Material Selection for Mechanical Mechanism Survival, and Use in the Lunar Night

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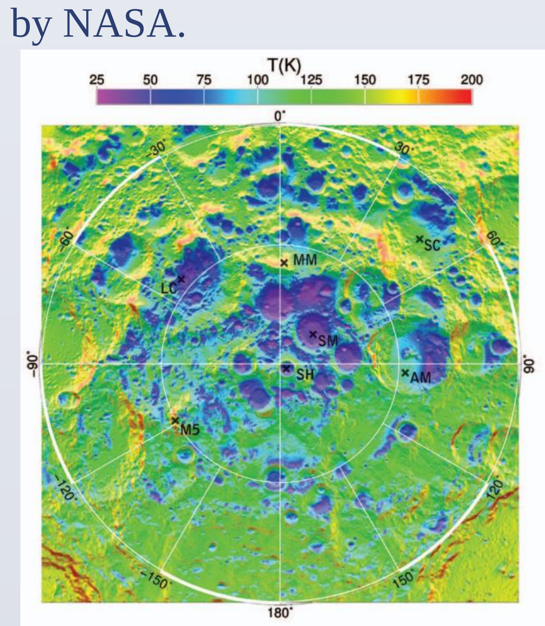
INTRODUCTION

The lunar night presents challenges for the survival of spacecraft mechanisms due to extreme low temperatures, typically 100 K at low latitudes [1] and less near the poles [2]. Some spacecraft components, such as those in a rover or lander body, can be protected from the extremely low temperature by use of heaters and adequate thermal design. However, those mechanisms on the appendages of a rover or lander, such as robotic arms, drills, scopes, lander legs, and rover wheels cannot be easily protected in this way because they are directly exposed to the ambient lunar thermal and vacuum environment. These mechanisms would be challenging to keep warm by applied heat and insulation because they must contact the lunar surface or otherwise be exposed to the radiative environment of the Moon by design. It is desirable to find design solutions that will allow mechanisms to function at the natural temperature of the lunar night. In this paper, we discuss materials and design approaches that allow such mechanisms to not only survive the lunar night, but have complete functionality in the lunar night environment. Our team is currently developing a drilling system capable of operating in the permanently shadowed regions on the lunar surface under an Early Stage Innovation (ESI) Program funded by NASA.



Courtesy :NASA Diviner

CHALLANGES

Adequate designs must encompass not only the low temperature vacuum environment on the lunar surface, but also the transition from Earth ambient. In mechanized systems, primary considerations include material mechanical properties (strength, modulus, hardness, wear resistance, etc.), efficient use of both good thermal-conducting and thermal-insulating materials, mechanical stresses induced by materials of varying thermal contraction behaviors, exposure or isolation of electrical components and subsystems, suitable lubricants, hermetic sealing or venting, and abrasion resistance or shielding.

SOLUTIONS

Materials such as 300-series stainless steel and 6000-series aluminum (face-centered cubic structures) have been used for decades in aerospace systems and will lay the foundation for the mechanical and thermal designs of mechanized lunar systems. Fiber-reinforced composite structures formulated with resin systems that are compatible with the cryogenic environment are also of high value. Our drilling system is being designed to utilize these materials in combination with other subsystem specific materials such as polycrystalline diamond compact (PDC) bits on the drill head that have shown excellent wear resistance while operating at cryogenic temperature [3].

DESIGN FOR SURVIVING THE NIGHT

- Temperature range observed by Apollo missions:+150 C to -150 C
- Thermal swings are a significant design issue
- Materials expand and contract creating stress on mechanical assemblies
- Electrical systems may fail due to the extent of thermal swings

DESIGN FOR PERMANENT SHADOW

- Cryogenic design for polar deployment is different than for equatorial thermal swings
- Stable temp ~25-40 Kelvin
- Lunar polar operations can leverage cryogenic conditions rather than fight them
- Must provide a solution to ensure stability of electrical systems at the thermal conditions

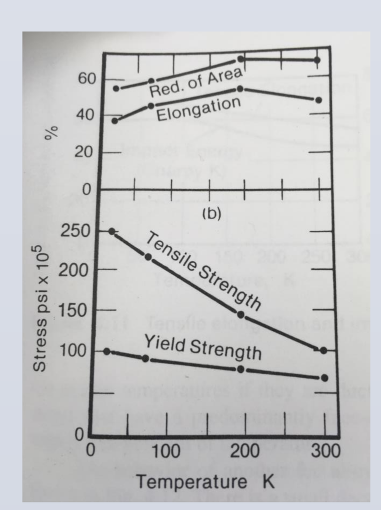
LUNAR POLAR DRILLING REQUIREMENTS

- Wear & abrasion
- Brittleness
- Cutting surfaces
- Service life

Courtesy:http://www.alanbeangallery.com/drilling-full.html

STRUCTURAL MATERIALS

- Aluminum and austenitic stainless steels exhibit higher strength at low temperature
- Composites formulated with cryogenic resin system
- Improved wear resistance



FEASIBLE CRYO-MATERIALS

- Polycrystalline Diamond Cutters
- 316 Stainless Steel

From Baker Hughes

CRYOGENIC LUBRICANTS

- Bearing and bushings for mechanized systems
- Solids
  - PTFE (teflon)
  - Graphalloy (metal impregnated into graphite)
  - Molybdenum disulfide (MoS_2)
  - Polyimide plastic (Vespel) with MoS_2
- Low-temperature greases
  - Apiezon
  - Flouinated polyethers (Krytox)

CRYO-FRIENDLY ELECTRONICS

- Electronics can work better at cryogenic temperature (more efficient)
  - Circuits
  - Discrete Devices
  - Sensors
  - Motors
- Superconductivity can be utilized without active cooling
  - Main obstacle to terrestrial systems
- Leverage technology and designs for quantum computing, communications and sensing.

CRYO-FRIENDLY MECHANISMS

- Materials exist that work well under cryogenic conditions (especially polar environments with stable temp)
- Manufacturing at room temp and deployment into operating environment is a challenge that needs to be addressed
- Integrated design and testing is needed

THERMAL SPACE Ltd CAPABILITES

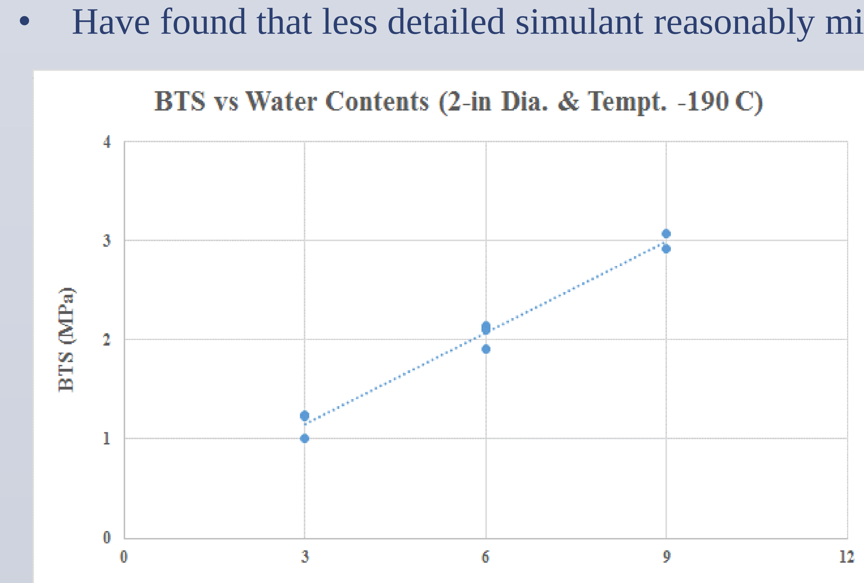
- Cryogenic system design and analysis
- Thermal management (2 K- 400 K) engineering
- Cryogenic testing
- Thermal systems and components

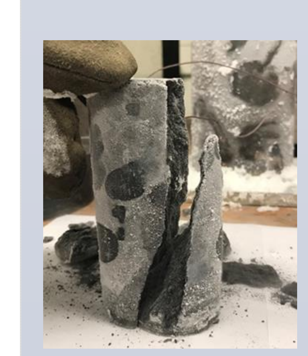
NASA ESI PROJECT UPDATE

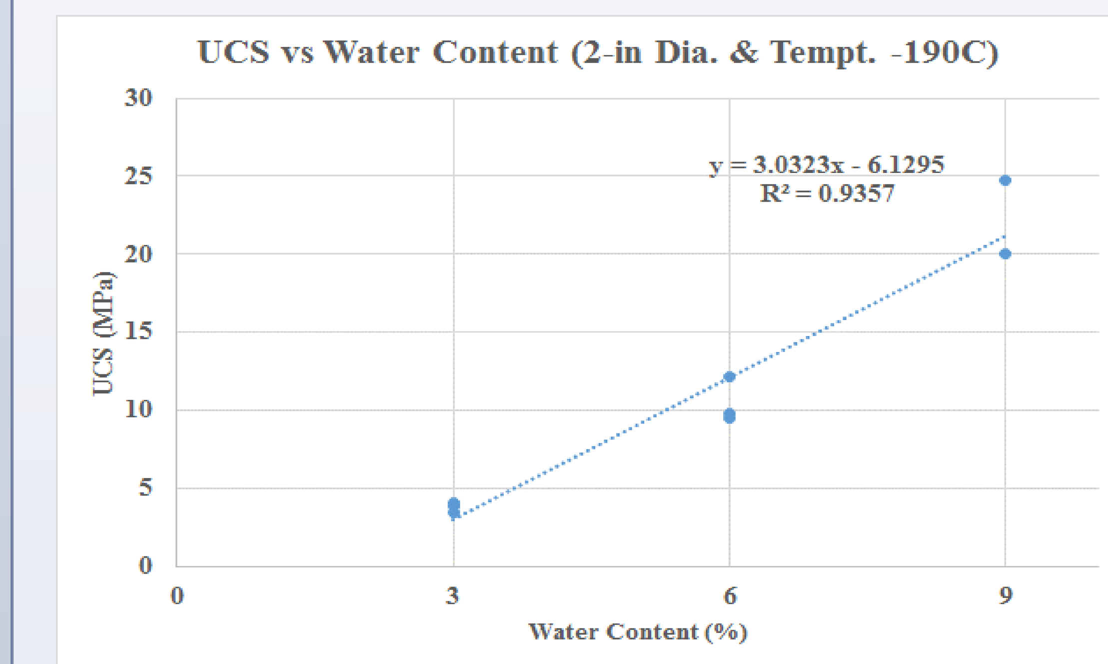
- Simulant has been confirmed to reasonably imitate lunar properties
- Drill prototype has been assembled
- Testing with hybrid basalt/cement is underway

Simulating Lunar Mechanical Properties

- JSC1A the standard
- Have found that less detailed simulant reasonably mimics properties







DRILL DESIGN BASICS

- Rotary Auger drill
- High-frequency drilling data acquisition system employed
- Currently using carbide tipped masonry bits
- Sensors used:
  - WOB
  - RPM
  - Torque
  - Distance Drilled
  - 3-axis Accelerometer
- Drilling Mechanical Specific Energy (MSE) used to automate the drilling operation
- Evaluating inclusion of Rotary-Percussive system for future testing

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