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Establishing a Standardized Test Method for Evaluating the Cut Resistance of Space Suit Glove Fabrics

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Overview

- Motivation and Purpose
- Background - Terrestrial Cut Testing
- Description of New Test Method
- Materials Tested
- Test Method Development
- Results of Testing and Analysis
- Recommendations
- Acknowledgements

Motivation and Purpose

- Motivation:
  - Artemis missions to Lunar surface will require the crew to handle sharp rocks, tools, dust, etc.
  - Deep cuts can result in damage to pressure retaining layer, causing suit leak
  - Gloves used for extravehicular activity (EVA) will need to be resistant to cutting from exposure to these and other hazards – WHILE AT ARTEMIS ENVIRONMENTAL CONDITIONS

- Purpose
  - This effort sought to develop a test method to evaluate space suit glove fabrics under ambient and cryogenic conditions.

- Goals
  - To provide a standardized test method to space suit vendors
  - To collect and report cut resistance data at ambient and cryogenic temperatures for current space suit glove materials



Phase VI TMG Fabric and Ply-up Locations

Background: Terrestrial Cut Testing

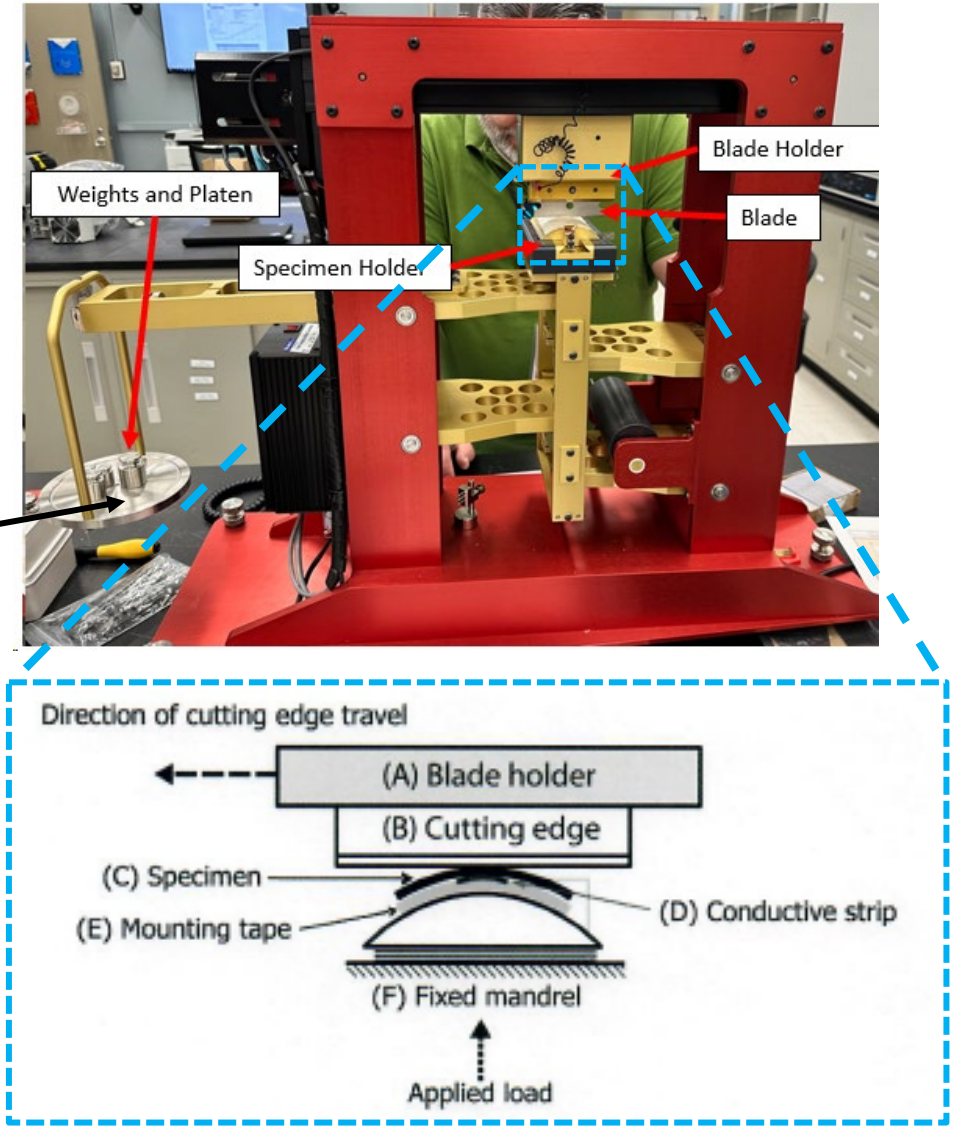
Terrestrial Glove Cut Testing used as starting point

- ASTM F2992-23 provides consistent and reliable method for testing the cut resistance of materials
- ANSI/ISEA 105-2016 outlines test procedures and requirements that gloves must meet to be classified into different cut resistance levels

- Terrestrial Method
  - Controlled **ambient** conditions
  - Fabric specimen (C) placed on a conductive strip (D) and mounting tape (E) to a metal specimen holder (F)
  - New blade (B) installed in blade holder (A)
  - Weights placed on Platen to apply force between blade and sample
  - Blade moves horizontally across the sample until an electrical circuit is made between the blade and the metal specimen holder
    - Distance cut before circuit is made is recorded and used to calculate the cut resistance

Gram-force	Rating	Range	Common Applications
200	A1	Low	General, Warehouse, Maintenance
500	A2		Construction, Injection Molding
1000	A3	Medium	Metal Stamping, Oil-gas
1500	A4		HVAC, Food Prep
2200	A5		Glass or Sheet Metal Handing
3000	A6	High	Machining, Paper Handling
4000	A7		Recycling, Movement of Sharp Objects
5000	A8		Metal Assembly, Waste Management
6000	A9		Food Processing

ANSI/ISEA 105-2016 Cut Resistance Glove Classifications



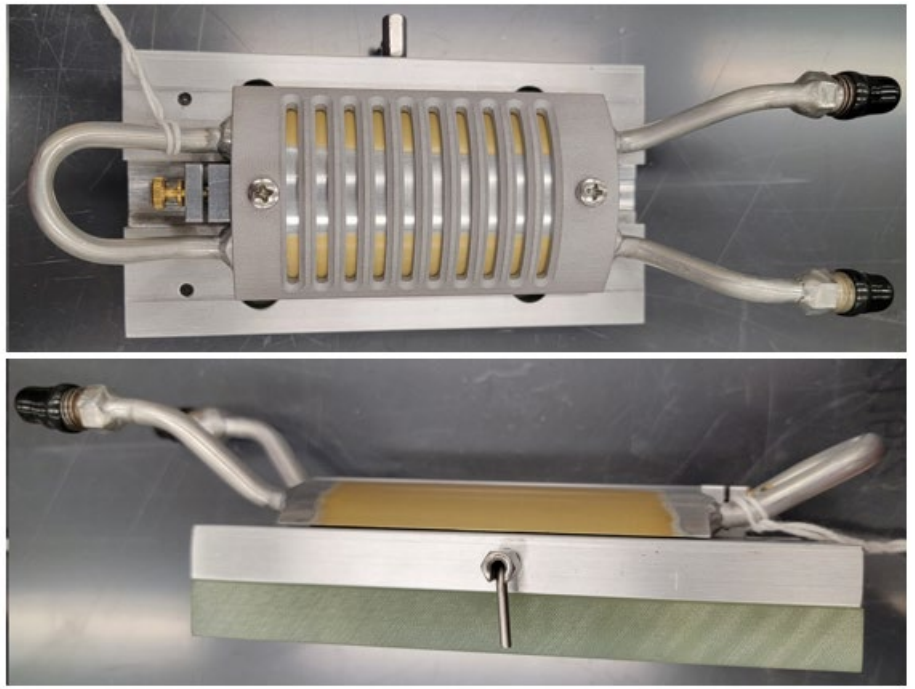
Tomodynamometer TDM-100 test apparatus used for terrestrial cut testing. (Credit: ASTM F2992-23)

Description of New Test Method

- F2992-23 used as the basis for the glove cut testing
- Four key differences between New Test Method and F2992-23

1. Liquid nitrogen (LN2) Modification (images right)
   - Allows for LN2 to flow through the sample holder to cool the sample during cut testing
   - Custom LN2 specimen holder, clamp, and base
     - Clamp can accommodate samples up to 20mm thick
     - 10-slot clamp vs the 7-slot used for F2992-23
     - G10 fiberglass insulative block to protect TDM-100

2. Adjustment to Cut Length Ranges
   - Full cut length of TDM-100 = 0-60mm
   - F2992-23 uses 2-56mm to avoid catching corners of fabrics
   - New Test Method uses entire range



Modified specimen holder with clamp attached showing LN2 lines (top) and side view of modified specimen holder with G10 insulative block (bottom).

3. Combination of Data Points
   - F2992-23 calls for three separate tests of 15 data points each. The data is then combined after testing is complete.
   - New Test Method calls for 45 data points collected in a single test. Allows for more accurate statistical analysis.

4. LN2 System Balancing
   - Addition of cryogenic specimen holder, holder base, and filled LN2 hoses required balancing of platen prior to adding weights.

Materials Tested

- Materials chosen based on Phase VI glove materials and layups to provide "reference" values for future material comparison.

Material	Location	Notes
Ortho Fabric	Phase VI; Outer layer of gauntlet	14.5 oz/yd², 3D basket weave, Gore-Tex, Nomex and Kevlar fibers
Teflon™ T-162 Fabric	Phase VI; Outer layer of hand back and fingers	9.3 oz/yd², plain weave, Teflon fibers
RTV 157 Pads	Palm, finger/thumb fronts and finger caps	3/16" thick, light grey
Turtleskin T9-816A	Palm side of the Thumb and first finger	6.9 oz/yd², tri-knit, Vectran fibers
EMU TMG ply-up	EMU suit TMG layup	Ortho Fabric, 5 layers of Aluminized Mylar, Neoprene coated Nylon
Phase IV Gauntlet TMG ply-up	Below hand of glove, covers suit wrist bearing	Teflon™ fabric, 3 layers of Aluminized Mylar, Teflon™, Ortho Fabric

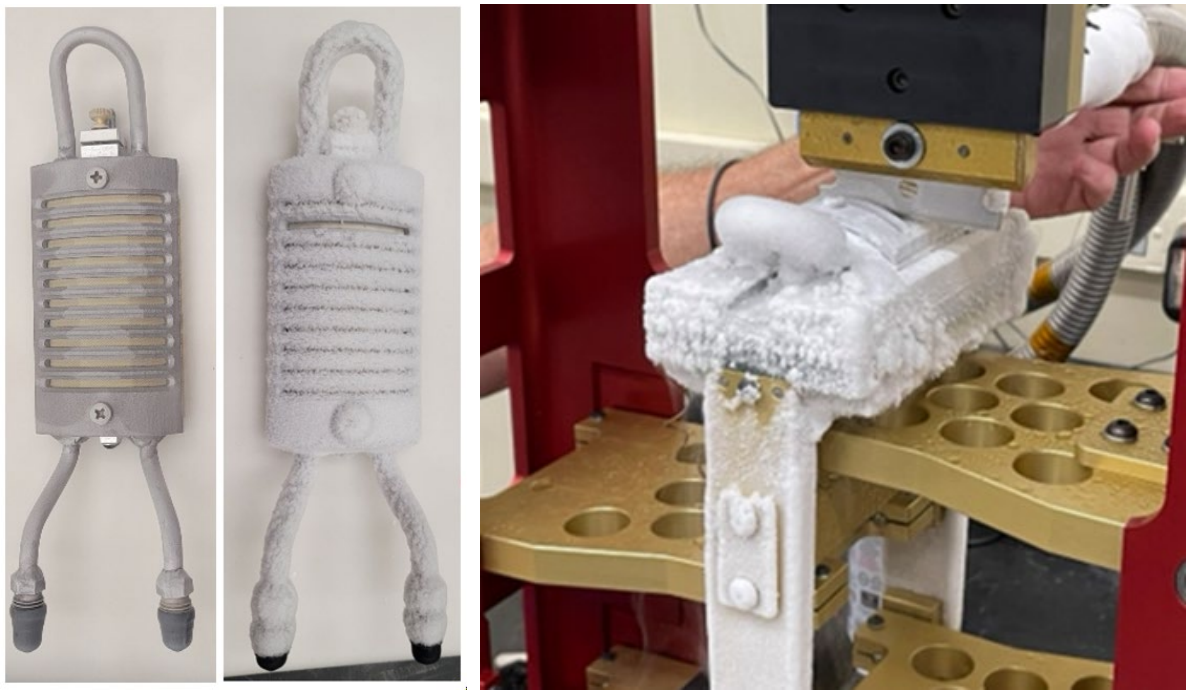
Test Method Development: Frost Formation

- Frosting identified as a potential concern due to humidity in laboratory
  - Exploratory testing conducted by submerging specimen holder in LN2 for 5 minutes, removing, and allowing to sit in the ambient environment
  - Observed frost build-up was an amorphous, powdery texture rather than solid ice – easily removed

- Determination - Frost buildup was deemed unlikely to significantly affect the TDM blade or cut force because:
  - Ice was easily removed/soft and did not mechanically impede movement of the blade
  - As long as the specimen holder was kept cold, the frost did not melt and wet the fabric
  - The material samples tested were highly hydrophobic not susceptible to water entrainment
  - More icing observed during testing

Observation:

Frost accumulation on the TDM-100 during cryogenic testing was easily removed with air or mechanical brushing. No frost was observed to form on the materials themselves. Because of the hydrophobicity of the materials and the ability to readily remove accumulated frost, the frost was deemed a non-contributor to differences in measured cut resistance, though no controlled study was conducted.



Specimen holder directly after being removed from LN2 cold soak (Far Left) Specimen holder after exposure to humid air for 20 minutes after LN2 cold soak (Center). Specimen holder in TDM-100 during cut testing (Far Right).

Test Method Development: Teflon and Temperature

- Teflon™ Fabric Challenges
  - Valid cut length could not be obtained
  - Possible explanation:
    - LN2 components require offset of loads to the beam balance
    - Offset effectively reduces the sensitivity of the system to measure low cut resistance fabrics (~100g)

Finding:

Teflon™ fabric could not be tested using the new test method. This is likely due to reduced sensitivity of the TDM-100 at low cut resistances as a result of the beam balance offsetting the load of the LN2 components. This is likely to occur with other low cut-resistant materials.

- Temperature Limits of System
  - Thermocouples attached to specimen holder and blade
  - Steady state temp at specimen holder achieved in ~10min = -250°F (116K)
  - Steady state temp at blade achieved in ~2min = 25°F (269K)
    - Not thermally isolated from blade holder

Observations:

The effects of moisture and temperature of the blade were not investigated during this study.

The effects of high temperatures on cut resistance were not evaluated in this effort. However, the test apparatus designed for the new method could be modified to accommodate high temperature testing.

Results

- Data collected at ambient and cryogenic conditions
- "Calculated load" represents the *theoretical load required to cut through the fabric or ply-up in 20mm*
  - R^2 values from ASTM consultants indicated a range of 0.3 to 0.7 is considered acceptable for textile values
- Percent increase in cut resistance calculated between ambient and cryogenic temperatures:

$$percent\ increase\ (\%) = \frac{|Final - Start|}{|Start|} X\ 100$$

Sample	Temperature Condition (°F/K)	Calculated Load (gf)	Est. Cut Rating	Standard Deviation (gf)	95% Confidence Interval (gf)	R^2	% Increase
Ortho Fabric	70/294	356.3	A1	7.5	±15.2	0.6874	126.8
	-250/116	808.0	A2	24.3	±48.9	0.5158	
Turtleskin	70/294	742.3	A2	18.8	±37.8	0.4441	117.1
	-250/116	1611.6	A4	38.6	±77.8	0.4871	
RTV-157	70/294	496.3	A1	23.2	±46.8	0.5337	358.1
	-250/116	2273.6	A5	52.1	±105.1	0.536	
P6 gauntlet TMG Ply-up	70/294	698.1	A2	9.0	±18.2	0.8057	118.8
	-250/116	1527.7	A4	43.5	±87.7	0.4883	
EMU TMG Ply-up	70/294	737.3	A2	16.0	±32.2	0.6622	604.3
	-250/116	5192.8	A8	56.7	±114.3	0.3605	

Finding:

The cut resistance of all tested fabrics and layups increased at cryogenic temperatures as compared to ambient temperature. The EMU Layup and the RTV-157 coupon saw significantly larger increases in cut resistance from cryogenic exposure compared to the other materials at 358.1% and 604.3%, respectively.

Analysis of Results

- An increase in cut resistance was observed for all materials/fibers at cryogenic temperatures
- "Stiffening" observed in the two layup samples (EMU Ply-up and RTV 157)
  - Retained curvature of the specimen holder for several minutes after removal from test apparatus
  - Retention of curvature not observed in stand-alone fabric samples
- Theory: Polymer structures in the RTV and the neoprene coated nylon layer of the EMU ply-up significantly stiffened at cryogenic temperatures resulting in significantly larger increase in cut resistance
- Awareness of glove designers will allow stiffening of fabrics to be accommodated for in the architecture of the glove assembly (i.e. how the fabrics are segmented, positioned, etc.)

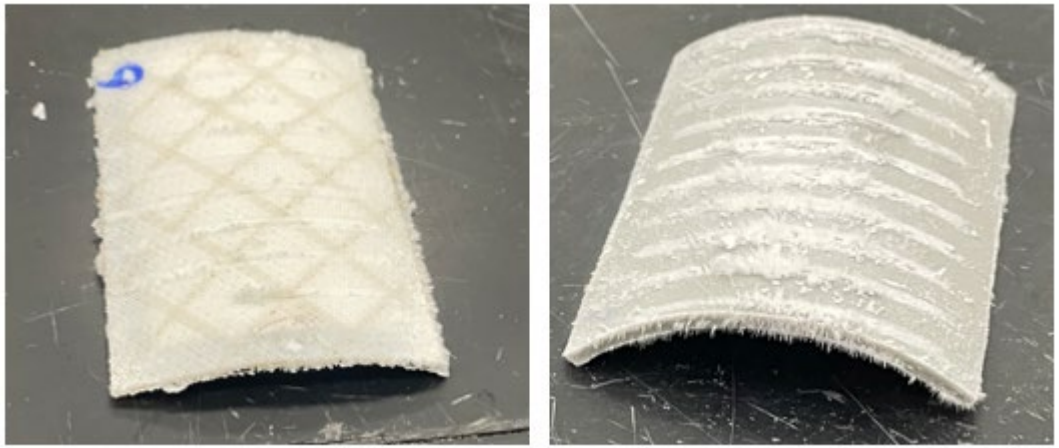
Findings:

Fabric layups showed significant stiffening of the materials at cryogenic temperatures. Stiffening of the RTV and neoprene coated nylon materials within the layups are believed to be the cause of the stiffening, as none of the other materials in the layups exhibited the same behavior.

Initial results indicate the new method is an effective process for evaluating the cut resistance of materials at ambient and cryogenic temperatures down to 116K and generates consistent data within the expected variability of the test apparatus.

Observation:

Increases in cut resistance caused by stiffening reduce the flexibility of the materials. For applications where a flexible material is desired (e.g. fingers, wrist, palm bar, etc.), the stiffening will impede dexterity.



EMU Ply-up (Left) and RTV Pad (Right). *Photographs taken directly after removal from the cryo specimen holder which shows the observed stiffening.*

(Preliminary)* NESC Recommendations

It is recommended that….

R-1. Spacesuit glove designers and developers use the New Test Method to evaluate spacesuit glove materials intended for use at cryogenic temperatures for materials with cut resistance >100 grams-force. (*F-1, F-2, F-4)*

R-2. NASA EVA Development project and/or Spacesuit glove developers conduct a controlled study to evaluate the effect of humidity and frost accumulation on cryogenic cut results for non-hydrophobic materials. (*O-1, O-2*)

R-3. NASA EVA Development project and/or Spacesuit glove developers investigate the cause(s) of increased cut resistance of all materials and increased stiffness of layups containing RTV-157 and Nylon Coated Neoprene at cryogenic temperatures. (*F-1, F-3, O-4*)

R-4. NASA EVA Development project develop a high temperature cut resistance test standard to cover the full range of Artemis thermal environments. (*O-3*)

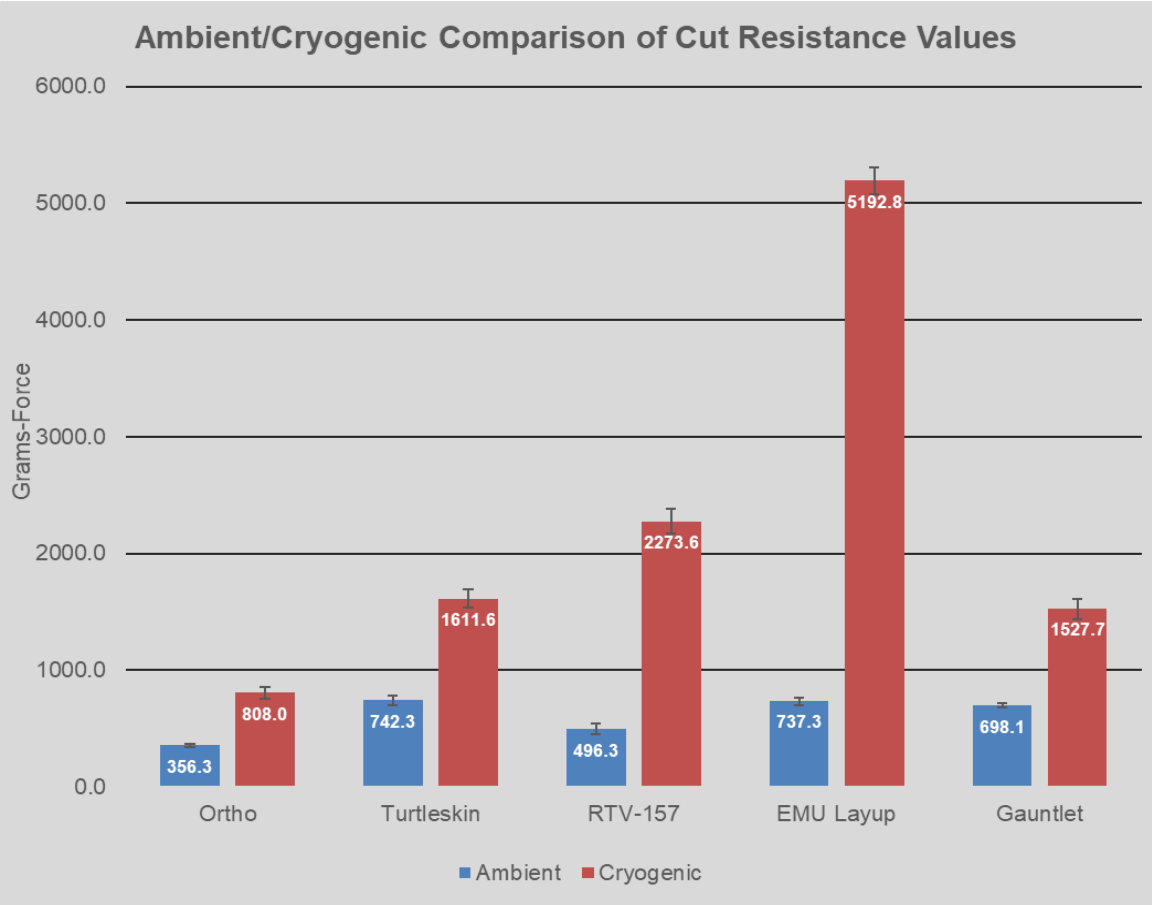
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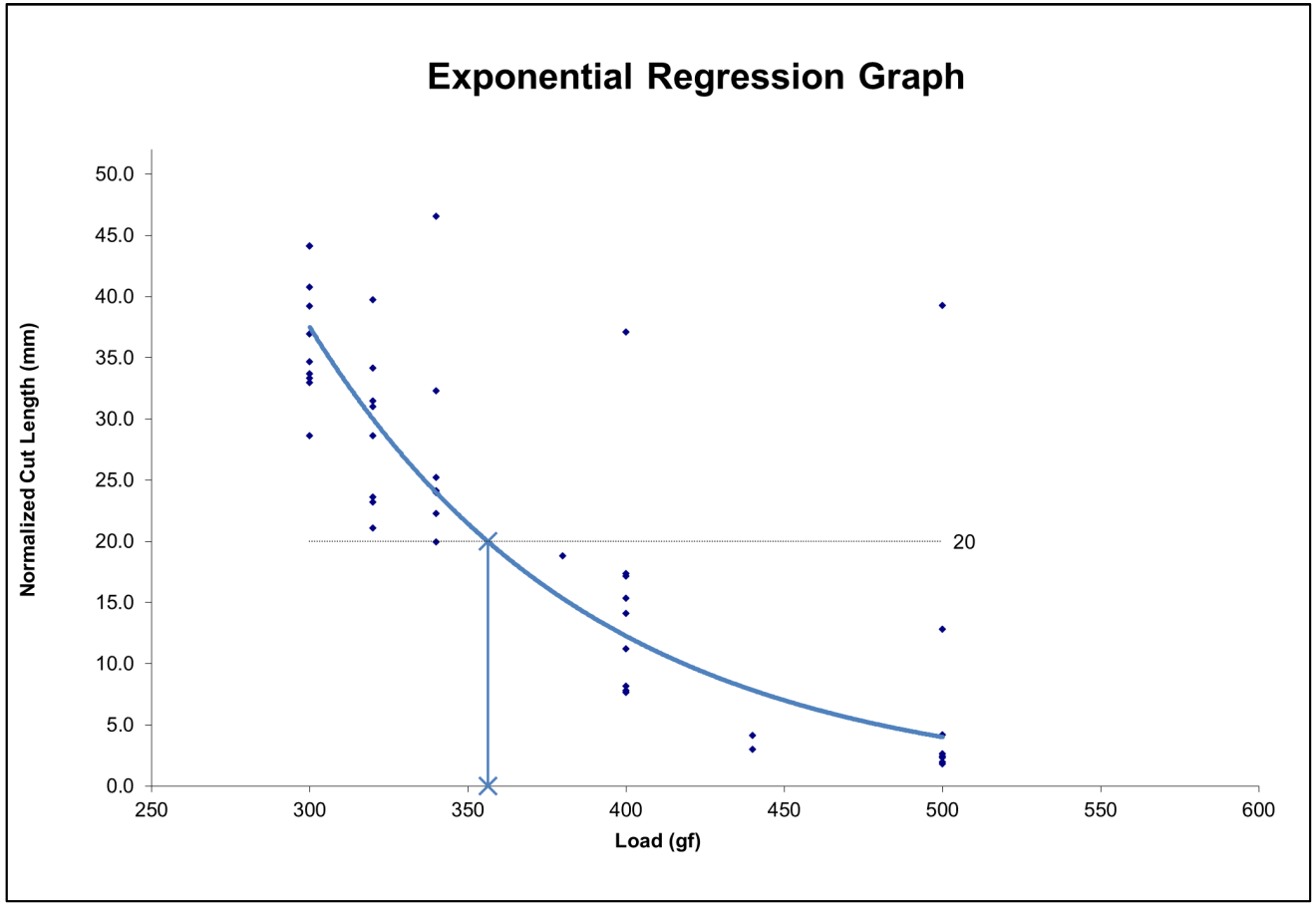
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Additional Information

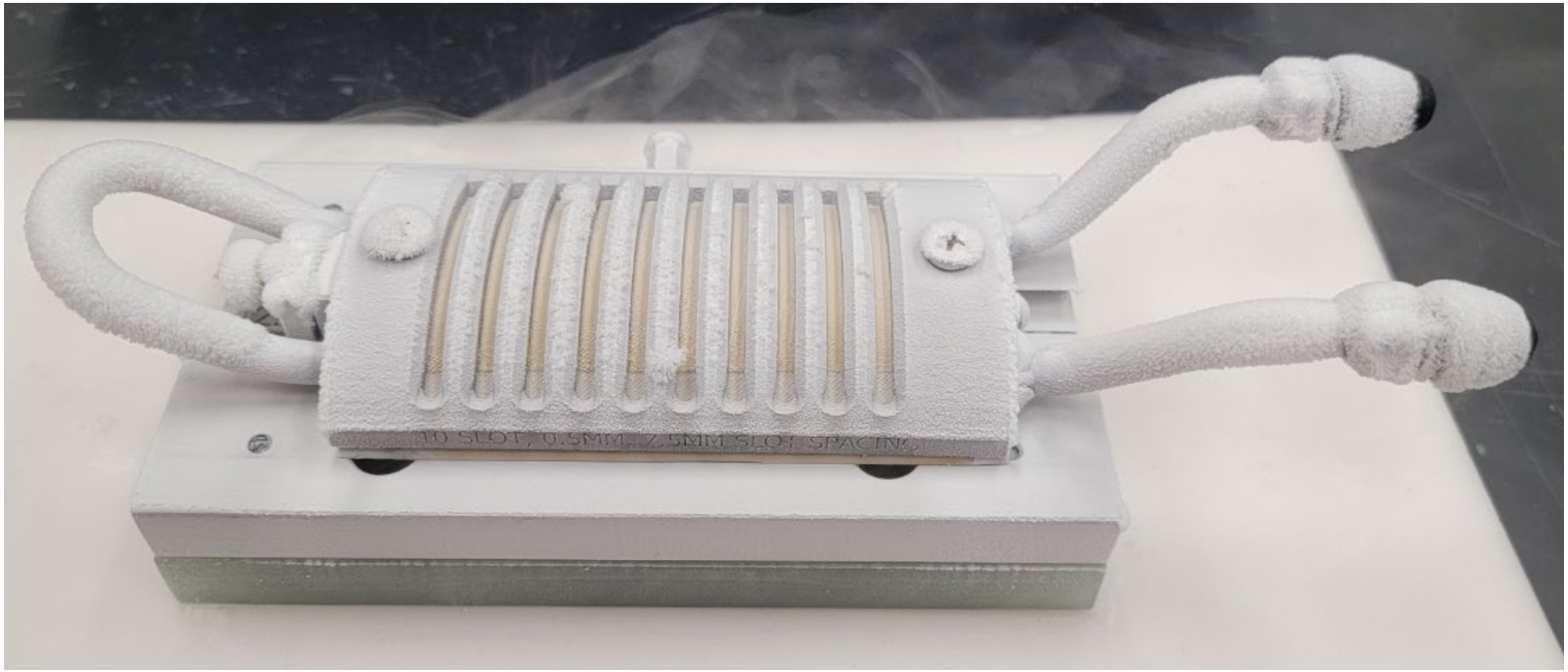
Results



Ambient and Cryogenic Cut Testing Results. *The calculated cut resistances from ambient testing are shown as blue columns. The cryogenic results are shown as red.*



Regression Analysis of Ortho Fabric at Ambient Temperature. *This graph shows the test data (dots) and the analysis for the best fit line through the data. This is then used to determine the load in gf corresponding to a 20 mm long cut.*


10 SLOT, 0.5MM, 2.5MM SLOT SPACING

