a description of the projected area versus contact depth (area function) is not required for pressure analysis. Several indenter diameters were used throughout the temperature range to stay within the load capacity of the frame and provide maximum resolution. Drag from the O-ring seals was calibrated at temperature with no sample.

Highlights

- **Few strength measurements for SN_2**
- **Developed the world's first and only instrumented indenter for cryogens**
- **Test temperature range 30-40 K**
- **SN_2 hardness 0.5 kg/mm² to 2 kg/mm²**
- **SN_2 strength is similar to dry ice at earth atmospheric pressure, but more ductile**

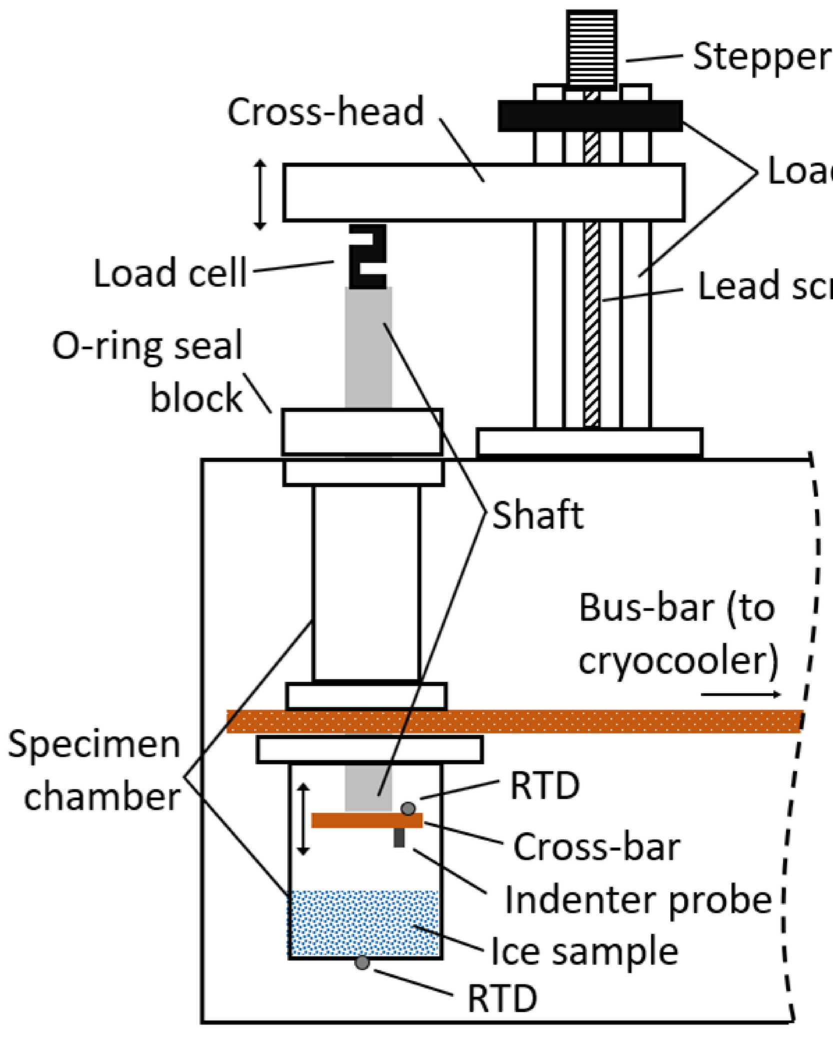

Figure 3. Schematic illustration of instrumented indentation tester.

The calibration force data were subtracted from the specimen data. This process was verified by substituting springs of known spring constant for the sample and showed acceptable results (Fig 4).

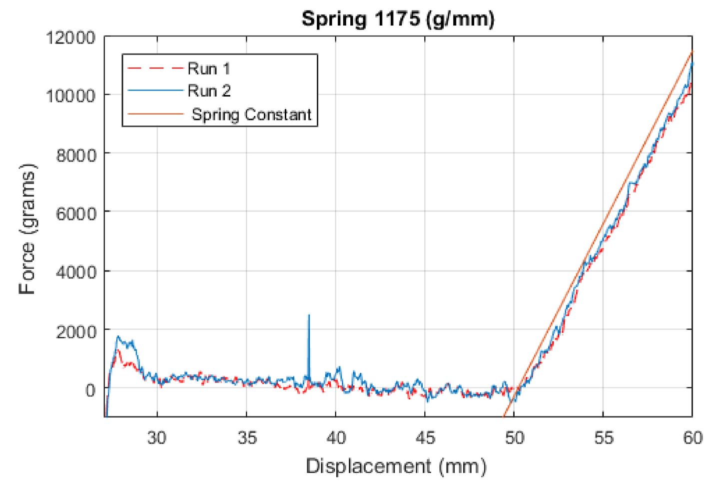

Figure 4. Typical spring verification data.

Results: Fig. 5 shows the pressure developed at the indenter surface versus displacement into the sample for several temperatures. The behavior of the SN_2 changed considerably with temperature. The curves show increasing pressure with increasing indenter penetration. This may indicate some degree of strain hardening or compressibility. At lower temperatures, a distinct reduction in pressure can be seen around 3.5 mm displacement into the sample.

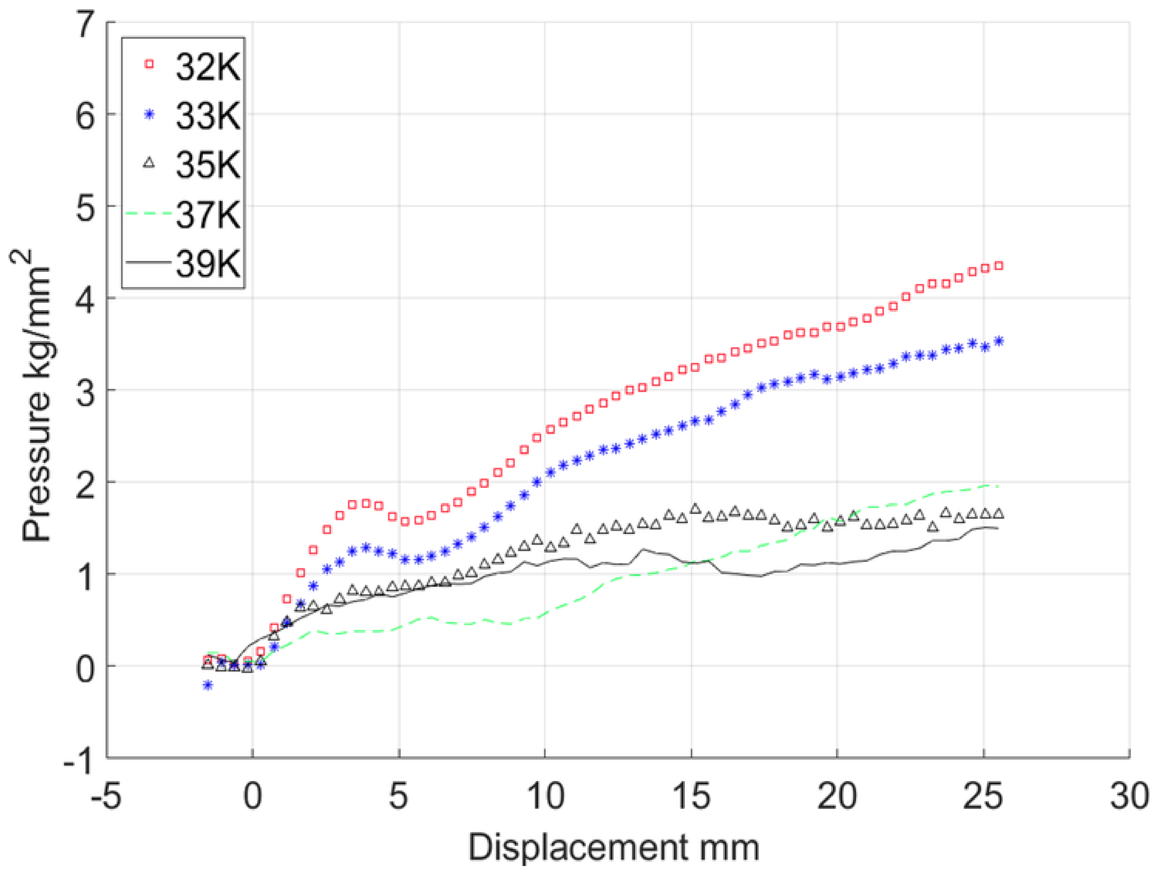

Figure 5: Hardness versus penetration.

Due to the pressure reduction, hardness values are calculated at the peak load before the drop. These ranged from 0.5 kg/mm² to 2 kg/mm². Trepp reported hardness between ~0.15. kg/mm² and ~0.6 kg/mm² in a similar range. Our results are somewhat harder due to several potential factors including: 1) selection of peak load for hardness calculation, 2) stainless steel indenter and structure in the previous experiment, 3) voids or bubbles in samples from previous experiments due to formation method. Dry ice at earth's atmospheric pressure was compared to SN_2 and shows similar behavior.

Figure 6: Testing dry ice.

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