Impact of Cryogenic Temperatures on the Mechanical Properties of *Steatoda Triangulosa* Spider Silk

Christina Kieffer, Brendan See, William Becker

Advisors: Dr. Edward Pogozelski and Dr. Stephen Padalino

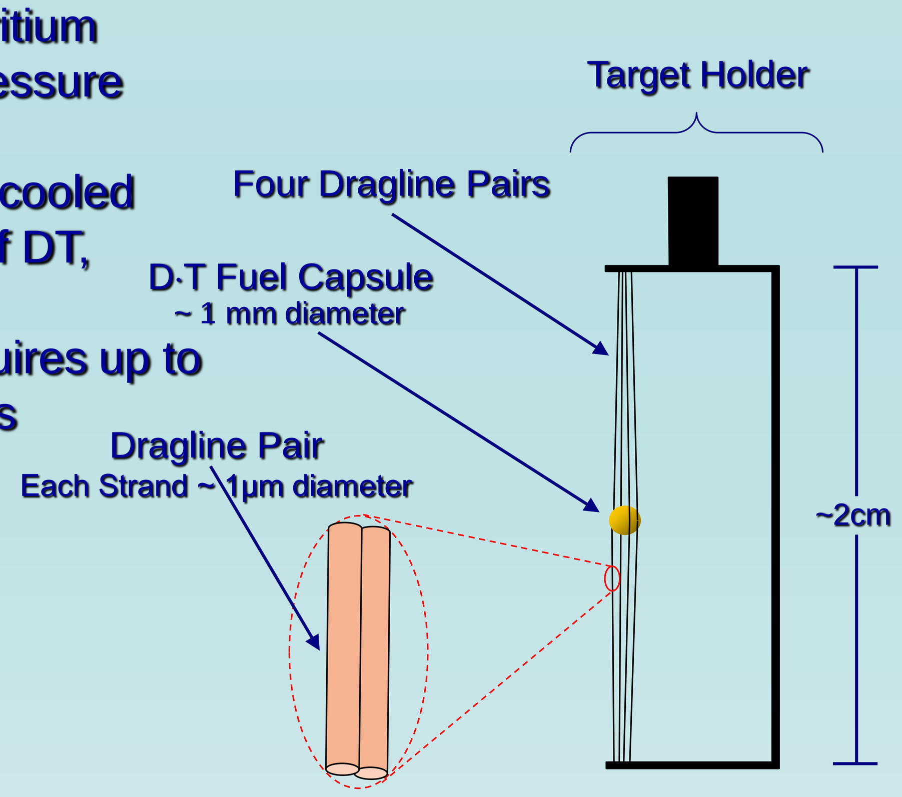
Laboratory for Laser Energetics

Abstract

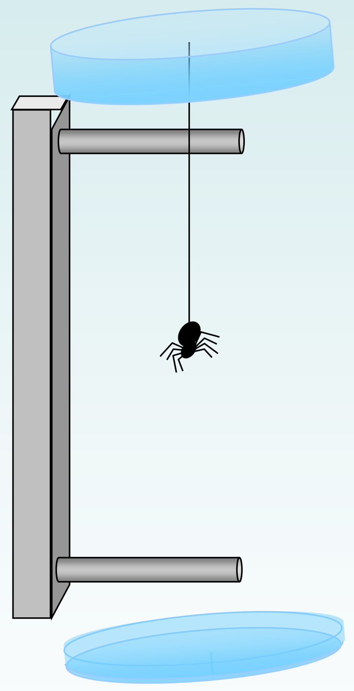
The mechanical properties of dragline spider silk from the species Steatoda Triangulosa are examined while submerged in liquid nitrogen. Dragline silk is used to hold deuterium and tritium laser fusion targets in place at the Laboratory for Laser Energetics (LLE) in Rochester, NY. When the targets are filled, the dragline is exposed to cryogenic temperatures. To simulate these temperatures, silk is dipped into liquid nitrogen. The mechanical properties of silk in air and in liquid nitrogen are compared. It was found that dragline silk is 64% stronger and 11% tougher when exposed to cryogenic temperatures.

Cryo-DT Target Holder

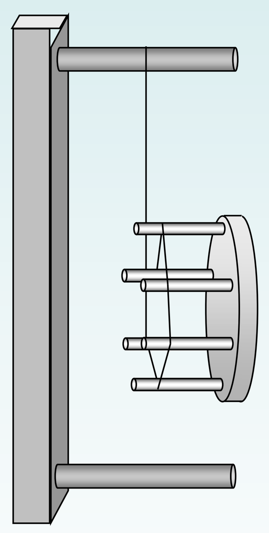
- Targets are placed in deuterium/tritium (DT) gas reaching a maximum pressure of 1500 atm
- DT gas diffuses into target and is cooled until the triple point temperature of DT, 19.7 K, is reached
- During this fill process, which requires up to 3 weeks, the silk is exposed to this cryogenic temperature

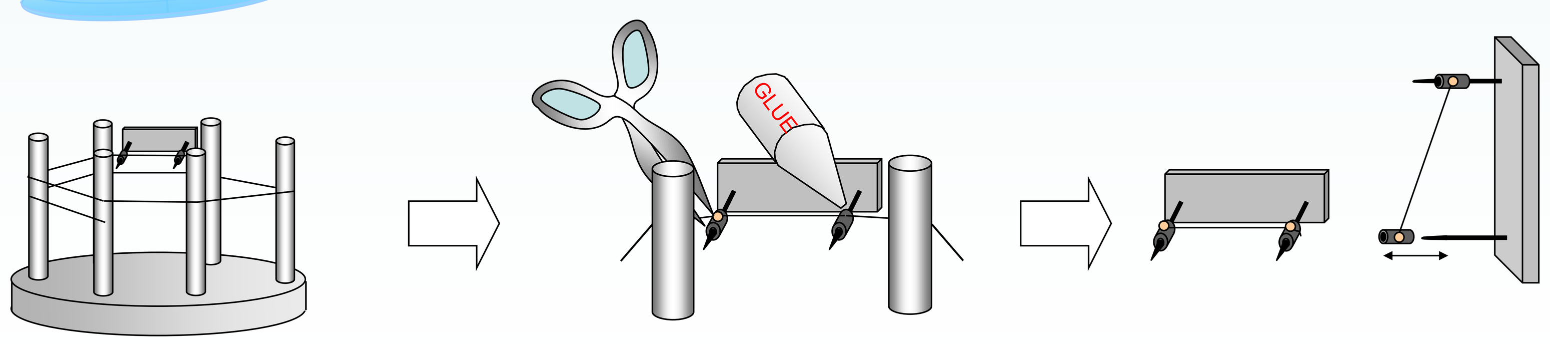


Harvesting/Mounting Silk



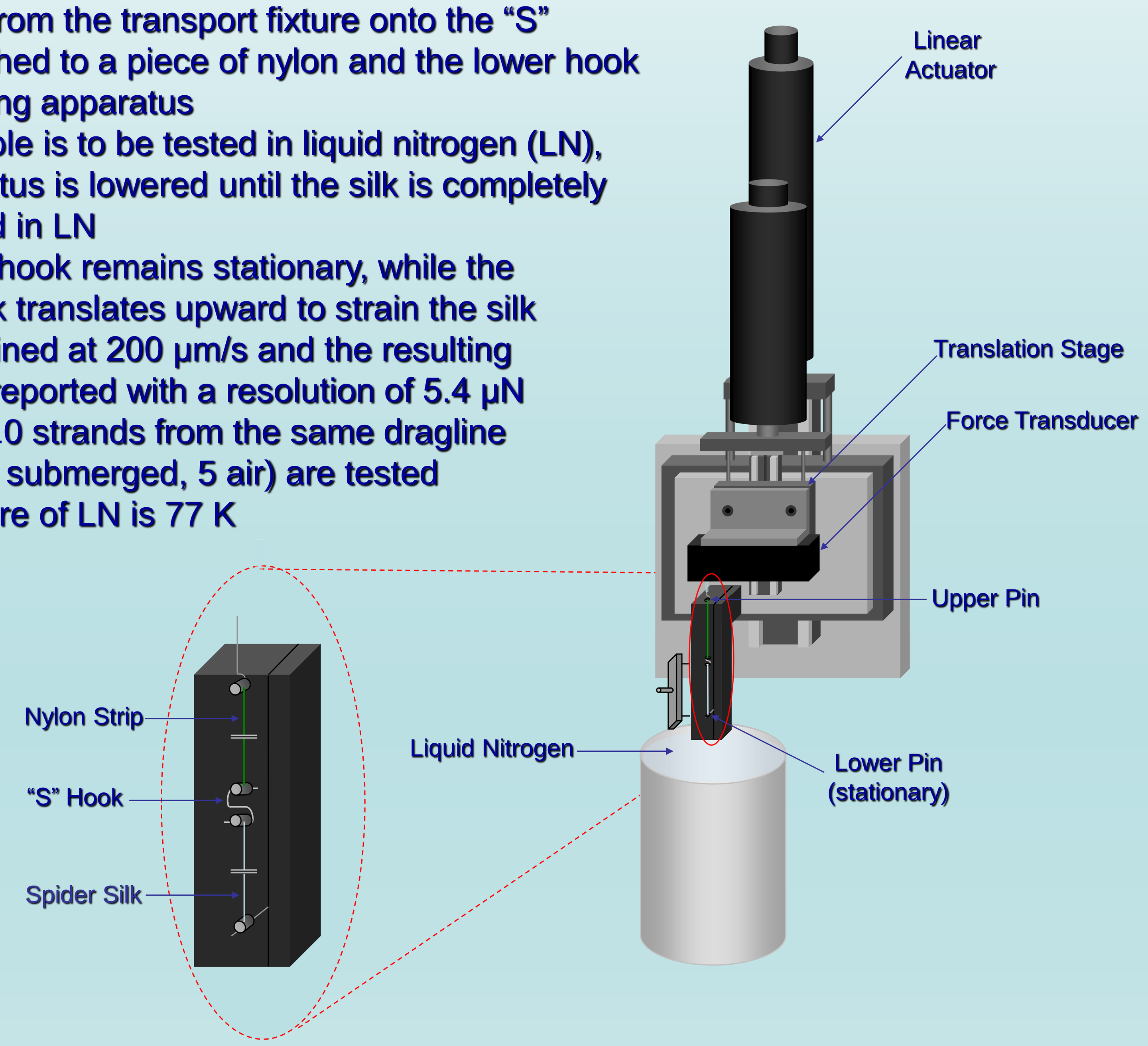
- Spiders release dragline silk when dropping from one surface to another
- Silk is caught between two pegs and then wound up onto a spool
- From the spool, silk is attached to two metal tubes with glue, and cut from the rest of the strand
- The tubes are free to slide on and off the transport fixture





Mechanical Testing

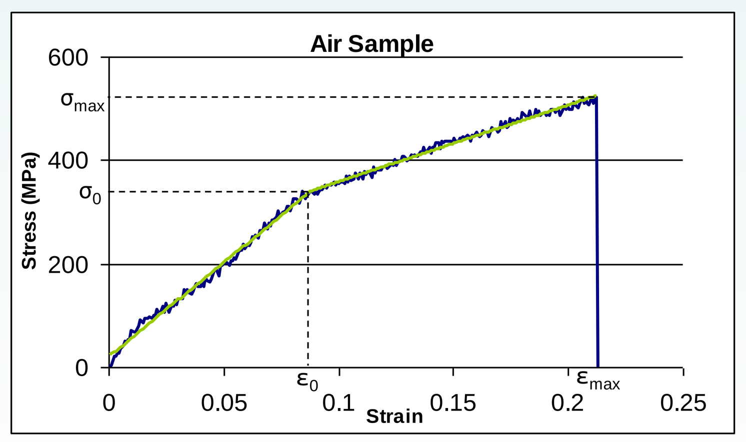
- Silk is mounted in our testing system by sliding the tubes from the transport fixture onto the "S" hook attached to a piece of nylon and the lower hook of the testing apparatus
- If the sample is to be tested in liquid nitrogen (LN), the apparatus is lowered until the silk is completely submerged in LN
- The lower hook remains stationary, while the upper hook translates upward to strain the silk
- Silk is strained at 200 μm/s and the resulting tension is reported with a resolution of 5.4 μN
- Typically, 10 strands from the same dragline drop (5 LN submerged, 5 air) are tested
- Temperature of LN is 77 K



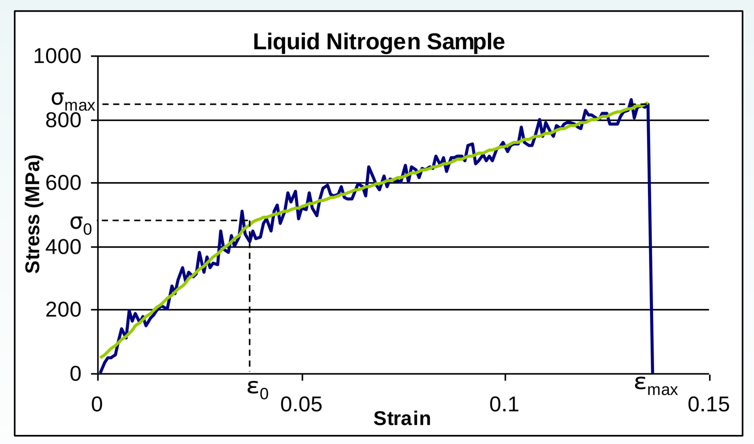
Data Analysis

- Stress-strain data are fit with two line segments
- Yield stress (σ_0), maximum stress (σ_{max}), yield strain (ε_0), and maximum strain (ε_{max}) are identified
- Young's Modulus (E_0 and E_1) of both linear regions are calculated
- Toughness (T) is calculated
- The statistics for the LN samples are averaged and compared with the average of the air samples
- LN plots are noisy due to constant boiling of LN

Sample Stress-Strain Analysis Results:



The average maximum stress for silk (4 strands) in air was 489 MPa

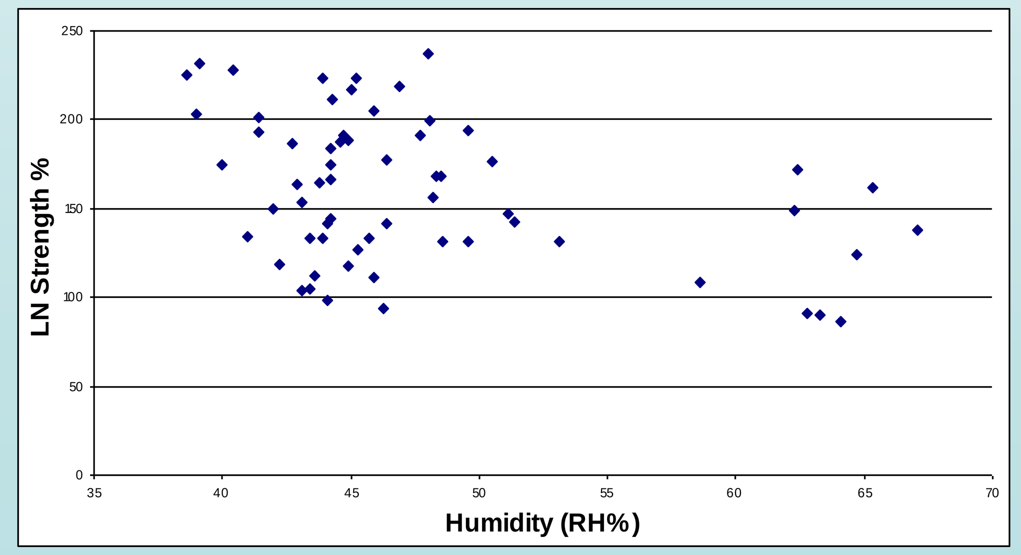


The average maximum stress for silk (4 strands) submerged in LN was 977 MPa

For this test, the relative strength of the silk submerged in LN was (199.8 ± 18.2)%

Humidity

- Does high relative humidity (RH) cause ice to form on the silk when submerged in LN, resulting in a measurement of ice's mechanical properties instead of silk's?
- Since LN strength decreases as RH increases, RH does not make it stronger – the natural variability of the strength of silk still predominates the results



Results

Average	LN	Air	LN / Air
σ_0 (MPa)	813 ± 26	461 ± 33	2.52 ± 0.13
σ_{max} (MPa)	1157 ± 26	734 ± 16	1.642 ± 0.032
ε_0	0.0513 ± 0.0018	0.106 ± 0.010	1.021 ± 0.099
ε_{max}	0.1180 ± 0.0038	0.2315 ± 0.0038	0.554 ± 0.023
E_0 (MPa)	15030 ± 310	4980 ± 160	3.60 ± 0.11
E_1 (MPa)	7910 ± 480	3170 ± 170	3.21 ± 0.18
T (MPa)	95.0 ± 4.4	100.0 ± 2.6	1.105 ± 0.068

- The values for LN and air are calculated by averaging each strand's properties
- The values for LN / Air are calculated by averaging each LN-dipped strand's ratio with each strand pulled in air from the same harvest

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