



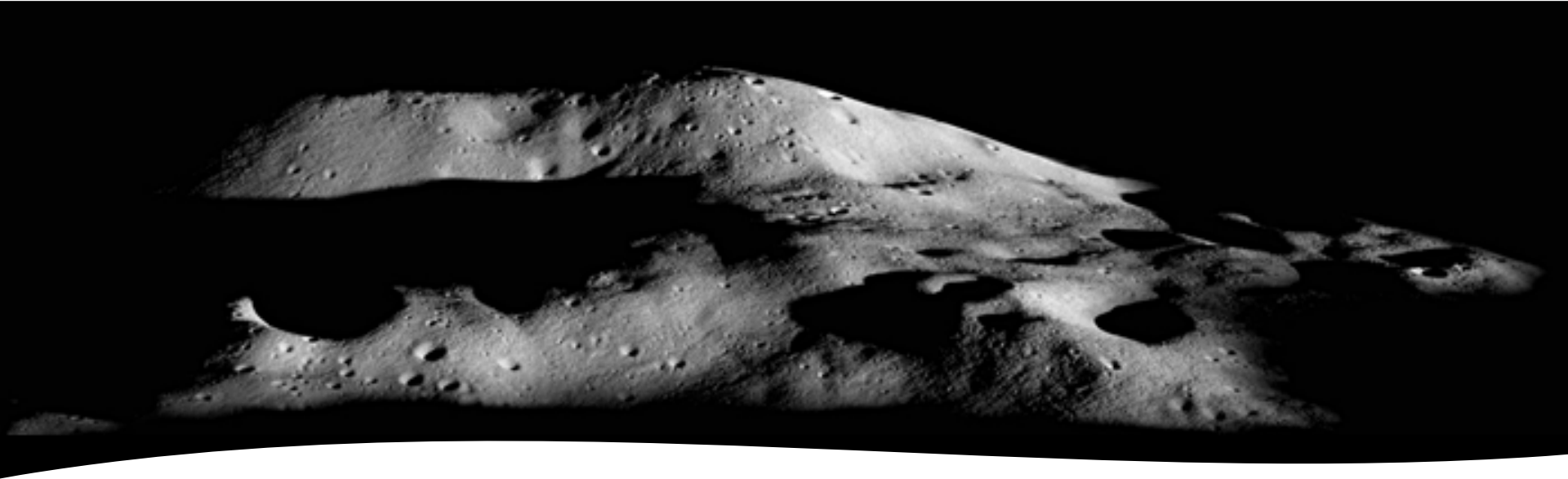
Resurrecting NASA Historical Fabrics to Meet the Thermal Challenges of Landing in the South Pole of the Moon

Evelyne Orndoff

: "Trade names are used in this presentation for identification only. Their usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration."



THE MOON



This South Pole adventure represents the greatest thermal challenge for visitors and machine because of its temperatures, its daylight and night times, and its craters as points of interest. The guide gives recommendations to the explorer on what to wear for outdoors adventure, and what to wear indoors to be safe and comfortable inside Lunar Landers.

Malapert Mountain, located at the lunar south pole, is a potential site for future missions due to the nearly constant sunlight and the ideal conditions for line-of-sight communications with Earth. [NASA/GSFC/Arizona State University]
Exploring the Moon – NASA EG-1997-10-116-HQ

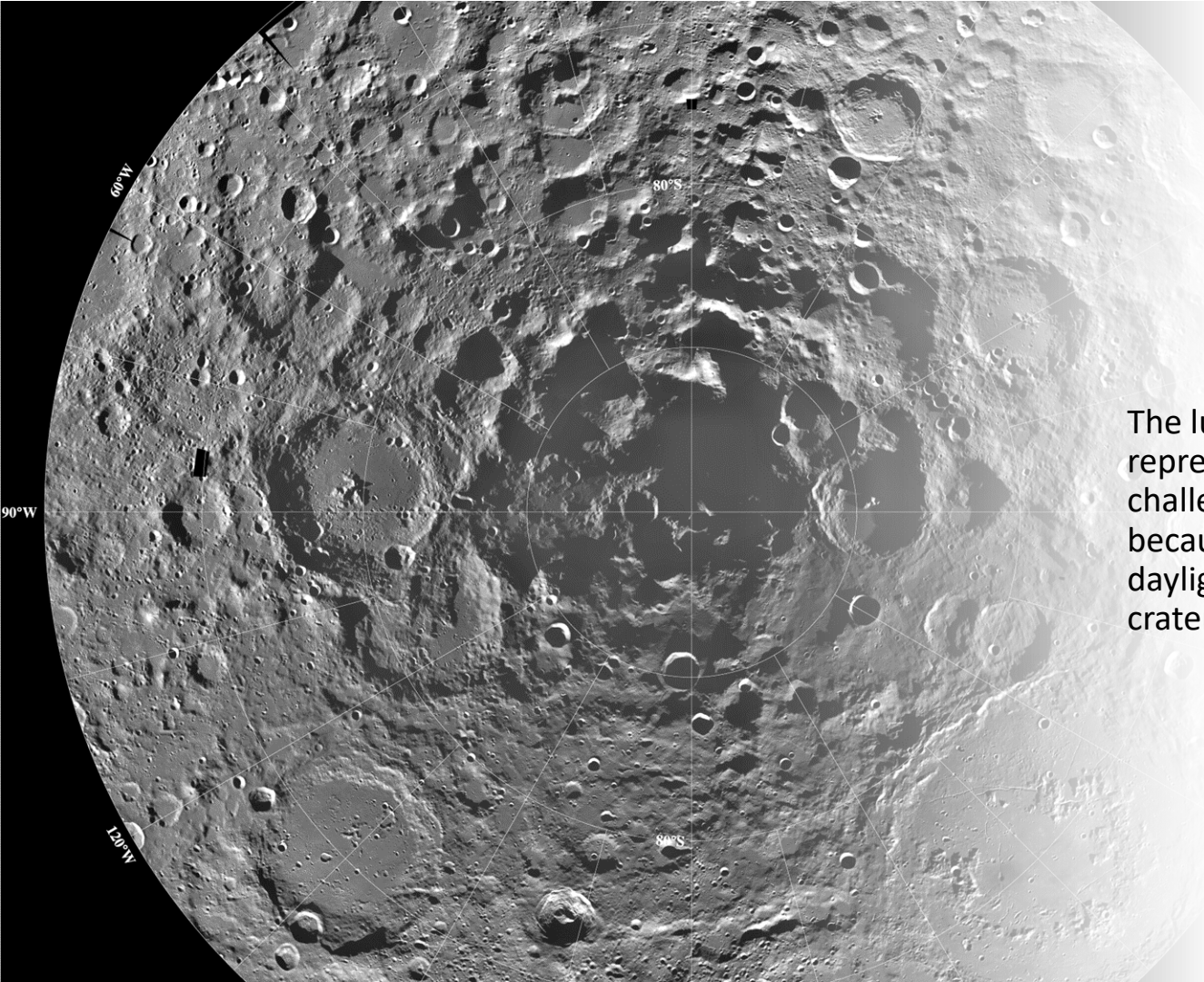
Adapting to the travel conditions and spending a few days on the Moon – it is much more than jet lag!



“Gravity, Atmosphere, Geography, Length of Day, Temperatures”

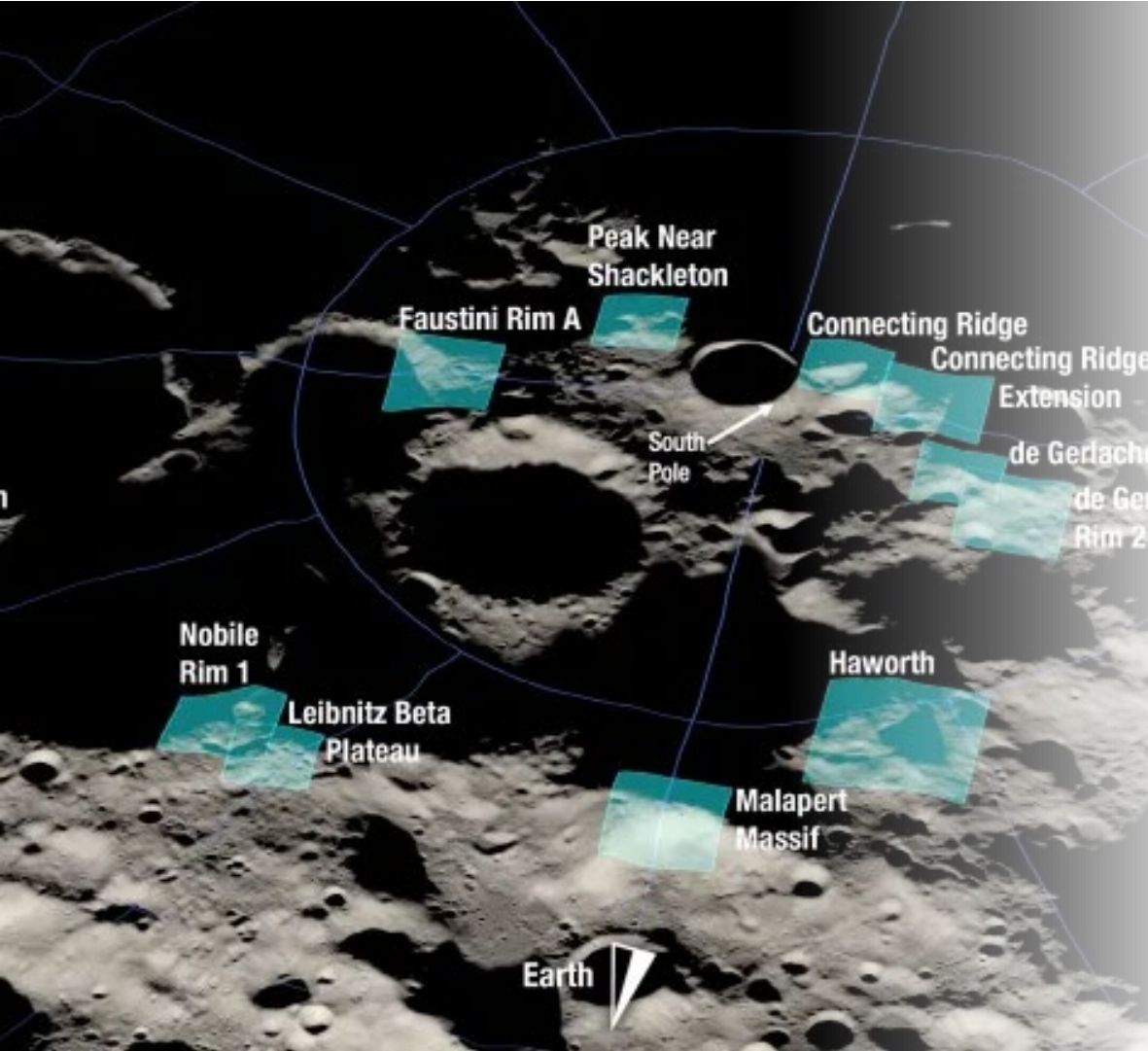
| Property * | Earth | Moon |
|--|---|--|
| Surface Gravity | 9.8 m/sec/sec | 1.63 m/sec/sec |
| Sediment or Regolith | Silicon and oxygen bound in minerals that contain water, plus organic materials. | Silicon and oxygen bound in minerals, glass produced by meteorite impacts, small amounts of gases (e.g., hydrogen) implanted by the solar wind. No water or organic materials. |
| Atmosphere (main constituents) | 78 % nitrogen, 21 % oxygen | Basically none. Some carbon gases (CO ₂ , CO, and methane), but very little of them. Pressure is about one trillionth of Earth's atmospheric pressure. |
| Length of day (sidereal rotation period) | 23.93 hours | 27.3 Earth days |
| Surface temperature | Air temperature ranges from -88°C (winter in polar regions) to 58°C (summer in tropical regions). | Surface temperature ranges from -193°C (night in polar regions) to 111°C (day in equatorial regions). |
| Surface features | 25 % land (seven continents) with varied terrain of mountains, plains, river valleys. Ocean floor characterized by mountains, plains. | 84 % heavily-cratered highlands. 16 % basalt-covered maria. Impact craters-some with bright rays, crater chains, and rilles. |

* Exploring the Moon – NASA EG-1997-10-116-HQ



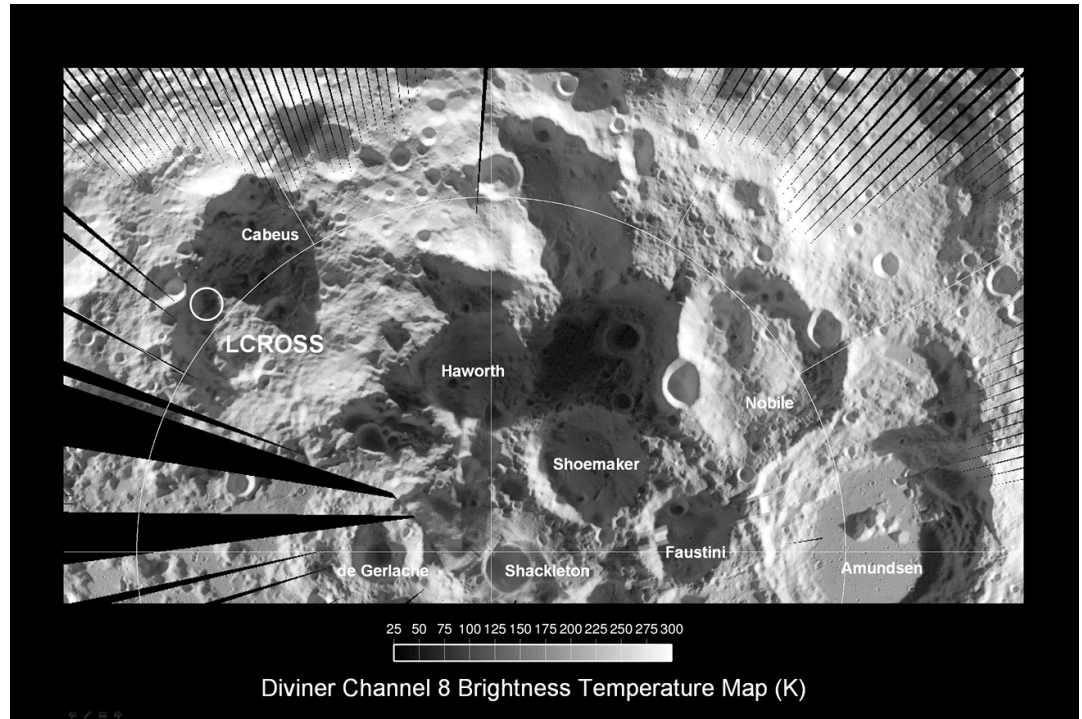
The lunar South Pole adventure represents the greatest thermal challenge for visitors and machine because of its temperatures, its daylight and night times, and its craters.

Landing Site



- **Candidate regions for an Artemis III lunar landing:**
- Faustini Rim A
- Peak Near Shackleton
- Connecting Ridge
- Connecting Ridge Extension
- de Gerlache Rim 1
- de Gerlache Rim 2
- de Gerlache-Kocher Massif
- Haworth

Shackleton crater from
the Diviner, an infrared
radiometer aboard
NASA's Lunar
Reconnaissance Orbiter
used to create
temperature maps of the
Moon's surface





Out of this World
Lodging!
Much more expensive
and more thrilling than
any five-star hotel

Illustration of SpaceX Starship human lander design that will carry the first NASA astronauts to the surface of the Moon under Artemis. **Credits: SpaceX**



The Astronaut's Gear for Space Exploration

- A spacesuit designed for specific environments in space
 - Vacuum, lunar surface, planetary surface (i. e., Low Earth orbit, Moon, Mars)
- Tools, lighting, cameras, tethers, containers, instruments, and more depending on the activities outside the spacecraft or space habitat

Apollo Lunar Gear



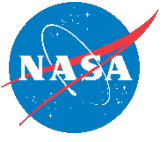
The New Lunar Gear

The outer fabric must have high emissivity and low absorptivity for thermal management of the space suit.

It must also be a barrier to lunar dust and be resistant to abrasion, prevent sharp lunar dust particles from penetrating the suit.

In addition, it should not attract positively charged dust.

In development...

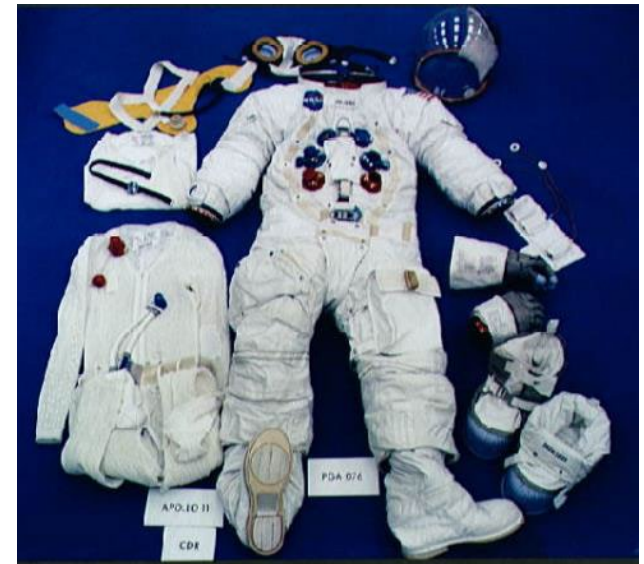


THE FABRICS

Apollo Extravehicular (EV) Suit

(rear entry zipper)

- Teflon Cloth: Abrasion/flame resistance
- Beta cloth (Teflon-coated silica fiber): Fire protection (non-flammable in oxygen atmosphere)
- Aluminized gridded Kapton: Reflective insulation
- Beta marquisette (Teflon-coated silica fiber, laminated to Kapton): Spacer between reflective surfaces
- Aluminized Mylar: Reflective insulation
- Nonwoven Dacron: Spacer
- Neoprene-coated nylon: Inner liner
- Nylon: Restraint layer for pressurized bladder
- Neoprene-coated nylon: Bladder material serving as an impermeable layer containing suit-pressurization oxygen
- Neoprene convolute: Pressure-retaining flexible joints
- Knit jersey laminate: Abrasion protection
- Lightweight Nomex cloth: Comfort





Apollo Intravehicular (IV) Suit

- Teflon-coated Beta cloth: Fire protection (non-flammable in oxygen atmosphere)
- Nomex cloth: Snag/fire protection
- Nylon: Restraint layer for pressurized bladder
- Neoprene-coated nylon: Bladder material serving as an impermeable layer containing suit-pressurization oxygen
- Lightweight Nomex cloth: Comfort



Apollo Constant Wear Garment (CWG)

- Cotton: Comfort

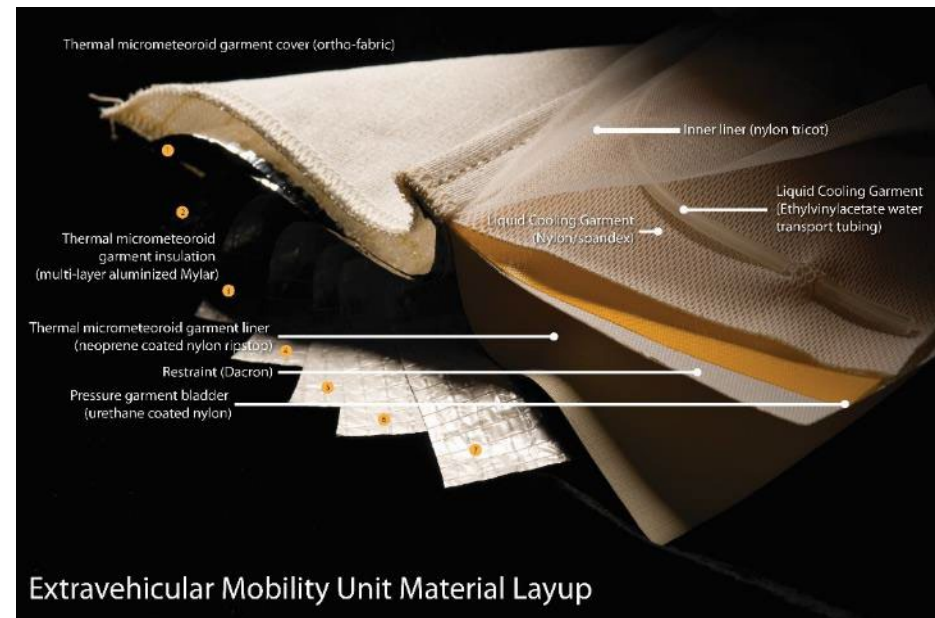




Shuttle Extravehicular Mobility Unit (EMU) Materials

- Thermal Micrometeoroid Garment (TMG)
 - Ortho-fabric: Gore-Tex (expanded Teflon) fibers woven together with Nomex and backed with ripstop network of Kevlar: Abrasion/flame resistance
 - Aluminized Mylar backed with unwoven Dacron: Insulation
 - Neoprene-coated nylon ripstop: Liner
- Pressure Garment Assembly (PGA)
 - Dacron Woven with primary and secondary axial lines: Restraint and control of longitudinal growth
 - Polyurethane-coated nylon: Bladder layer for pressurization
- Liquid cooling and Ventilation Garment (LCVG)
 - Nylon acetate spandex woven with ethylene vinyl tubing: Restraint to keep tubing near body
 - Nylon acetate: Comfort

The first nine layers are integrated with the protective, vest-like fiberglass shell to form the hard upper torso assembly (HUT). For the lower torso assembly (LTA), the materials are integrated with the body seal closure, waist bearing, legs, and boots.



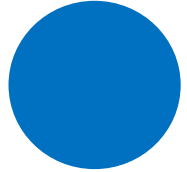
Beta Silica Fiber

- Nonflammable in oxygen enriched environment
- Melting temperature 1,550°F
- Beta Applications
 - Flame protective layer of Apollo space suit
 - Apollo Space suit thermal insulation spacer
 - Apollo flight suit
 - Apollo Spacecraft window shade
 - Medical Kits
 - Rucksacks
 - Towel bags
 - Space accessories kit
 - Life vest assembly kit
 - PLSS covers
 - Crew provision container
 - Oxygen hose cover
 - Containers for accessories of survival equipment and crew provision items

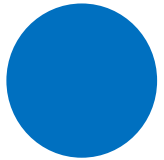
- NASA emblems
- American flags
- Name plates
- ground tape for Astros Velcro fasteners
- Astronaut's couch
- Fire protective barriers
- Heat shields
- Spacecraft insulation
- Skylab shower enclosure
- Shuttle Orbiter payload bay and door liner
- Shuttle Orbiter remote manipulator arm's cover
- IMAX camera cover



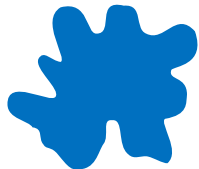
Beta
¼ denier diameter
3.8 microns



Nylon
1 ½ denier
14 microns



Polyester
1 ½ denier
12 microns



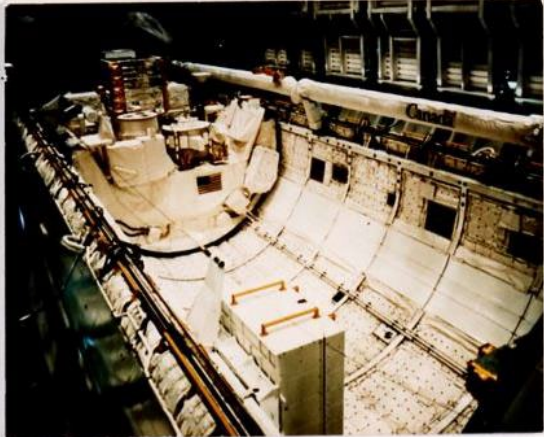
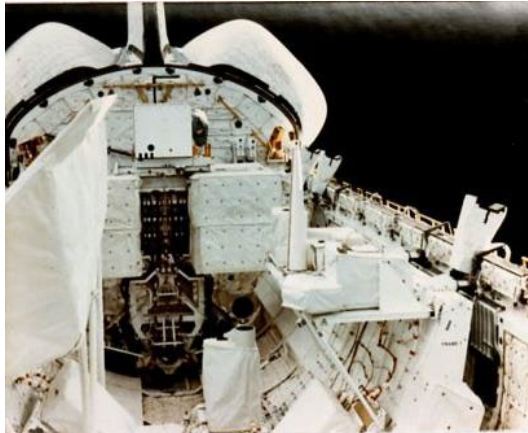
Viscose
1 ½ denier
16 microns



Cotton
1 ½ denier
16x6 microns



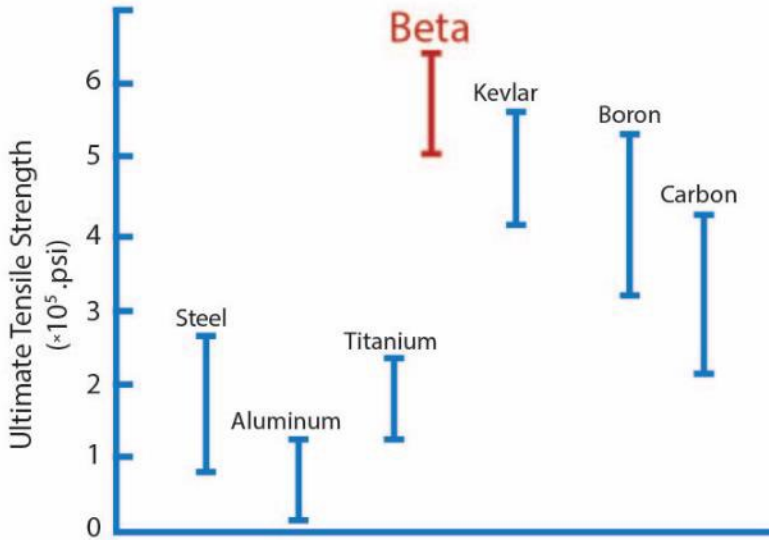
Silk
1.2 denier
14x8 microns



Beta Silica Fiber

MATERIAL SAMPLES

- TEFLON-COATED BETA YARN WOVEN FABRIC
- TEFLON COATED BETA FABRIC
- BETA CORD





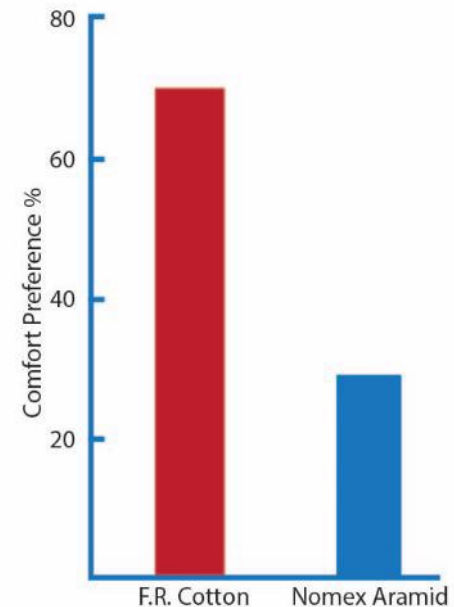
Cotton

- Flame resistant in 30% oxygen at 10 psia
- Space Shuttle flight suit
- Space Shuttle Training suit
- Space Shuttle Sleeping pad
- Space Shuttle sleeping bag

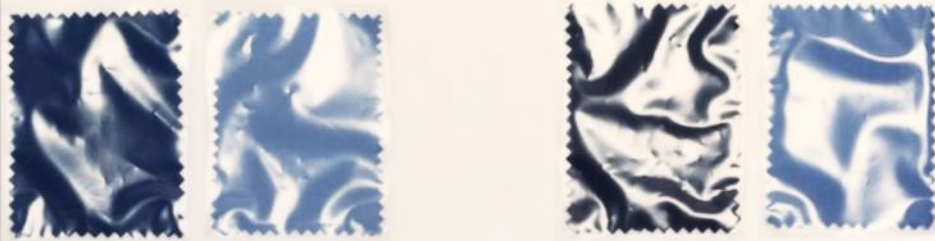


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Comparative Comfort
Space Shuttle FR Cotton Flight Suit vs.
Nomex Aramid Flight Suit



MATERIAL SAMPLES



Cotton



NOMEX
14.3 PSIA
25.9% OXYGEN

FLAME RESISTANCE TEST

COTTON
10.4 PSIA
30% OXYGEN

S86-35108



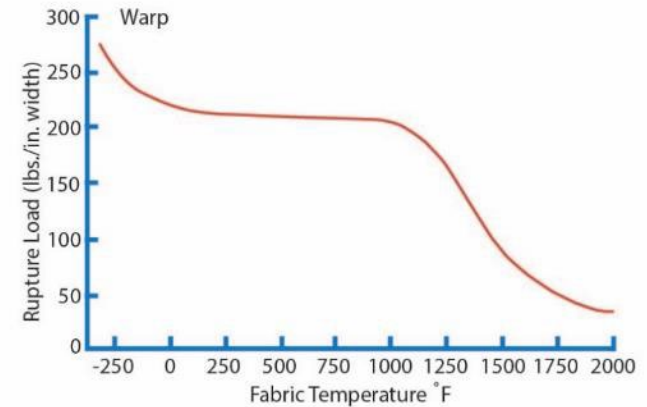
Chromel R

- High performance metallic fiber
- Applications
 - Gemini space suit trousers (to protect astronaut from the plumes of the astronaut's maneuvering unit)
 - Apollo space suit gloves and boots
 - Apollo space suit abrasion patch

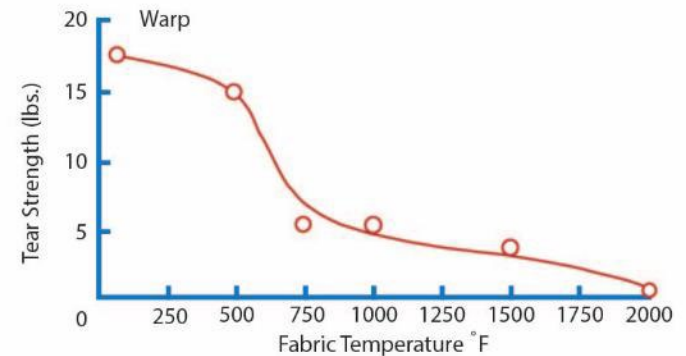
CHROMEL R



Rupture Load vs. Temperature of Chromel R Fabric



Tear Strength vs. Temperature of Chromel R Fabric



Chromel R



Durette – Modified Aramid

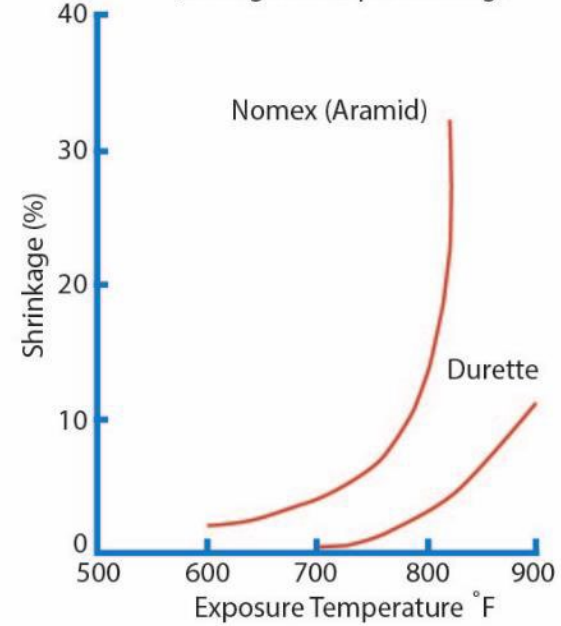
- Dimensionally stable at high temperature
- Applications
 - Skylab flight suits
 - Skylab inflight boots and gloves
 - Apollo-Soyuz inflight suit

MATERIAL SAMPLES



Shrinkage of Nomex and Durette Fabrics at Elevated Temperatures

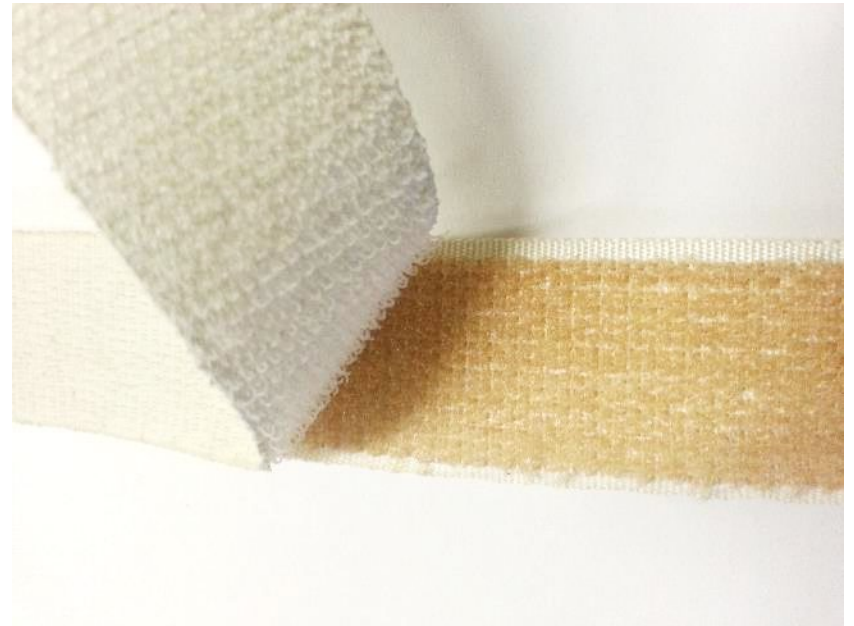
(Average of warp and filling)





Astro-Velcro Fastener

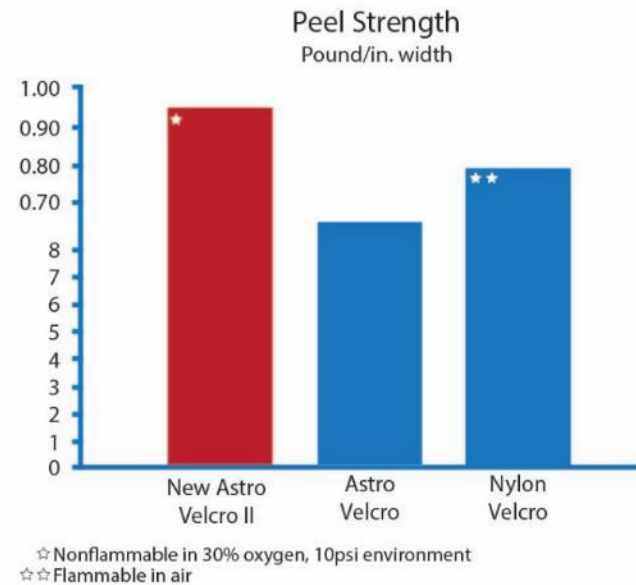
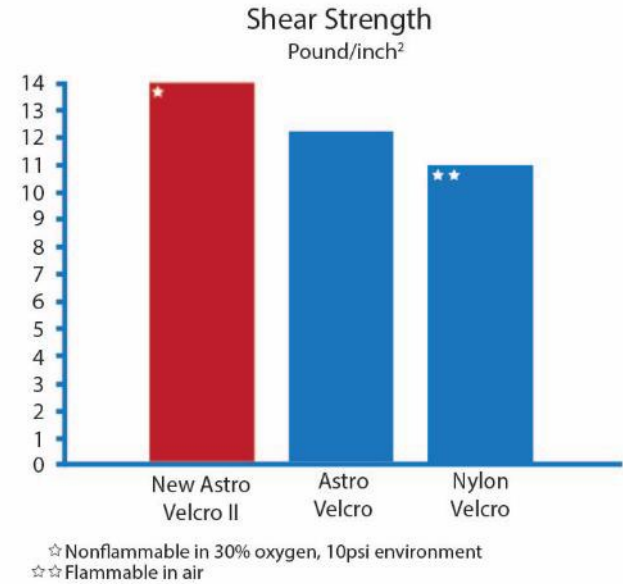
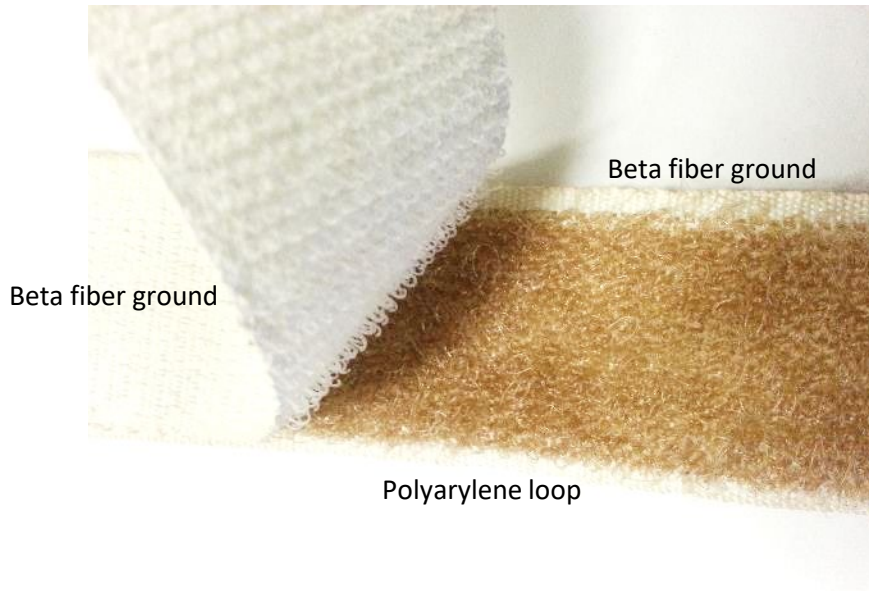
- This closure was designed for manned space flight where the crew cabin environment is oxygen enriched. It was introduced into the Apollo program and has been used in Skylab and all Shuttle flights. It is made of polyester hooks and Teflon loops woven in Beta glass ground tapes.



Astro Velcro II

- Comparison with Astro Velcro
 - Higher peel and shear strength
 - Resilient hook structure
 - Better endurance cycle life
 - Flame Resistant in oxygen enriched environment

Polyarylene hook



Hi-Garde Fastener

- Steel wires are woven into Type 304 corrosion resistance steel yarns to form a closure capable of withstanding temperatures up to 800°F for extended duration. This product is often used around rocket engine exhausts to secure protective thermal insulation blankets. It has been used on the Shuttles for such purposes.





Fluoroelastomer

- Hexafluorpropene and vinylidene fluoride high temperature and flame resistant elastomer
- Resistance to temperature extremes 9-75°F - 600°F) unaffected exposure at 400°F continuously 3,000 hours at 450°F
- Excellent resistance to oxidation and ultraviolet radiation
- Exceptionally good compression set values at high temperatures
- Flame resistant in oxygen enriched environment
- Outstanding resistance to oils, fuels, lubricants and chemicals

• Applications

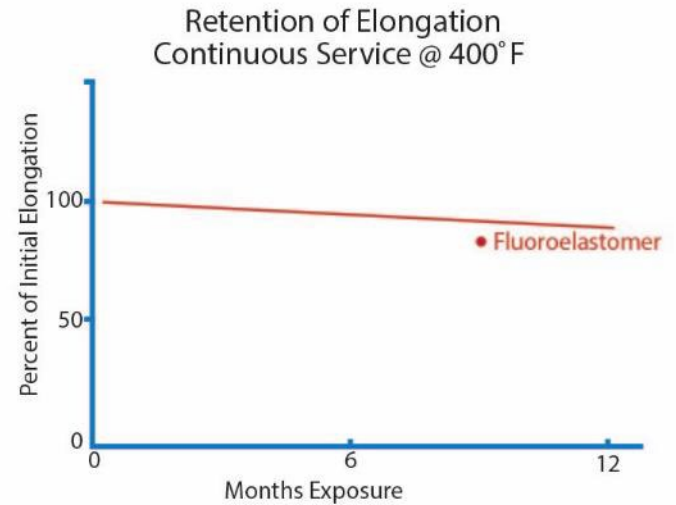
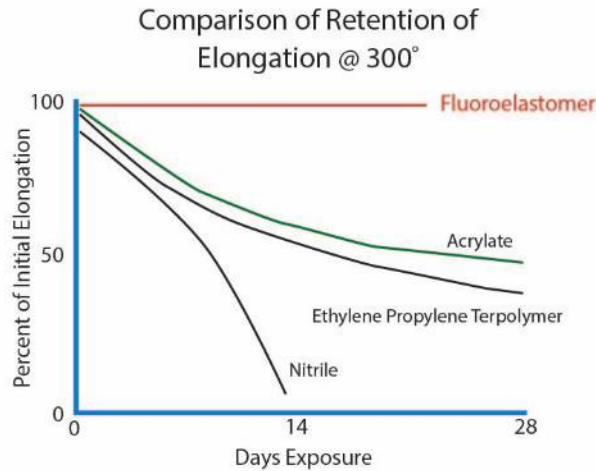
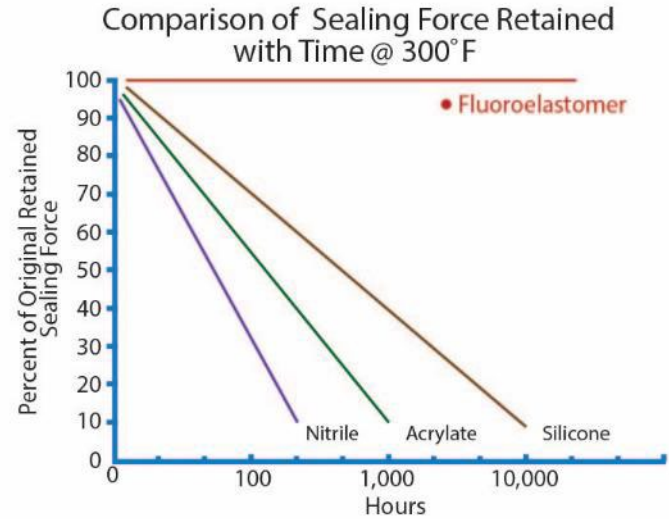
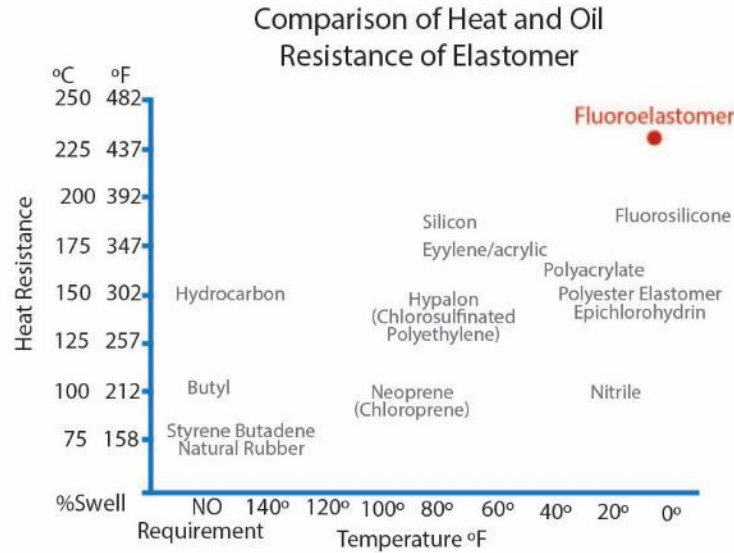
- Abrasion resistant patch
- Boot soles
- Circu9it breaker coating
- Coated harness
- Coated stainless steel fibrous structures
- Edgelock
- Fireproof coating
- Flexible magnets
- Foam – closed cell and open cell
- Gloves and Glove coating
- Headrest
- Helmet liner
- Life vest belt
- Optical glass eye piece
- Oxygen hoses
- Oxygen masks
- Oxygen umbilical hoses
- Shock absorbers
- Spacers
- Urine hoses
- Window shades

• Development

- Cable coating
- Spray coating
- Dip coating
- Conformal coating
- Fluorescent coating
- Various colored paint
- Adhesives
- Caulking compound
- Molding compound
- Extrusion compound



Fluoroelastomer



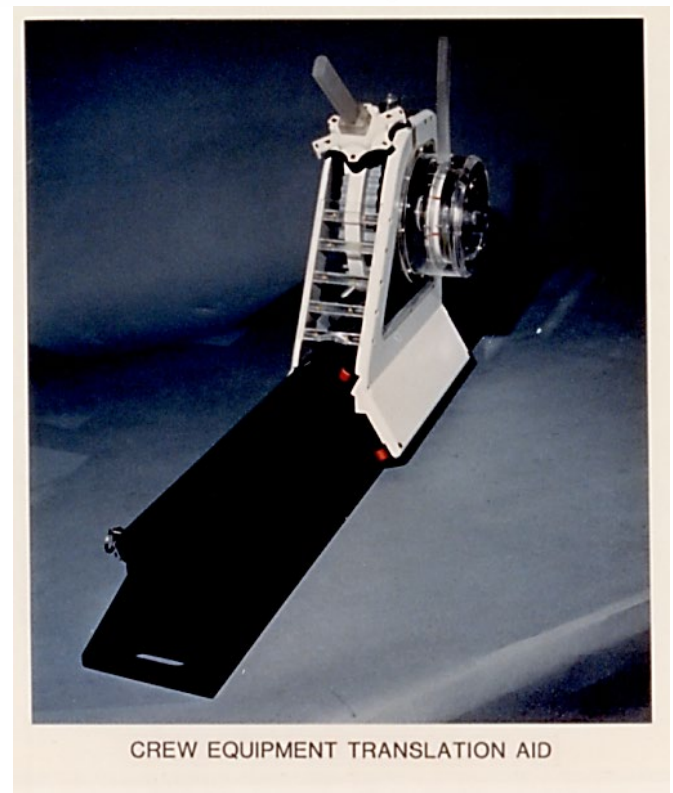
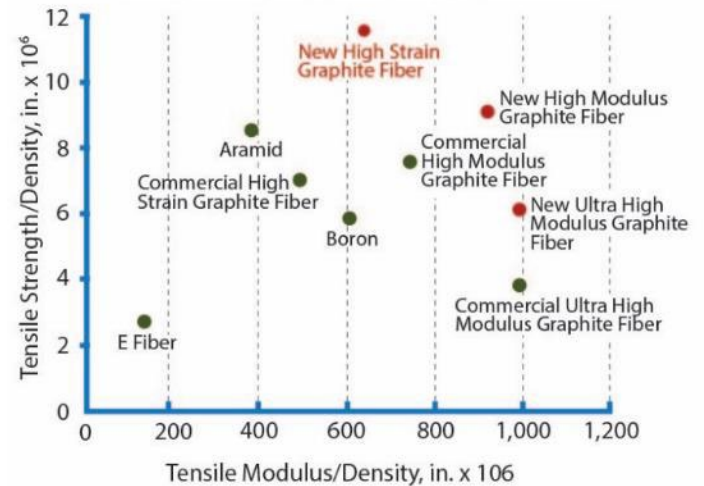
High-Strain Graphite Composite

- Outstanding combined tensile strength and modulus values
- Withstand severe thermal and mechanical stress
- Dimensional stability under temperature extremes



S88-48237

Comparison of Specific Properties With Other Reinforcement Materials



CREW EQUIPMENT TRANSLATION AID

Modified Life Raft/Life Vest Materials

- 2/2 center line reversal twill chloroprene coated nylon
- Improvements over existing life raft/life vest material
- Elimination of flotation tube distortion
- 700% higher abrasion resistance
- 200% higher breaking strength
- 50% lower permeability
- 35% lighter weight



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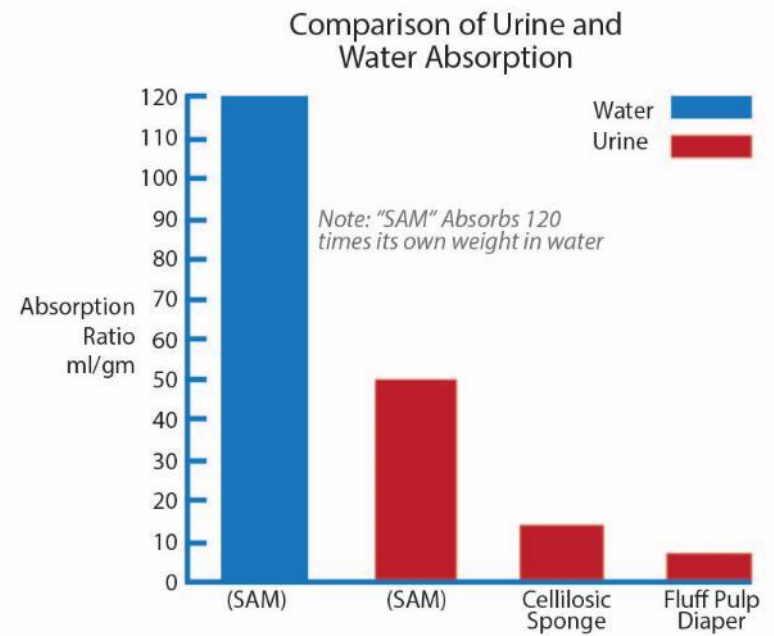


Super Absorbent Material (SAM)

- Urine collection
- DACT – Disposable, Absorption Containment Trunk



S88-48242





Ortho Double Face Fibrous Structures

- Excellent abrasion and wear resistance
- Flame resistant in oxygen enriched environment
- High temperature and chemical resistant
- Low temperature flexibility
- Physical/thermal radiative properties:
 - Specific gravity, gm/cc front face 2.2/back face 1.4
 - Breaking strength, lbs./in. width 230
 - Ultimate elongation, % 60
 - Emissivity (infrared) 0.77
 - Absorptance (solar) 0.18

Front face



100% Gortex fiber,
400 Denier, 6
harnesses split basket
weave, fancy draw.
Warp 52 ends X filling
41 picks

Back face



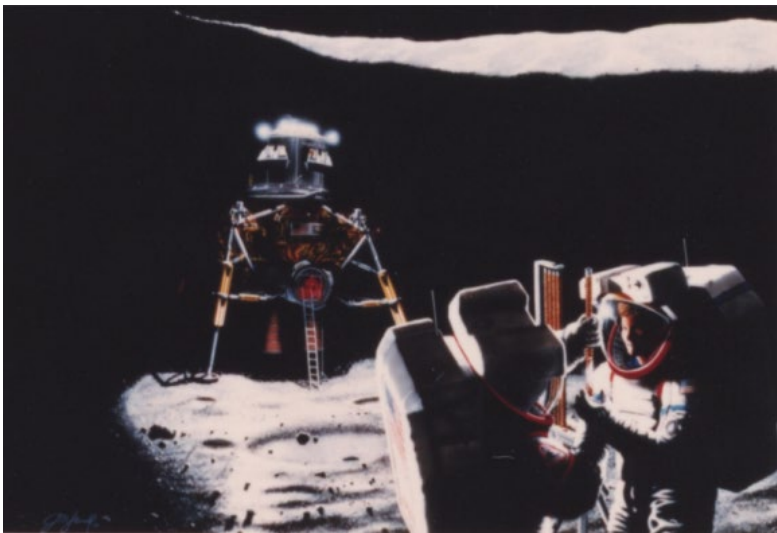
200 Denier/2-ply filament
Nomex, 6 harnesses split
basket weave, fancy draw
with 2-end repeat of 400
denier Kevlar yarn after
every 16 Nomex yarns in
warp and filling directions.
Warp 39 ends X filling 32
picks

Typical Application:
Extravehicular Mobility Unit outer layer



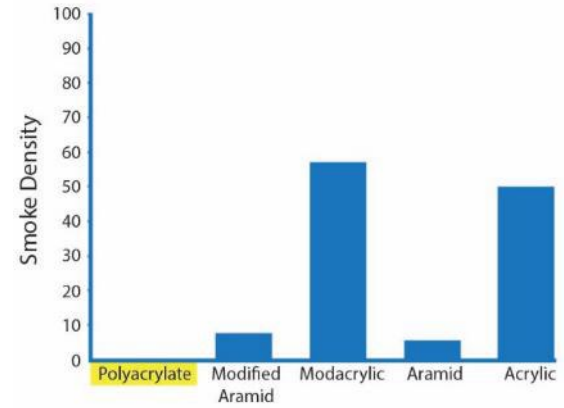
Polyacrylate

- Excellent thermal stability
- Non-melting, minimum char
- Non-smoke generation
- Flame resistant in oxygen enriched environment

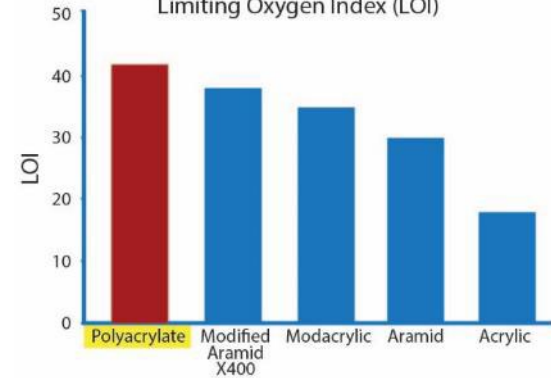


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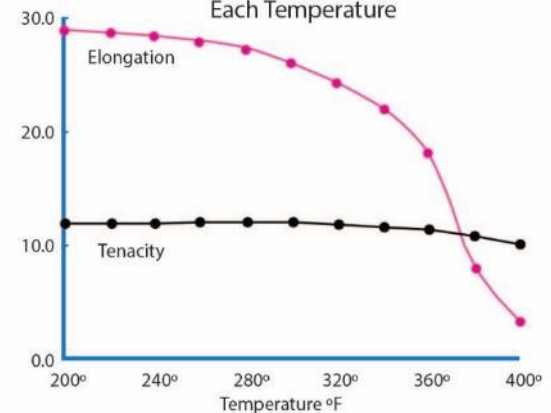
Comparison of Smoke Density



Flammability Comparison of Limiting Oxygen Index (LOI)

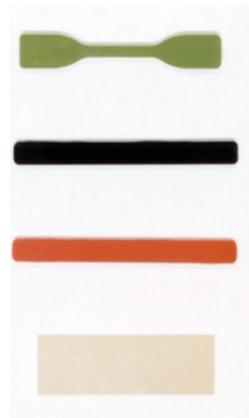
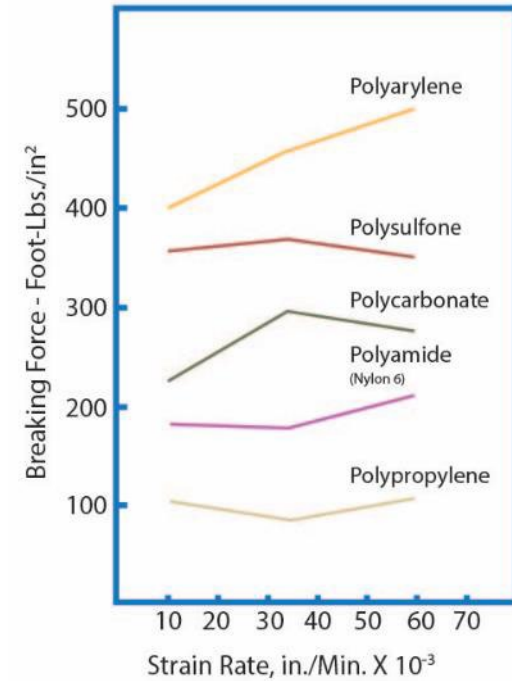


24-Hours Exposure at Each Temperature



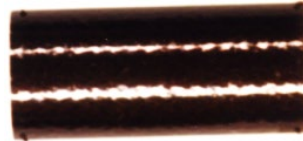
Polyarylene

- Outstanding radiation resistance
- Excellent mechanical toughness
- Superior resistance to wear
- Chemically stable in st

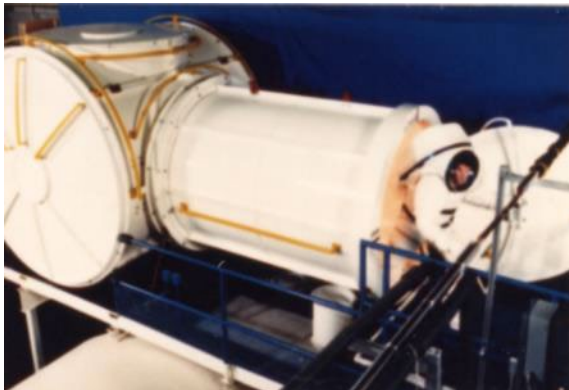


Polybenzimidazole

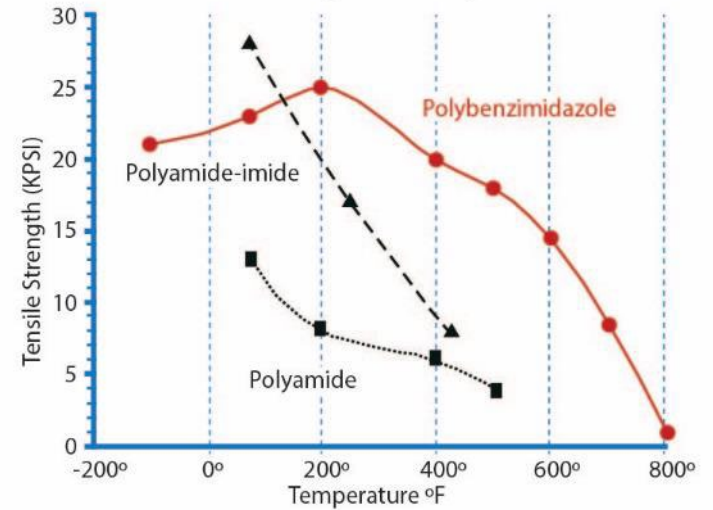
- High temperature resistant
- Flame and thermal shock resistant
- Excellent stability to chemicals & hydrolysis
- Low coefficient of friction
- Typical Applications
 - CETA Carriage Housing
 - Airlock Hatch Bumper



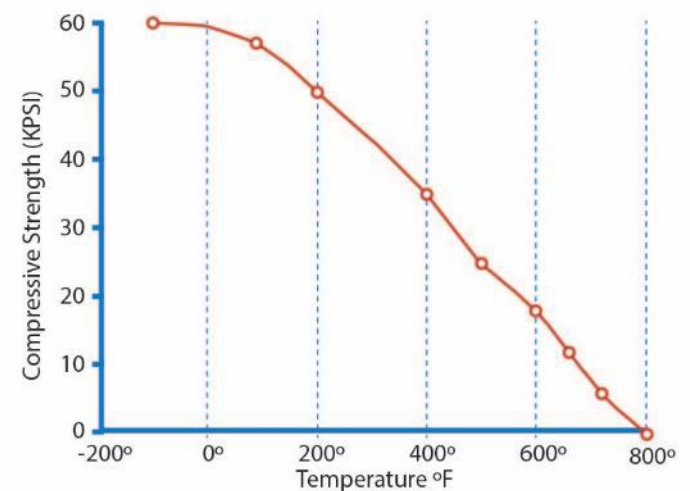
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Tensile Strength vs. Temperature



Compressive Strength vs. Temperature



Polybenzimidazole (PBI)

- Stabilized PBI fiber high temperature and abrasion resistant
- Apollo spacecraft seat restraint
- Apollo LM seat restraint
- Apollo lunar rover seat restraint
- Apollo lunar equipment tether
- Apollo telescope mount film
- Retrieval tether (Back-up)
- Apollo inflight knitted shirt
- Skylab inflight underwear
- Skylab inflight stockings
- Skylab sleeping bag
- Skylab sleep monitoring systems
- Skylab m-171 ergometer restraint harness
- Skylab M-133 sleep monitoring cap
- Skylab oxygen Mask assembly
- Skylab feeding system canister assembly
- Skylab dual life vest
- Shuttle stowage partitions (orbiter middeck)
- Peap hose cover
- MMU restraint systems
- Thermal protection systems tie-down
- Sewing thread



BRAIDED CORD



WEBBING



WOVEN FABRIC

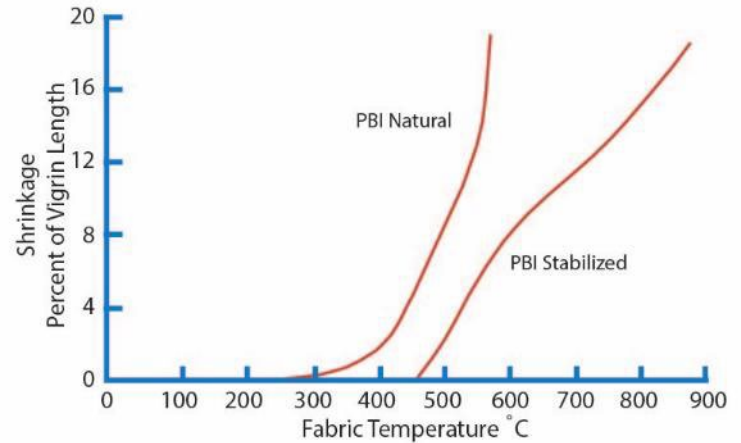


RASCHEL FABRIC

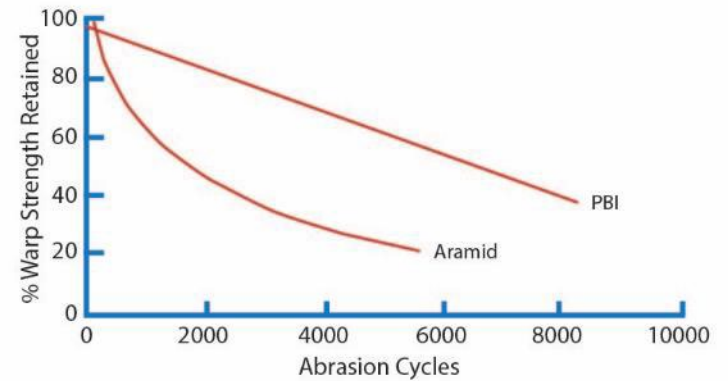


KNITTED FABRIC

Thermal Dimensional Stability of Natural and Stabilized PBI



Abrasion Resistance of PBI and Aramid Fabrics - Taber Abrader



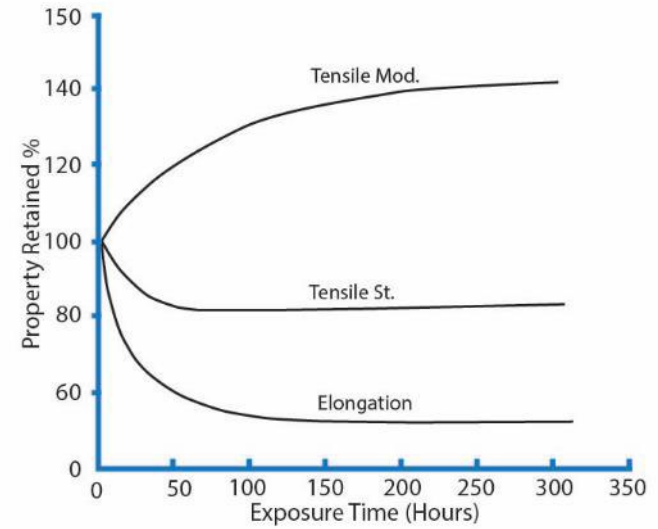
Polyimide

- Ultraviolet radiation stable fiber
- Shuttle orbiter thermal protection system tie-down cord

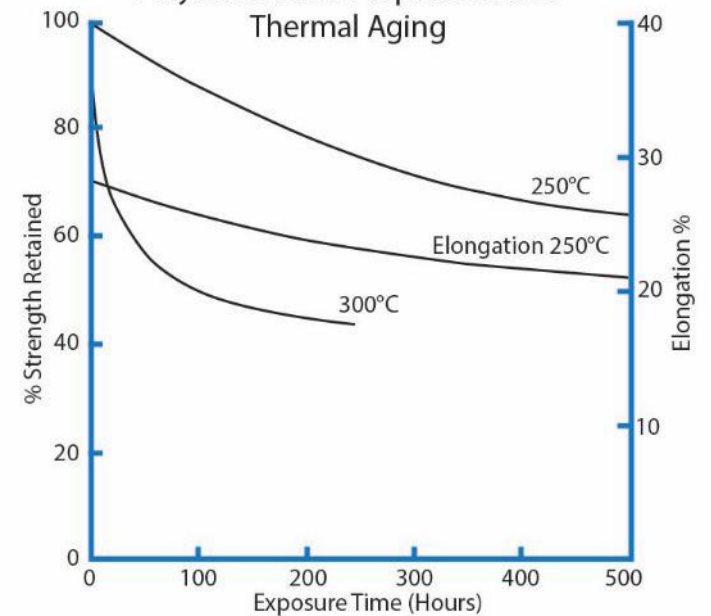


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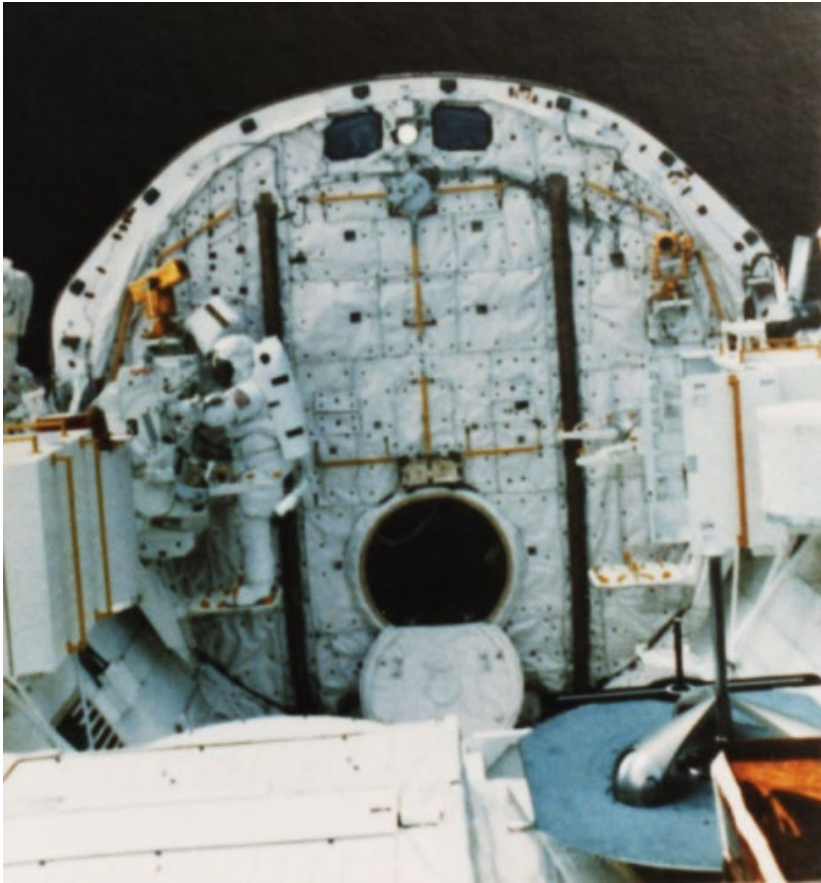
U.V. Stability of Polyimide Fiber



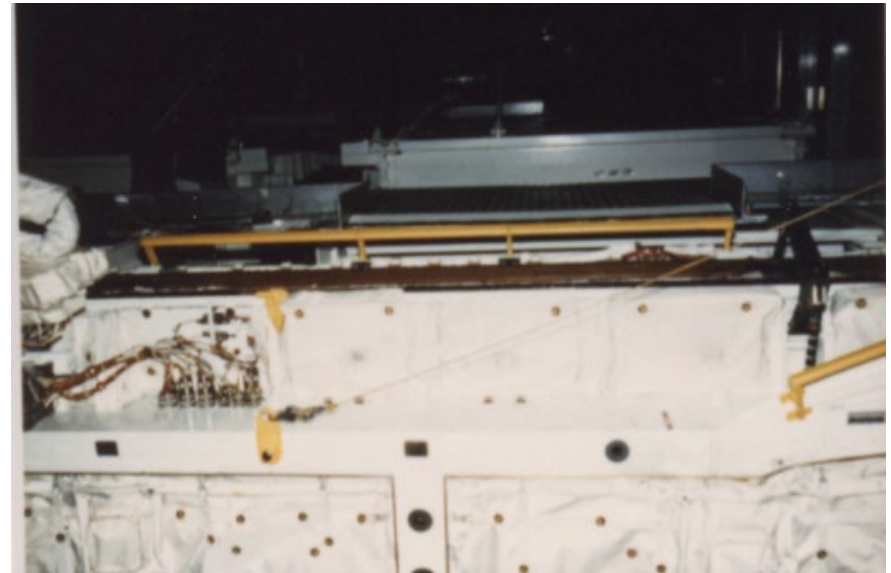
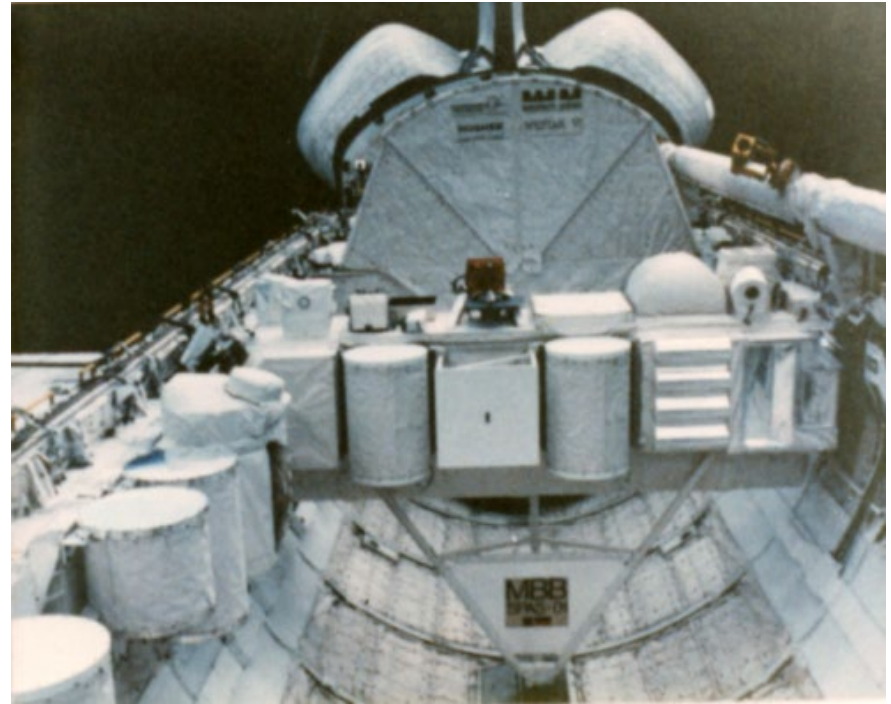
Polyimide Fiber Properties After Thermal Aging



Polyimide

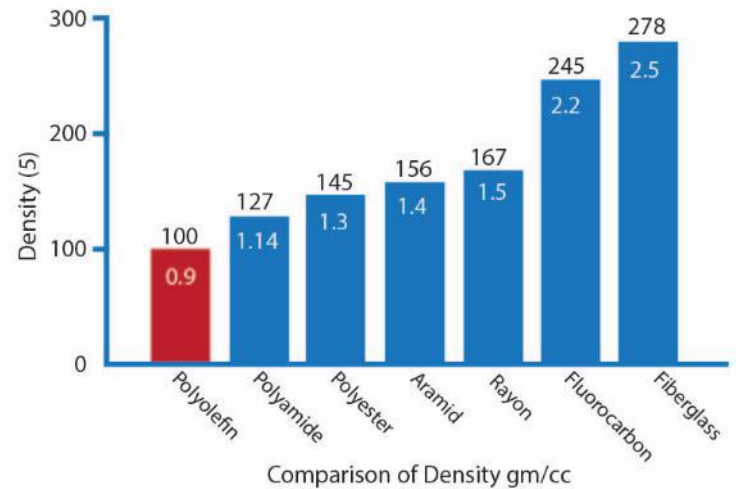
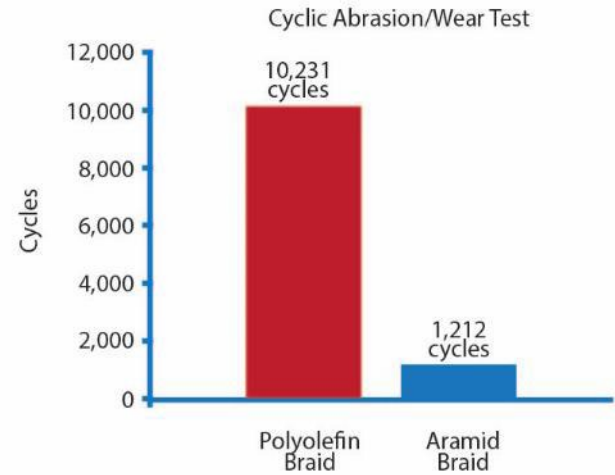
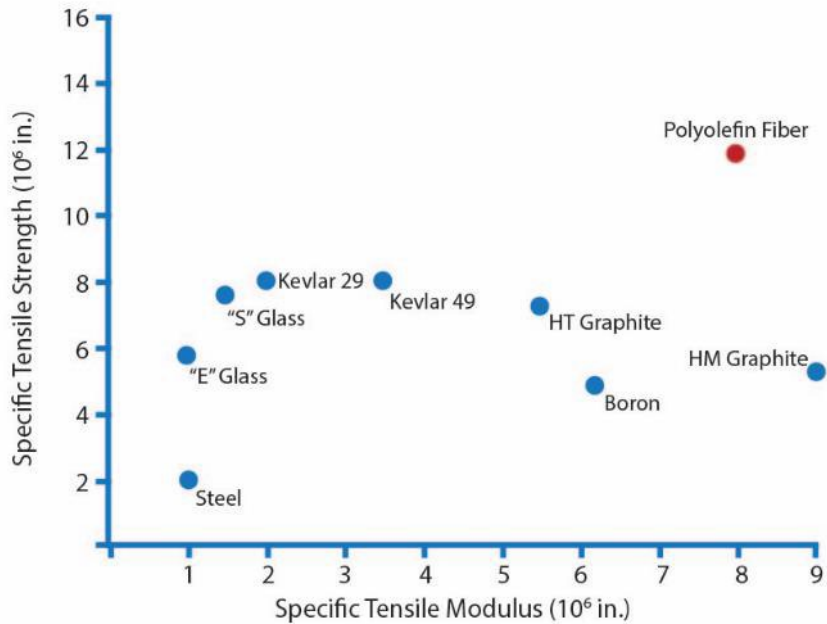


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Polyolefin Fibrous Structures

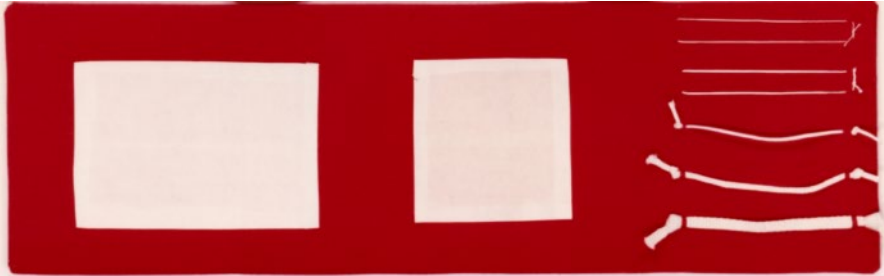
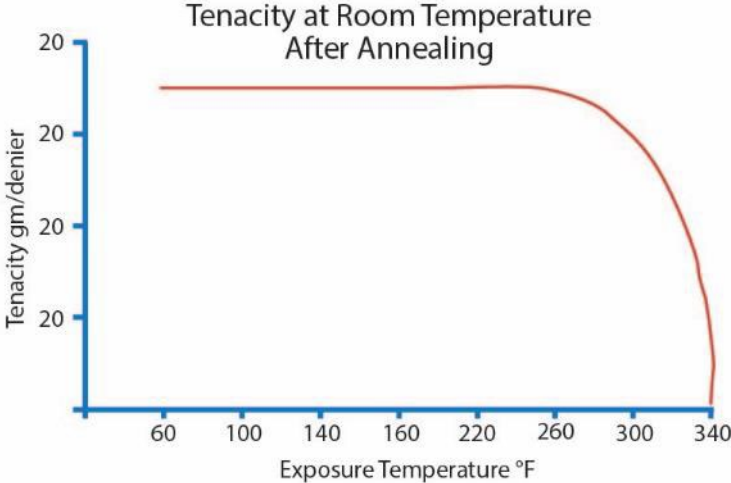
- Ultra high tensile strength
- High abrasion resistance
- High specific tensile modulus
- Lightest weight



Polyolefin Fibrous Structures



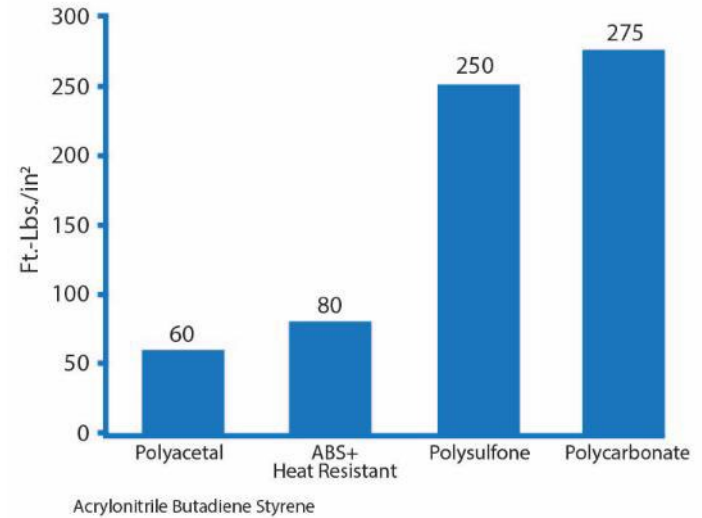
S88-48247



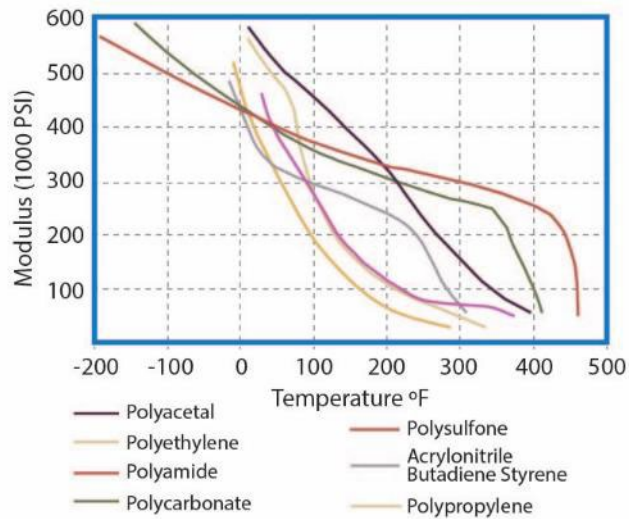
New Visor/Helmet Polysulfone/ Polycarbonate Laminate

- Superior chemical protection
- Outstanding impact strength
- Excellent optical properties
- Dimensional stability and creep resistance

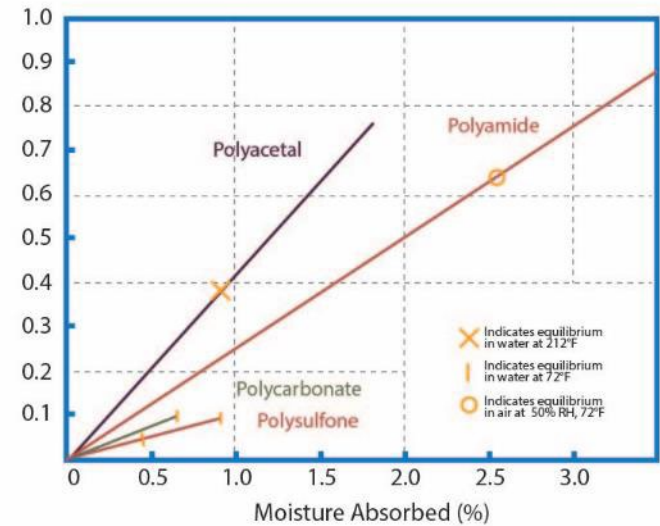
Tensile Impact



Temperature vs. Modulus

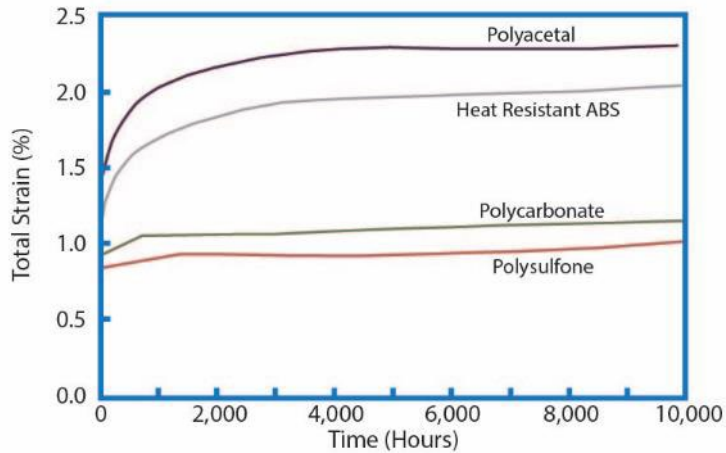


Dimensional Change Due to Moisture

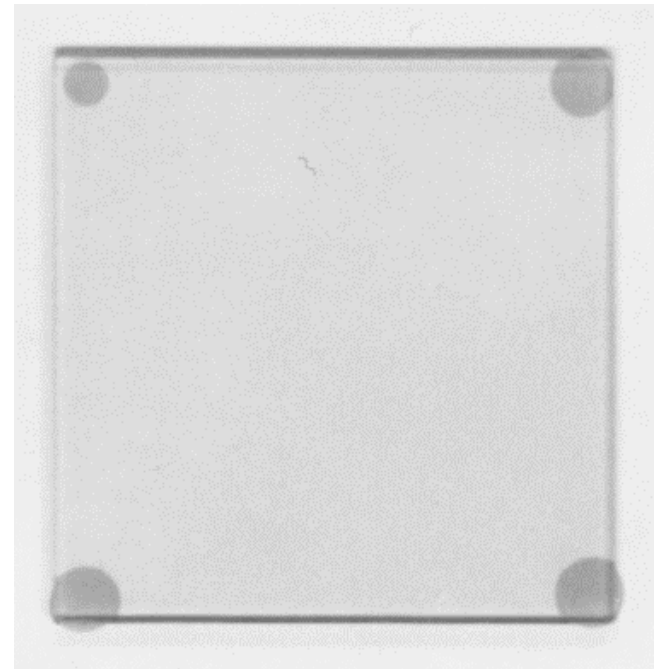


New Visor/Helmet Polysulfone/ Polycarbonate Laminate

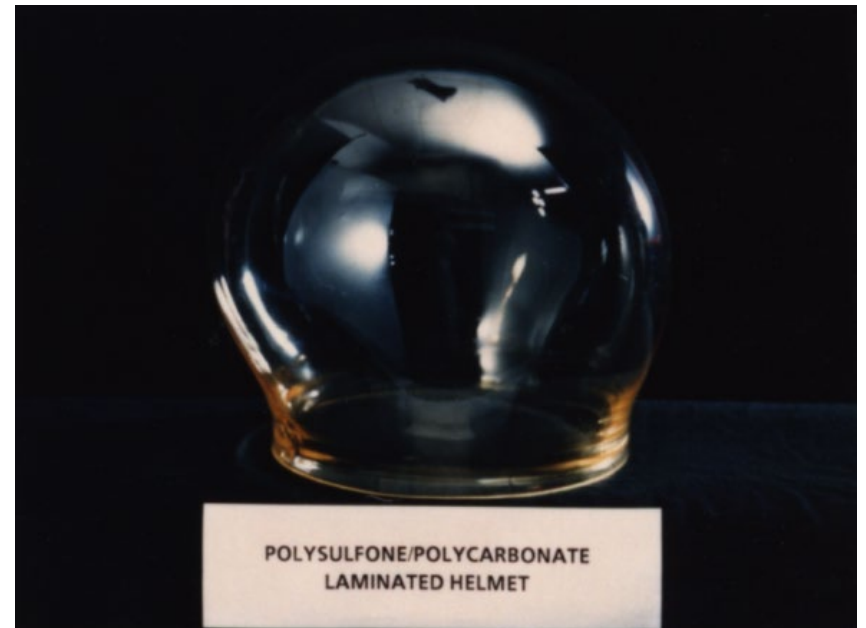
Comparison of Creep Behavior @72°F
Stress + 3,000 psi Tension



Acrylonitrile Butadiene Styrene



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POLYSULFONE/POLYCARBONATE
LAMINATED HELMET