COMMUNICATION TETHERS MAY SURVIVE SHEARING ACROSS ICE FAULTS ON EUROPA.

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Introduction: Maintaining robust communication over the duration of an exploration campaign is a central component of mission design. For ocean worlds exploration, this entails extended communication with a melt probe as it descends through what may be 10s of km of a tectonically (and/or chemically) hostile environment. To ascertain the feasibility of employing various forms of *optical* communication on Europa and other ocean worlds, our multi-disciplinary team is testing the mechanical and data transfer performance of commercial optical tethers, as currently used for polar submersible exploration as they might perform across a pre-existing active fault in the brittle portion of an ice shell—which we identified as a mission risk scenario.

Methodology: Our initial efforts [1] have focused on characterizing shear strength and optical integrity of various communication tethers embedded into ice blocks and sheared under applied force. We tested two particularly robust tether types: Linden Photonics Inc. Strong Tether Fiber Optic Cable (STFOC) and Linden High Strength STFOC (a jacketed, kevlar-reinforced STFOC referred to here as HS STFOC). A 3-section die was fabricated for sample preparation that applies pre-tensioning of the tether (via in-line mandrels) and freezes uniform, reproducible polycrystalline ice around the tether (via the standard ice method [2]) as in Fig. 1a. Sections were frozen in steps (first the central block, then outer blocks) with interfaces lubricated with Sprayon MR315 release agent and canola oil.

To conduct the tests, a servo-controlled cryogenic biaxial apparatus described in [3] was used in double-direct shear configuration (Fig. 1b). The sample assembly was pushed together under feedback-controlled normal stress (σ_n=100 kPa) and the central sliding block was forced down under controlled velocity. Velocities chosen represent a potential range of fault sliding behavior on Europa [4], from creeping (ramps of 0.5, 1, and 10 μm/s) to seismic, stick-slip events (100, 200, and 300 μm/s, each following a zero velocity hold) (Fig. 1c). Load cells located outside the cryostat measured normal and shear load over time.

Our experimental temperature range (100 – 260 K) was chosen to approximately represent the full range of thermal conditions in an ice shell. Temperature was maintained by a Liquid Nitrogen (LN)-cooled circulating chiller, which pumped low temperature fluid through copper channels next to the sample in a cryostat. In the case of lowest two temperatures, the cryostat was directly cooled by LN. Vacuum was used for thermal insulation, and temperature was monitored to ±0.1 K by RTDs embedded in the walls of the cryostat just adjacent to the sample.

Optical transmission loss was measured prior to freezing a tether inside ice blocks & during testing, by using an OptoTest OP250 Stabilized Light Source at 1310 nm with OP735 Benchtop Optical Power Meter.

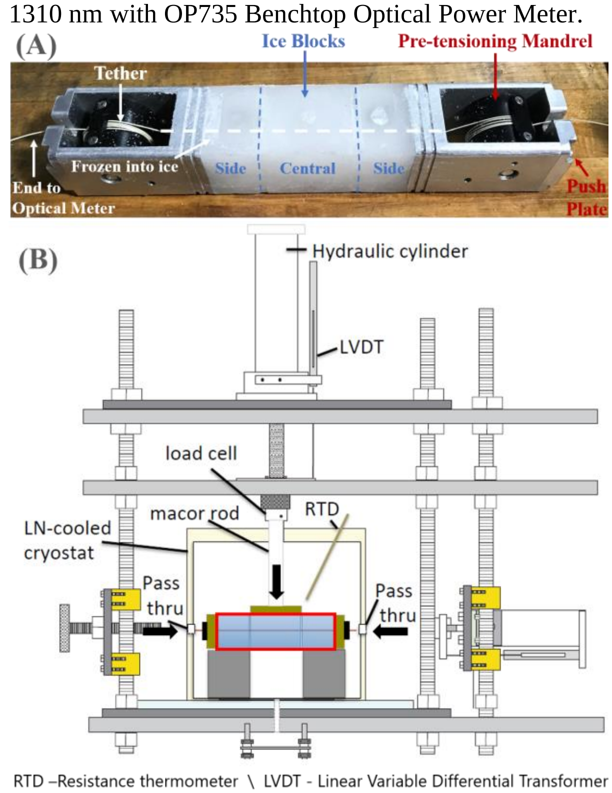

Figure 1: (a) A custom 3 block die with tether is placed inside (b) the cryogenic biaxial apparatus for shear testing.

Results: The initial strength of the ice block-tether assemblage, until cracking at interfaces, depends primarily on the strength of ice and as such depends on temperature. Fig. 2a. showcases the transition from ice-ocean interface to the surface of the ice shell. Subsequent cracking behavior (e.g. frequency, time period) show an additional dependence on shear velocity (Fig 2a. inset), with repeatable load drops and 'stick-break' events where shear stress is accommodated by (a) cutting/cracking of central ice block, and/or (b) increased load on horizontal load cells. Both STFOC and HS STFOC tethers survive the range of conditions tested, offering resistance to shear.

At relatively warm temperatures consistent with the ice–ocean interface (235-260 K): Ice interface breaks at a peak stress of ~70–300 kPa, with measured friction (shear/normal stress) exceeding that of the known friction of ice at these conditions (0.38-0.42). Both tethers cut a groove through the warm ice, sliding along the interface (Fig. 2b.i). All 3 blocks preserved their shape through testing.

At colder temperatures consistent with the inside of the ice shell (195-230 K): Ice breaks at the two shear planes at a peak stress of ~1.06–1.2 MPa (**1.06 MPa represents a minima as data was clipped in some runs)*. Here, the central ice block is pulverized during the ice-quakes and subsequent ramps, with side blocks preserving their shape. ***This indicates a potential ductile to brittle transition between 220–230 K.***

At even colder temperatures consistent with the surface of the ice shell (95–125 K): Ice cracks at a higher peak stress of ~1.3–1.5 MPa. Both central/side blocks are pulverized by the end of the test. Further, the protective outer layer of STFOC breaks for the first time, revealing the optical fiber which remains intact. HS STFOC tether also survives with a minor cut to the outer layer, and a kink at the interface (Fig. 2b.iii, iv).

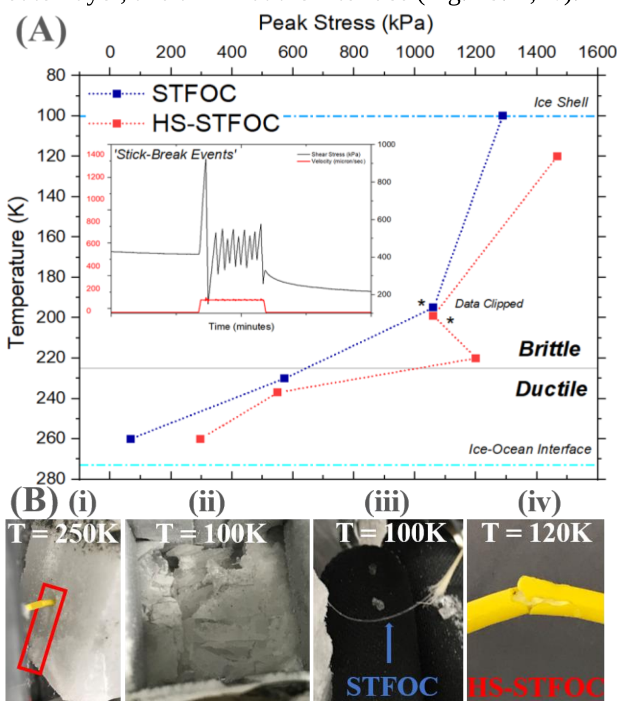

Figure 2: (a) Peak Stress vs Temperature for both tether types, and (b) images of central block (i) intact at 250 K with a groove, (ii) pulverized at 100 K – combined, they indicate a potential transition from ductile to brittle behavior between 220–230 K. (b. iii & iv) showcase the damage to the outer layer of STFOC and HS STFOC, to accommodate shearing.

Optical Transmission Loss: For HS STFOC, the signal was fully restored to pretesting values after: (i) installation in die; (ii) storage overnight at 260 K (for freezing in ice), and (iii) damage during testing at 100 K. Variation in signal during creeping ramps/icequakes is less than 0.1 dB (Fig. 3). During other experiments, the maximum observed loss was ~10 dB. STFOC tethers fully restored their signal post-test at 195 K & 260 K, with additional optical tests needed at 100 K.

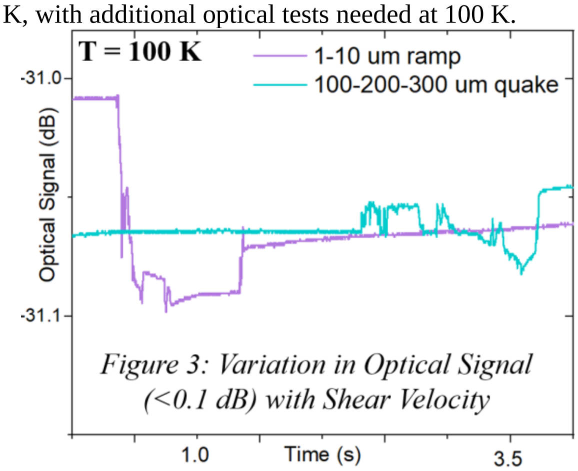

Figure 3: Variation in Optical Signal (<0.1 dB) with Shear Velocity

Our work suggests that the entirety of a water-ice shell may potentially be a viable stress regime for communication with tethers (HS STFOC faring better).

Future/Synchronous efforts: Although the work presented here focuses on the mechanical & optical behavior of two tethers in ice, our ongoing efforts will include the influence of impurity phases (various salts and sulfuric acid), particularly on the long term integrity of the outer tether shielding and how that affects performance of the inner fiber. Simultaneous efforts are being conducted by our team to improve our knowledge of the anticipated thermal and stress field in the Europan ice shell (see abstract Lien et al., for this meeting) — which the tether would encounter with depth and over time. Finally, we are exploring alternate modes of communication, such as RF and acoustic, which, combined with the results from these tests, will aid us in ultimately providing a recommendation for the optimal combination of robust and redundant communication through the entirety of the ice shell throughout the duration of a probe mission.

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