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Beta Cloth Durability Assessment for Space Station Freedom (SSF) Multi-Layer Insulation (MLI) Blanket Covers

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INTRODUCTION

SSF program requirements (SSP 30233) indicate a 30-year life for MLI blankets with no EVA time scheduled for blanket repair or replacement. As a result, the long term durability of candidate blanket materials and configurations in the low Earth orbit (LEO) environment must be determined to assure compliance with program requirements and expectations. This technical memorandum documents the results of laboratory and spaceflight studies used to evaluate the durability of two different types of a Teflon coated glass fabric commonly known as Beta cloth.

BACKGROUND

Several space environment factors present in LEO can degrade materials. Atomic oxygen, solar ultraviolet and vacuum ultraviolet (UV/VUV) radiation, micrometeoroids and orbital debris (MM/OD), thermal cycling, mechanical loads and handling during EVA, shuttle engine plume impingement, ionizing radiation and plasma interactions can all contribute to property loss of exposed materials and configurations. The only components of MLI blankets directly exposed to the environment are those on the outer surface. Table I provides a compiled list identifying current MLI applications for the WP-II components such as the insulation systems for the pressurized modules, resource nodes, airlock, truss segments, propulsion modules, utility tray components, mobile transporter, etc. Of the space environment factors listed, atomic oxygen, solar UV/VUV, thermal cycling and mechanical handling/loads are the dominant factors determining the life of exposed MLI materials. The Space Station Freedom Natural Environment Definition for Design (JSC-30425) contains a detailed description of the LEO environment.

Atomic oxygen and UV/VUV interact to produce a photochemical removal of Teflon from Ram-oriented surfaces in LEO (S. L. Koontz, L. Leger, K. Albyn, J. B. Cross; *J. Spacecraft and Rockets*, Vol. 27, No. 3, pp. 346-348). The measured reaction efficiency of Teflon varies with the VUV dose and surface temperature. Teflon samples on the Long Duration Exposure Facility (LDEF) produced atomic oxygen reaction efficiencies between 0.1 and 1 x 10 $^{-24}$ cm^3/atom with an average value of 0.3 x $^{-24}$ cm^3/atom (official estimate of LDEF Materials Special Investigation Group, MSIG). Beta cloth specimens flown by investigators at the Marshall Space Flight Center (MSFC) showed nearly complete removal of Teflon from Ram-oriented surfaces (Dr. Ann Whitaker, MSFC, personal communication), though the Teflon coating remained intact on the anti-Ram side of the exposed material.

The atomic oxygen reactivity of Teflon raises several durability issues for MLI blankets with Beta cloth outer covers. First, is the Teflon going to be completely eroded away from the glass fabric or only removed on one side? Second, is the glass fabric/Teflon remaining after a worst case oxygen atom attack permeable to atomic oxygen? Finally, after oxygen atom attack has removed much of the Teflon, will the remaining glass fabric be subject to rapid degradation resulting from self-abrasion of the glass fibers during thermal cycling or mechanical handling/loading?

Solar UV/VUV has effects in addition to the photochemical synergism with atomic oxygen. Degradation of polymer material properties with UV/VUV radiation has been observed in samples of Teflon exposed on the wake (no significant atomic oxygen) side of LDEF (A. E. Steigman, D. Brinza, M. Anderson, T. Minton, E. Lane, R. Liang; "An Investigation of the Degradation of FEP Teflon Thermal Blanketing Materials aboard LDEF and in the Laboratory," JPL Publication 91-10, May 15, 1991) and has been the subject of some academic research (Adams, Garton; "Far-Ultraviolet Degradation of Spacecraft Polymers," Symposium L, Spring Meeting of the Materials Research Society, April 29-May 30, 1991, Anaheim, California). Beta cloth on the wake side of SSF will not be removed by atomic oxygen attack but will be degraded by UV/VUV attack on the Teflon coating, possibly producing particle release and discoloration.

EXPERIMENTAL

I. Materials

Two Beta cloth fabric types were used in this investigation: (1) Rockwell specification MBO 135-027 (Chemglas 250), equivalent to MDSSC STM-0484-1 (or MDSSC DPM 4273), and (2) Sheldahl G414500 (MDSSC DPM 8413). The Rockwell specification material is the same as that used for the payload bay liner in the Space Shuttle cargo bay. The Sheldahl material has been used in Delta rocket payload farings and upper stages. Samples of MBO 135-027 type Beta cloth (Chemglas 250 Beta glass fabric from Chemfab) were aluminized on one side by vapor deposition of 1200 angstrom of aluminum after sandblasting treatment of the Beta cloth on one side only. The aluminized Beta cloth (Chemglas 250) is the baseline for work package 2 MLI blankets.

II. Atomic Oxygen Reactivity Measurements

A. High velocity oxygen atom beam testing: Los Alamos National Laboratories

Preliminary atomic oxygen effects testing of MBO 135-027 and G414500 was done in the high energy atom beam facility at the Los Alamos National Laboratories (LANL). The objective of the preliminary testing was to compare the two types of Beta cloth by microscopic and visual examination after both had received a high velocity O atom dose corresponding to several months of exposure on a Ram-oriented SSF surface. The high velocity atom beam system has been previously described (L. Leger, S. L. Koontz, J. T. Visentine, J. B. Cross; "Laboratory Investigations Involving High Velocity Oxygen Atoms," Fourth European Symposium on Spacecraft Materials in the Space Environment, proceedings of the symposium held at CERT, Toulouse, France, Sept. 6-9, 1988, ONERA, Toulouse, 1989, pp. 393-404). In a preliminary screening test, samples of MBO 135-027 and G414500 were exposed to the atomic oxygen beam for 16 hours at an atom flux of 4×10^{16} atoms per square centimeter per second and a nominal atom kinetic energy of 1.5 eV. The samples were held at a temperature of 150 degrees centigrade during the exposure. In a final test, a sensitive integrating atomic oxygen detector (a silver actinometer) was placed behind a sample of a Work Package 2 baseline Beta cloth for a total of 69 hours at an atom flux of 4×10^{16} atoms/cm^{2}sec and a nominal kinetic energy of 2 eV (sample temperature of 150 degrees centigrade). The total atom fluence was 1×10^{22} atoms/cm^2. The atom beam contains significant vacuum ultraviolet radiation such that FEP Teflon shows a reaction efficiency of 1.5×10^{-24} cubic centimeters per atom in the Los Alamos atom beam system under the condition used for Beta cloth testing. Samples exposed to the high velocity oxygen atom beam at Los Alamos were examined by scanning electron microscopy (SEM, Amray Model 1400).

B. Oxygen Plasma Testing

Oxygen plasma testing of Beta cloth samples was conducted at JSC in the LFE Corp. model LTA-302 plasma asher by methods varying slightly from those previously reported (S. L. Koontz, K. Albyn, L. Leger, "Materials Selection for Long Life in Low-Earth Orbit," Journal of the IES, March/April 1990, pp. 50-59). The objective of the plasma asher testing was to provide test materials with worst case atomic oxygen and UV/VUV damage. The plasma asher operating conditions were selected to produce a very high rate of removal of the Teflon coating (i.e., a very high acceleration factor for atomic oxygen degradation). The plasma asher treated Beta cloth was examined by SEM and tested for mechanical durability and oxygen permeability as described below. In the present work, samples were tested at a total pressure of 1.0 Torr of aviators breathing oxygen (ABO, Mil-O-27210E) and 200 watts of radio frequency power. The sample holders were allowed to rest on the bottom of the cylindrical plasma chamber. Only one side of the Beta cloth sample was directly exposed by the sample holder. As for the aluminized Chemglas 250 samples, only the Beta side was subjected to direct exposure. Samples were weighed every 19 to 20 hours on a 5 place analytical laboratory balance to determine the kinetics of mass loss. Samples subjected to oxygen plasma attack in the plasma asher were subsequently tested for optical properties (α/ε), mechanical durability and oxygen permeation using the methods described below.

III. Mechanical Durability Testing

The mechanical durability of the Beta cloth specimens was evaluated using: (1) a Dupont Model 980 Dynamic Mechanical Analyzer maintained by the Structures and Mechanics Division, (2) the Flex/Fold Tester developed by the Chrysler Corporation, (3) a CSI Dart Drop Apparatus, and (4) an Elmendorf Apparatus which are all maintained by the Crew and Thermal Systems Division at JSC. Teflon was removed from the nonaluminized and aluminized Beta cloth samples prior to mechanical durability testing by both oxygen plasma asher treatment.

The function of the Model 980 Dynamic Mechanical Analyzer Apparatus is to hold the specimen of uniform cross section so that the specimen acts as the elastic and dissipative element in a mechanically oscillating system. This technique measures the viscoelastic response of a polymer when subjected to a sinusoidal stress. Samples were subjected to 172,800 mechanical cycles of .178 percent surface strain (at room temperature) to simulate a full 30 years of thermomechanical cycles. Samples were mounted with the warp and weave of the glass fabric oriented 45 degrees to the direction of motion to maximize fiber-fiber motion and abrasion. Specimens were then examined for abrasion and wear by SEM after the test.

The flex test was performed on a Chrysler Flex and Fold Test machine. The assembly consisted of two smooth parallel specimen clamps, one of which makes a reciprocating motion of approximately 100 double strokes per minute. The flex sample was inserted between the two clamps and then securely tightened. The lower clamp was rigidly supported to provide free movement of the reciprocating clamp plates. All specimens were cut from Beta cloth material with the longitudinal direction of the specimens parallel to the warp direction of the material. Specimens were run until they ruptured and a counter registered the number of cycles that was required to break the material. Samples were then visually inspected for any evidence of aluminum flaking.

The free falling dart drop test was performed on a CSI-Dart Drop Apparatus per ASTM D1709-85. It consisted of a dart with a 2-inch diameter hemispherical head dropped from a height of 60 inches onto a 5-inch diameter sample (which was held in place by annular clamps). Each hemispherical head of the dart was fitted with a 1/4 inch diameter shaft to hold removable incremental weights. Samples were then inspected for evidence of fiber rearrangement or breakage.

The falling pendulum tearing strength test was performed on an Elmendorf Apparatus. The specimen was fastened to the clamps and the tear was started by a slit cut in the specimen between the clamps. The pendulum was then released and the specimen was torn as the moving jaw moved away from the fixed one. The tearing force in grams could then be read directly from the scale attached to the pendulum. This method was used to determine the force required to propagate an initial tear of 10 mm on a sample by measuring the work done in tearing it through a fixed distance.

A tape peel test was used to determine the mechanical durability of the vapor deposited aluminum on the Work Package 2 baseline MLI Blanket material. The tape peel procedure was obtained from Sheldahl Corporation (Sheldahl Specification Q000084).

IV. Atomic Oxygen Penetration Testing

Three types of atomic oxygen permeation tests were conducted. First, because only one surface of the Beta cloth specimen was exposed to the plasma in the plasma asher, weight loss data indicated how rapidly Teflon was lost from the interior and protected side after complete removal of Teflon from the front or exposed surface. Second, a sample of MBO 135-027 was treated for 72 hours in the plasma asher (1 torr ABO, 200 watts) with both sources exposed to the plasma so that only 2-3 percent of Teflon remained (by thermogravimetric analysis in air). The 72-hour oxygen plasma treated specimen was then used in a configurational oxygen penetration test in LEO during STS-41 on the Intelsat VI Solar Array Coupon flight experiment. A piece of silver foil and a Kapton film were placed behind the 72-hour Beta cloth specimen and the assembly was exposed to Ram atomic oxygen during the ISAC portion of the mission. Direct comparison of exposed silver foil and Kapton samples with those behind the 72-hour Beta cloth specimen yields a direct assessment of atomic oxygen penetration. The ISAC experiment package received an oxygen atom fluence of 1.2×10^{20} atoms per square centimeter. Third, as described above in section II, a sample of the aluminized Chemglas 250 was placed in the O-atom beam at Los Alamos for a fluence of 1×10^{22} atoms. During the ISAC exposure a piece of silver foil was placed behind the specimen to record any O-atom penetration. A sensitive silver octometer was used to detect O-atom penetration during the Los Alamos exposure.

The mechanical durability of the vacuum deposited aluminum on the back side of the Beta Cloth was also investigated. Samples of MBO 135-027 were exposed in an oxygen plasma asher at JSC. A standard tape peel test was then performed on the aluminum side. Since the aluminum was applied to serve primarily as a light block, transmittance (τ) measurements (Cary 14 spectrophotometer) were made on the aluminized Beta cloth to determine any transmittance changes.

V. Thermogravimetric Analysis

Thermogravimetric analysis (TGA) with a Cahn model 2000 TGA apparatus was used to determine the amount of Teflon and other thermally labile materials present in Beta cloth specimens, both as received and after oxygen plasma or high temperature oven treatments. TGA analysis was conducted in the air, beginning at room temperature and ramping to

1090 degrees centigrade at a rate of 5.9 degrees centigrade per minute. The air purge rate was 120 cc/min. Mass loss between 520 and 550 degrees centigrade is attributed to Teflon. No other significant mass loss events were observed.

VI. Solar UV Degradation Testing

The UV stability of the Beta cloth was investigated under xenon lamp exposure in vacuum at NASA-LaRC. Three samples of Beta cloth with varying amounts of polysiloxane by weight were exposed for a total of 800 equivalent sun hours (ESH) at two suns. Small amounts of non volatile polysiloxane (< 1 degree centigrade) remained in Beta cloth as a result of the manufacturing process and have been implicated in UV darkening of the Beta cloth. The xenon lamp source cutoff is at 180 nanometers. The changes in solar absorptance (α) were recorded.

VII. Thermo-Optical Property Measurements

Optical property measurements were conducted with a Gier Dunkel MS-251 solar reflectometer and a Gier Dunkel DB-100 infrared emissometer. A Cary 14 spectrophotometer was used for transmittance measurements.

RESULTS AND DISCUSSION

I. Atomic Oxygen Reactivity and Penetration Testing

SEM photomicrographs of both atomic oxygen exposed and unexposed portions of a sample of Rockwell MBO 135-027 type Beta cloth from the preliminary screening tests at LANL are shown in figures 1a and 1b. The atomic oxygen exposure in the LANL high velocity atom beam system (see experimental section above) produces a total fluence of 2×10^{21} atoms per square centimeter or about 1 percent of the full-life Ram fluence anticipated for the Space Station Freedom. The unexposed portion of the sample shows a tightly woven glass fabric covered with a Teflon coating which holds broken glass fibers in place (figures 1a and 1b). Atomic oxygen attack results in almost complete removal of the Teflon coating from the exposed surface. Some residual Teflon is visible on the exposed surface. No evidence of oxygen penetration to the reverse side of the exposed area was visible, a direct result of the physical barrier produced by the tightly woven glass fabric. A razor cut made on the unexposed portion of the MBO 135-027 sample is compared with one made in the oxygen exposed region. The role of the Teflon coating in limiting surface impact damage is evident (figures 2a and 2b).

In contrast, the more open weave glass fabric characteristic of the Sheldahl G414500 type Beta cloth provides no barrier to atomic oxygen after the Teflon coating is removed by oxygen atom attack in the same preliminary screening test series. Results of atomic oxygen exposure in the LANL high velocity atom beam (see experimental section above) are shown in figure 3. The exposure was identical to that given to the MBO 135-027 sample described above. As can be seen in figure 3, atomic oxygen attack completely removed the Teflon producing large openings between the glass threads. The thin vapor-deposited film of aluminum metal on the back side of the G414500 sample partially disintegrated to produce particulate contamination. Evidence of high velocity oxygen atom attack was visible on the sample holder behind the Sheldahl G414500 specimen.

Oxygen atom reactivity testing in the LTA 302 plasma asher produced similar results. Oxygen plasma attack rapidly removed the Teflon from the Sheldahl G414500 material exposing the fragile vapor-deposited aluminum backing which became visible through the open weave glass cloth.

In contrast, the MBO 135-027 material showed an initial rapid mass loss as Teflon was removed from the exposed surface of the test article, followed by a much slower mass loss as Teflon was removed from the interior of the glass fabric. Teflon on the protected side of the test article was not attacked and remained adherent. On inverting the test article to expose the protected side to the oxygen plasma, rapid mass loss was again observed as the newly exposed Teflon was removed. Test article mass is shown as a function of time in figure 4 for two different samples of MBO 135-0278 equivalent materials (Fluoroglas X389-7). The results show that the glass fabric in MBO 135-027 or equivalent materials is a good barrier to oxygen plasma attack.

II. Atomic Oxygen Penetration Testing

More definitive penetration testing was conducted as a part of the ISAC flight experiment (STS-41, October 1990) as described in paragraph IV of the Experimental section of this technical memorandum. After a total atom fluence of 1.2×10^{20} atoms per square centimeter, no evidence of oxygen atom penetration could be found on either the Kapton or the silver foil specimens. The weight of the silver foil specimen was unchanged after treatment with concentrated ammonium hydroxide to dissolve any silver oxide present on the surface. In contrast, samples of the same silver foil exposed directly to the atomic oxygen Ram flux on ISAC showed an average mass loss of 5 percent in measurements made by the Microelectronics Division at Comsat Laboratories. However, it should be noted that the reaction of atomic oxygen with silver is a highly nonlinear process. Studies at the Los Alamos National Laboratories reported in NASA TM 102175 show that more than 50 percent of the final oxide film thickness for a 1×10^{20} oxygen atom per square centimeter dose is developed after the first 2×10^{19} atoms. As a result, our detection limit for O atom penetration using the silver foil as an O atom detector is on the order of 1 percent of the full Ram fluence.

The silver foil can detect both high velocity and thermally accommodated oxygen atoms because the oxygen atom reaction with silver exhibits little or no dependence on atom kinetic energy. In contrast, the oxygen atom reactivity of Kapton is 4 orders of magnitude smaller with thermal energy (0.04 eV) atoms than with high velocity (5 eV) atoms (S. L. Koontz, K. Albyn, L. J. Leger; "Atomic Oxygen Testing With Thermal Atom Systems," *J. Spacecraft and Rockets*, March-April 1991). In addition, Kapton develops a distinctive surface morphology when subjected to high velocity O atom attack. Photomicrographs of the control, shielded and exposed Kapton surfaces are shown in figures 5a, b and c. The Kapton sample shielded by the Beta cloth specimen shows no trace of high velocity atom attack. We conclude that MBO 135-027 or equivalent materials provide an acceptable barrier to oxygen atom penetration even after removal of nearly all the Teflon coating by oxygen atom attack in LEO.

Similar results were obtained when the Work Package 2 baseline Beta cloth was tested in the Los Alamos atom beam. After a total fluence of 1×10^{22} atoms, no oxygen penetration could be detected with a sensitive O atom detector (behind the Beta cloth sample).

The Sheldahl G414500 material was not subjected to further testing because the oxygen atom reactivity tests showed it to be unsuitable for use in exposed environments on the Space Station Freedom.

Removal of the Teflon coating from the Beta cloth by oxygen plasma asher did not affect the vacuum deposited aluminum coating on the back side. The standard tape peel test did remove a portion of the aluminum coating, although this was not unexpected due to the conservative nature of the test. Transmittance measurements, reported in table II, show that the transmittance increases from approximately 2% to 10% after the partial removal of the aluminum coating. This increase in transmittance is not considered detrimental to the Beta cloth performance and the aluminum coating is considered satisfactory for long term thermal applications on SSF.

III. Mechanical Durability Testing

Dynamic mechanical analyzer testing of MBO 135-027 after Teflon removal by oxygen atom plasma or high temperature furnace burnoff showed no evidence of fiber degradation by self abrasion after 172,800 cycles with 0.178 percent surface strain. Surface strain in this case is identified as oscillatory deformation which was applied at a sinusoidal frequency to the specimen (figure 6). SEM photomicrographs of cycled and control samples are shown in figures 7 and 8.

Flex /Fold testing of the aluminized Chemglas 250 after being exposed to atomic oxygen for 12 hours in the plasma asher (only the Beta side was directly exposed to oxygen plasma attack in the plasma asher) showed excellent resistance to flexing. An average of 155,000 cycles was required to rupture the specimens. In addition to strong flex resistance, no flaking in the aluminum coating was observed during the course of testing.

Tearing resistance testing of the aluminized Chemglas 250 as received and after Teflon removal by oxygen plasma showed a slight decrease in tearing strength. Teflon coating was placed within the Beta fiber to prevent interfiber friction to avoid strength loss. When this coating is removed, weaker tearing resistance is expected (tables III and IV). However, the results still yield acceptable tearing properties.

Two Teflon removed aluminized Chemglas 250s were tested at a maximum load of 1620 grams on the Dart Drop Apparatus. Since Beta cloth in general is a strong fibrous material compared to common textile fibers, it is not expected for the material to fail this test. No breakthrough or broken filaments were observed in the tested samples, but there were a number of loose fibers around the clamped areas caused by the distributed energy impact. Overall, the result gave a good indication of the response of Beta to free falling impact situation.

IV. Solar UV Degradation Testing

Table V shows changes in solar absorptance with ESH for the three Beta cloth samples with varying amounts of polysiloxane. The baseline Orbiter payload bay liner material, Form GW, showed little change in α, as did the silicone free material. The Form F material showed slight but acceptable degradation.

V. Thermo-Optical Property Measurements

Solar absorptance and thermal emittance of samples of MBO 135-027 were unchanged by removal of the Teflon coating in the oxygen plasma asher. Prior to oxygen plasma asher treatment, α is equal to 0.24 and ε is equal to 0.91. The values are within experimental error. Thermo-optical property measurements on several Beta cloth materials are summarized in table II. The results of the tape peel test as applied to plasma asher treated aluminized Beta cloth (WP-2 baseline) are also shown in table II. Thermo-Optical properties are stable in very conservative degradation tests. The aluminum coating shows more than adequate adhesion and no significant increase in transmittance.

SUMMARY AND CONCLUSIONS

Beta cloth produced to the Rockwell MBO 135-027 specification (or equivalents) exhibits acceptable durability for use in exposed environments on the Space Station Freedom. The available data indicate a 30-year life in LEO. Sheldahl G414500 was found to be unsuitable for applications in exposed environments on the Space Station Freedom. The Work Package 2 baseline material, an MBO 135-027 equivalent coated with 1000 Å of Aluminum on one side only, was also found satisfactory for long-term use on the Space Station Freedom.

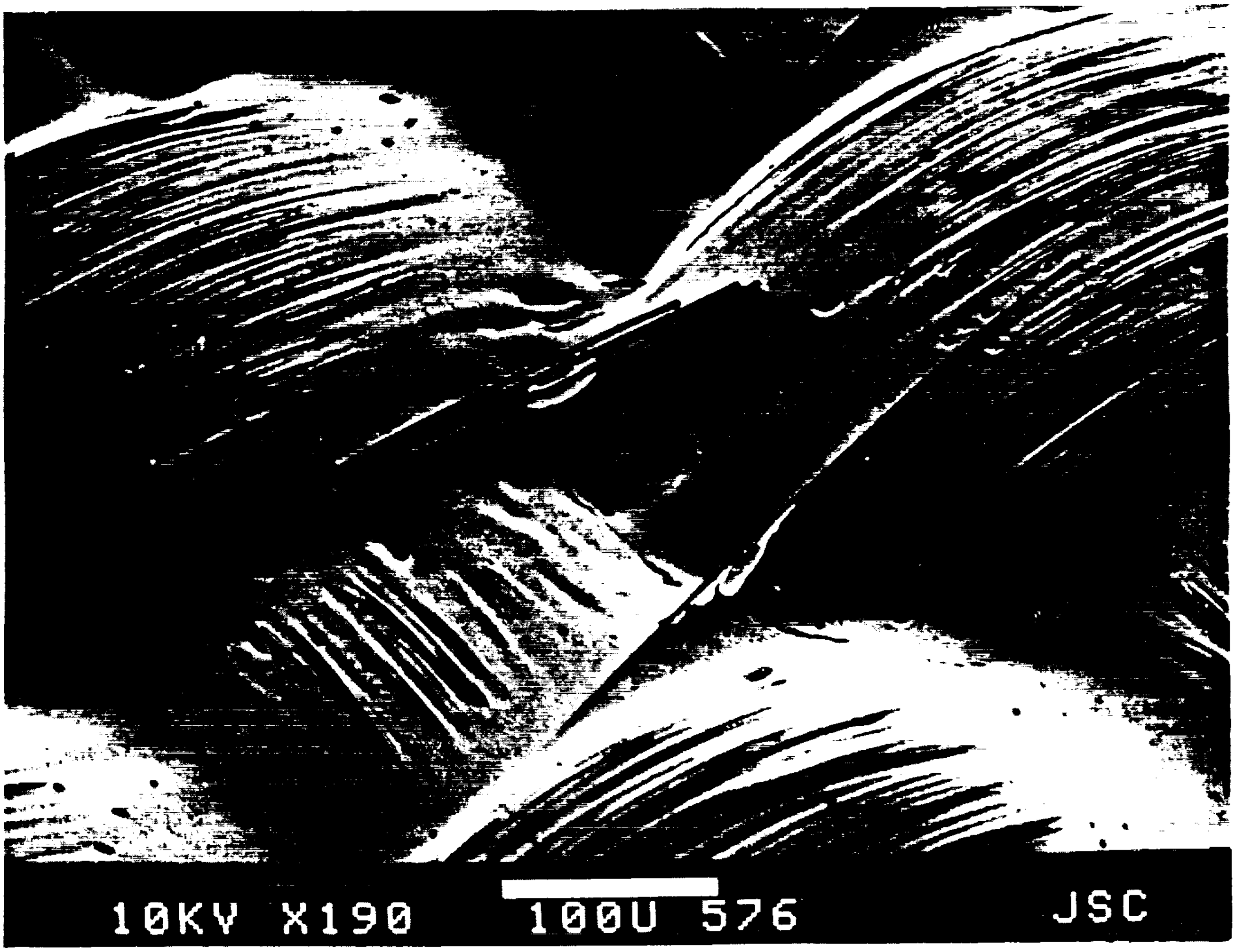

Figure 1a. MBO 135-027 specification Beta cloth after (a) no atomic oxygen attack, and (b) an atom fluence of 2.3 x E21 atoms per square centimeter. Sample temperature was 150 degrees centigrade. Oxygen atom kinetic energy was 1.5 eV.

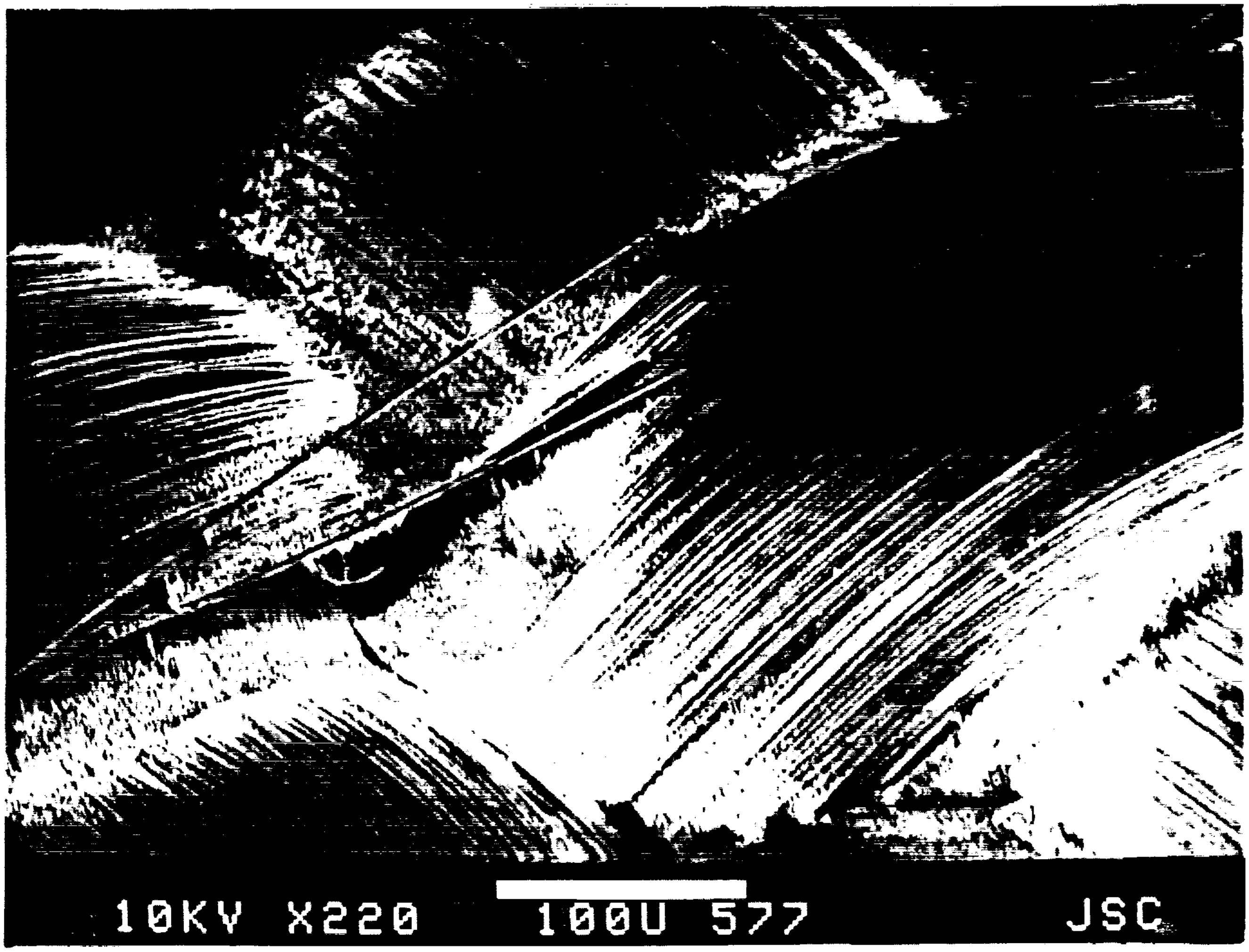

Figure 1b. MBO-135-027 specification Beta cloth after (a) atomic oxygen attack, and (b) an atom fluence of 2.3 x E21 atoms per square centimeter. Sample temperature was 150 degrees centigrade. Oxygen atom kinetic energy was 1.5 eV.

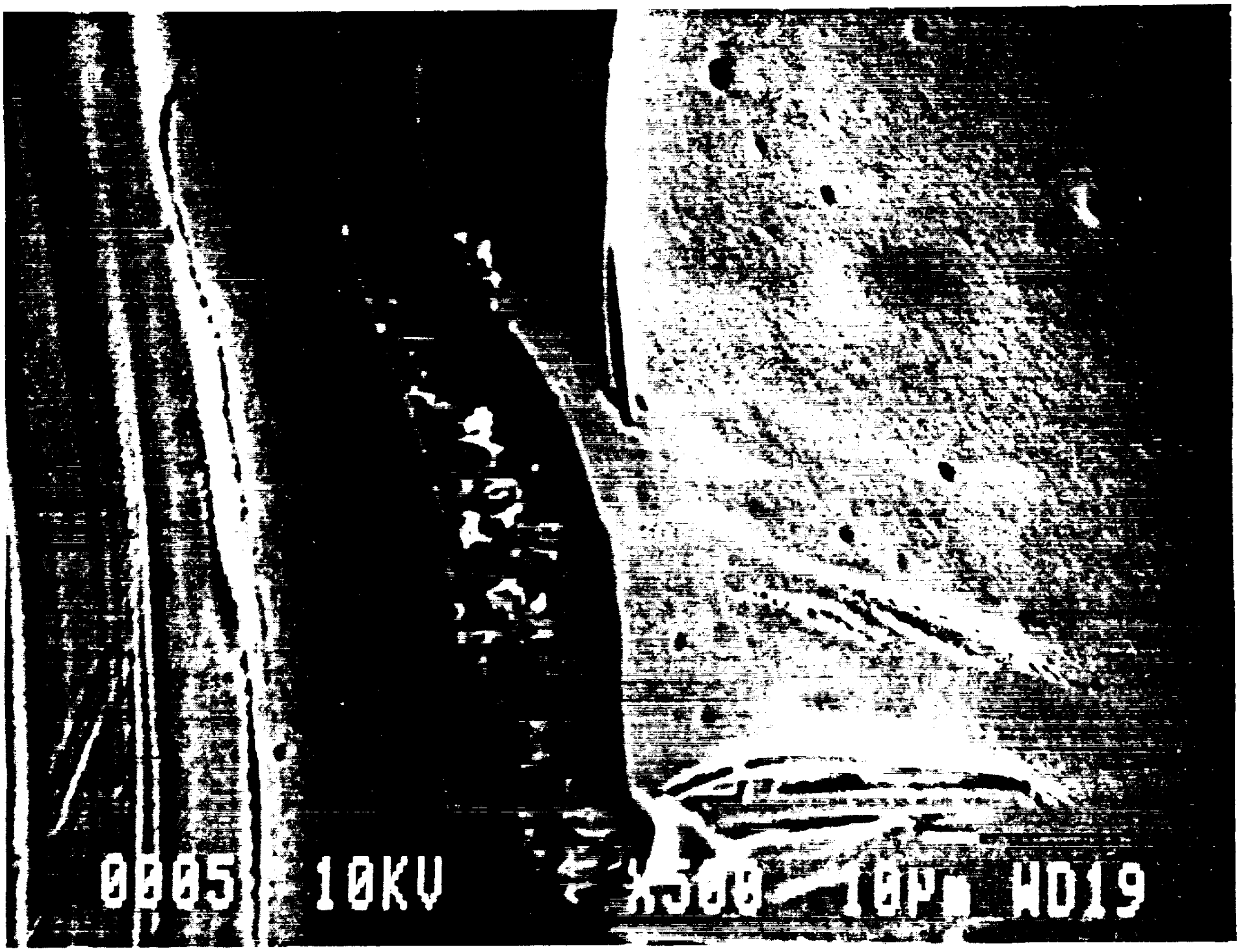

Figure 2a. A razor cut section made on an unexposed MBO 135-027 sample.

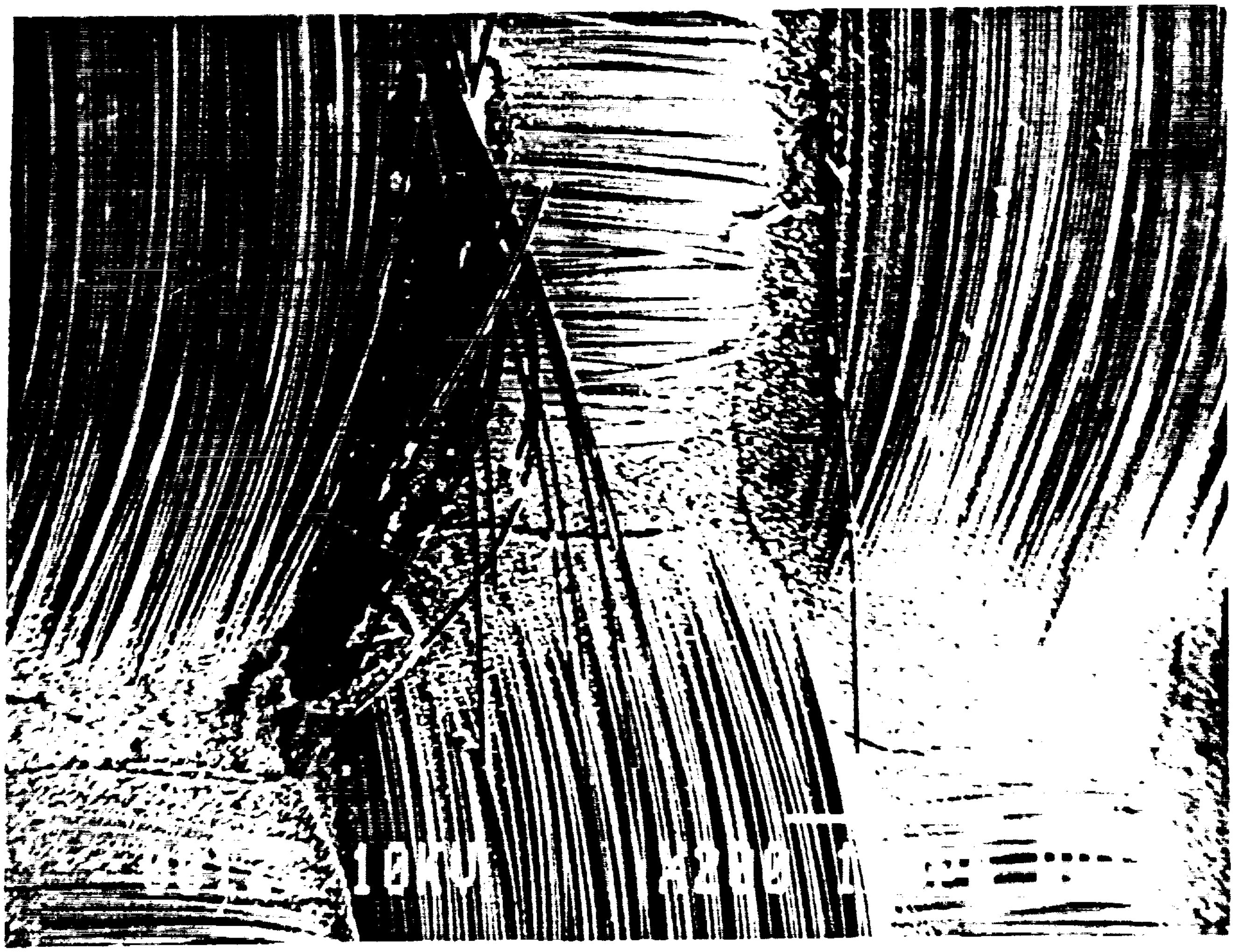

Figure 2b. A razor cut section made on an atomic oxygen exposed MBO 135-027 sample.

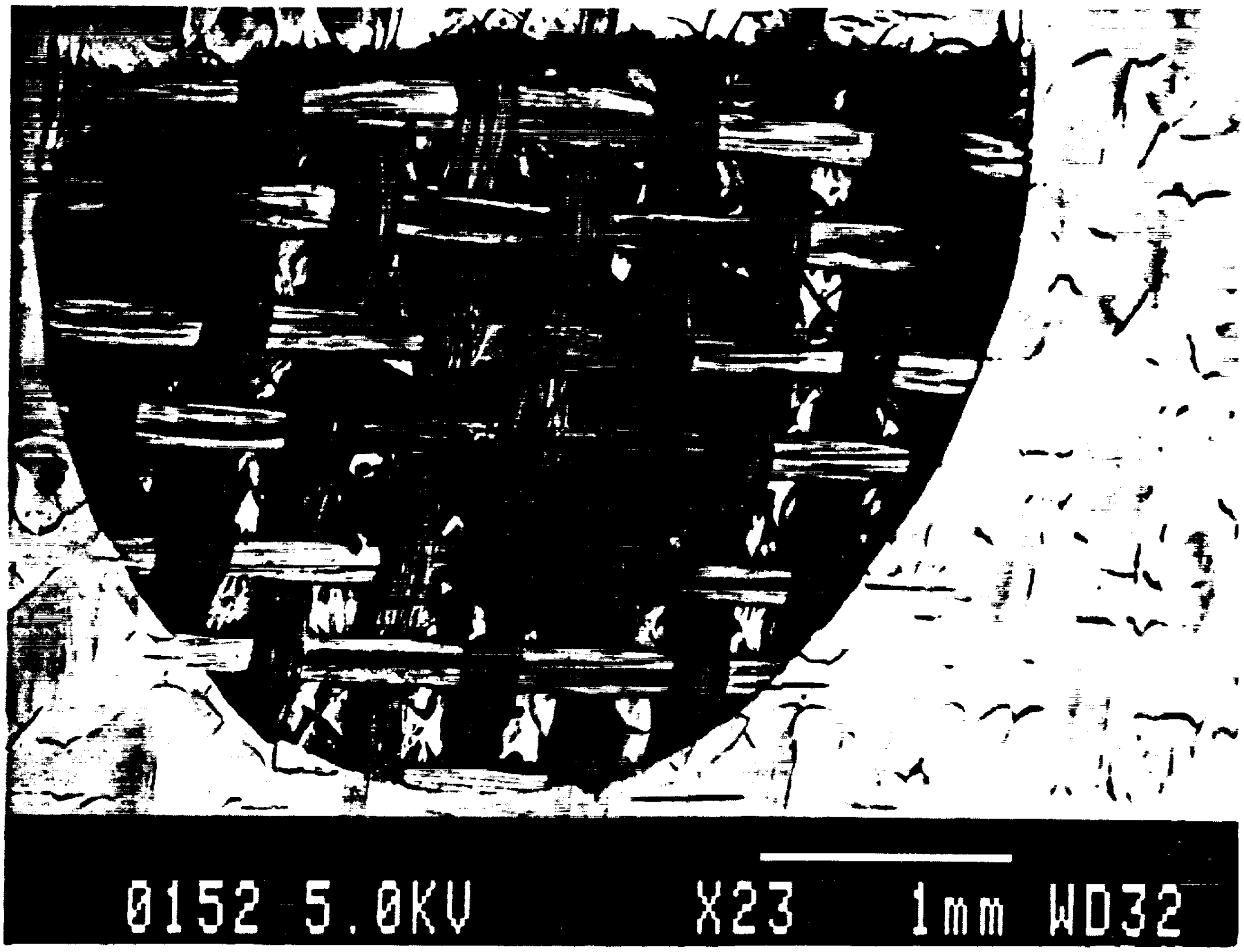

Figure 3. Sheldahl G414500 after an atom fluence of 2.3 x E21 atoms per square centimeter. A stainless steel mask with a semicircular aperture protected much of the sample from atom beam impingement. The region subjected to atom beam attack is the semicircular damaged area near the center of the figure. The sample temperature was 150 degrees centigrade. Oxygen atom kinetic energy was 1.5 eV.

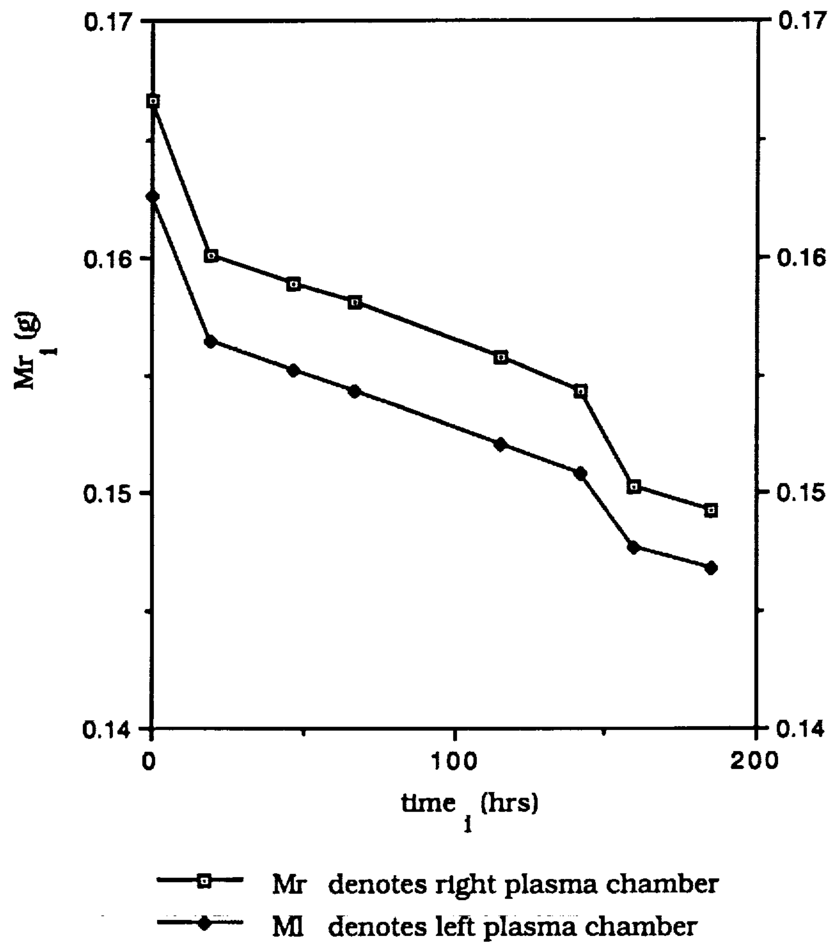

Figure 4. Oxygen plasma attack on Chemglas 250, an MBO 135-027 equivalent. Sample mass is plotted against plasma exposure time. A rapid mass loss is noted in the first 19 hours as Teflon is removed from the exposed surface. Much slower mass loss follows for several days. A rapid mass loss is observed when the sample is turned over to expose fresh surface, demonstrating that the glass fabric provides effective protection of Teflon on the unexposed or back surface of the sample.

Figure 5a. Photomicrograph of the control Kapton surfaces from ISAC flight experiment.

Figure 5b. Photomicrograph of the shielded Kapton surfaces from ISAC flight experiment.

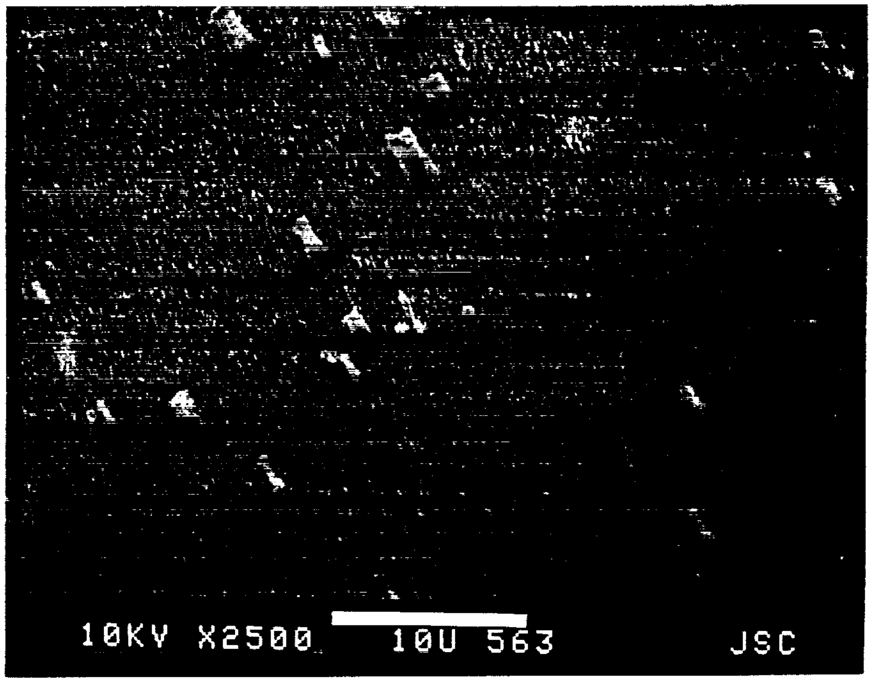

Figure 5c. Photomicrograph of the exposed Kapton surfaces from ISAC flight experiment.

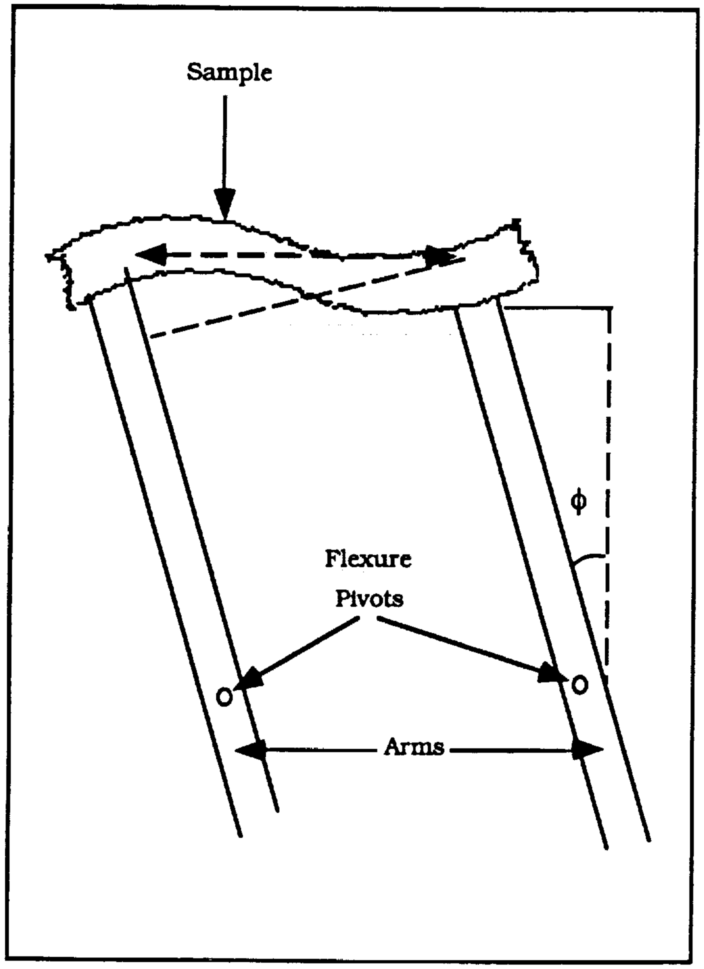

Figure 6. DMA Schematic
Dynamic Mechanical Analysis (DMA) can be used to evaluate structure-related performance and processing characteristics. This technique measures viscoelastic response of a material when subjected to a sinusoidal stress. Material viscoelastic constants are related to the system parameters by expressing the sample strain in terms of ϕ and stress in terms of M.

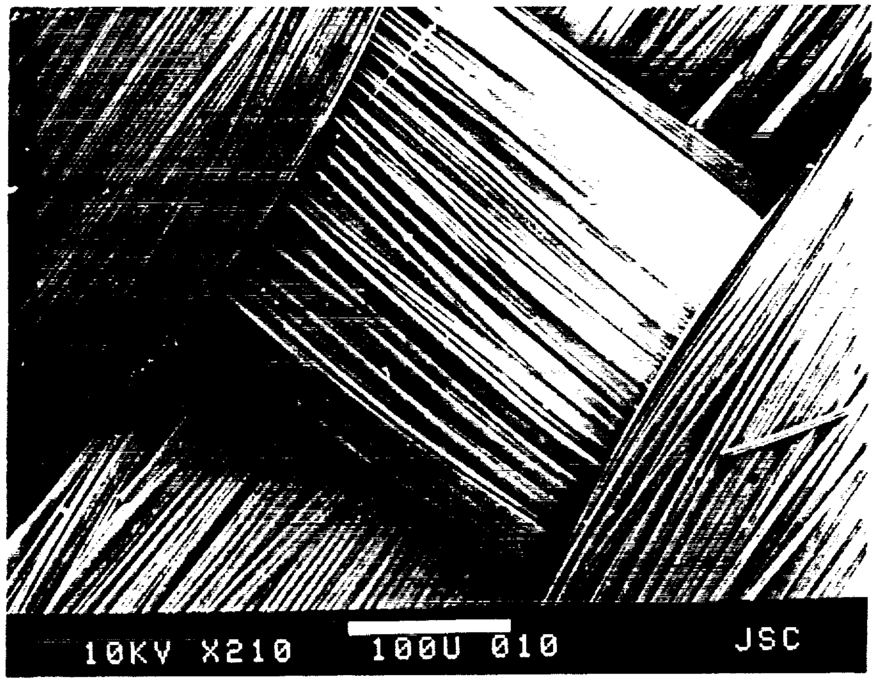

Figure 7. SEM of Chemglas 250 before material subjected to DMA.

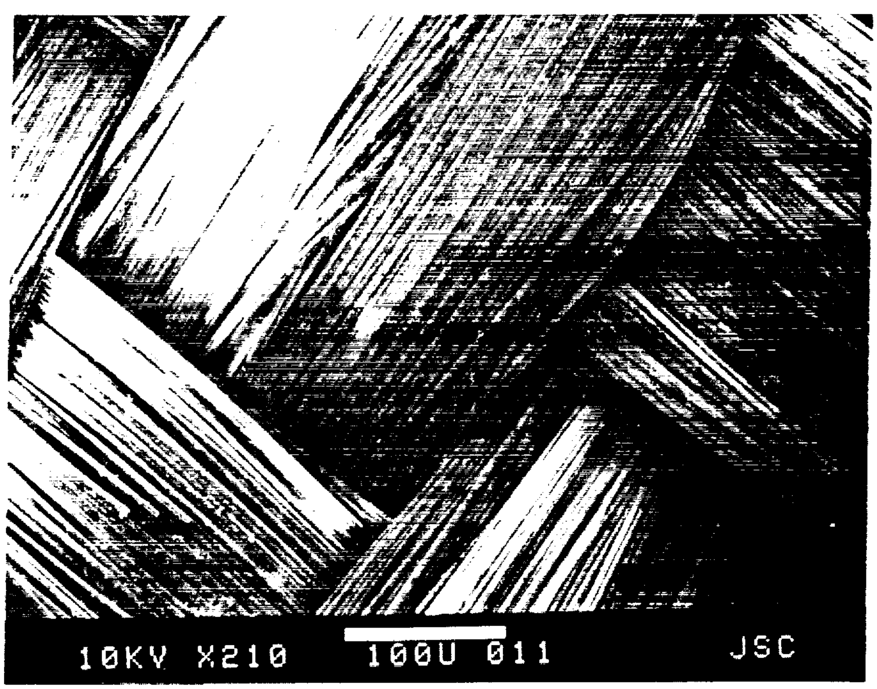

Figure 8. SEM of Chemglas 250 after material subjected to DMA.

TABLE I. WP-II MLI

SYSTEM/ELEMENT DESCRIPTION	FLIGHT	INTERIOR OR EXTERIOR TO STRUCTURE
TRUSS SEGMENT 1 (STBD SEGMENT 1)		
MLI ON MISCELLANEOUS ORUS	MB-1	EXTERIOR
MLI ON WASTE GAS LINES	MB-1	INTERIOR
SARJ MLI	MB-1	EXTERIOR
PROPULSION MODULE MLI (2 PMS)	MB-2	INTERIOR
TRUSS SEGMENT 2 (STBD SEGMENT 2)		
MLI ON MISCELLANEOUS ORUS	MB-2	BOTH
MLI ON UTILITY LINE UMBILICALS	MB-2	INTERIOR
MLI ON WASTE GAS LINES	MB-2	EXTERIOR
CMG MLI (4 CMGS)	MB-2	EXTERIOR
ASSEMBLY CONTINGENCY SYSTEM (ACS)/STS DERIVED S-BAND MLI ON ANTENNAS (C&T)	MB-2	EXTERIOR
ASSEMBLY CONTINGENCY SYSTEM (ACS)/STS DERIVED S-BAND MLI ON EQUIPMENT (C&T)	MB-2	EXTERIOR
KU-BAND ANTENNA MLI (C&T)	MB-3	EXTERIOR
KU-BAND EQUIPMENT MLI (C&T)	MB-16	EXTERIOR
TRUSS SEGMENT 3 (STBD SEGMENT 3)		
MLI ON MISCELLANEOUS ORUS	MB-3	BOTH
MLI ON UTILITY LINE UMBILICALS	MB-3	INTERIOR
MLI ON WASTE GAS LINES	MB-3	EXTERIOR
UHF ANTENNA MLI (C&T)	MB-3	EXTERIOR
TRUSS SEGMENT 4 (CENTER SEGMENT)		
GAS CONDITIONING SYSTEM MLI (GAS LINES)	MB-4	EXTERIOR
CRYOGENIC CARRIER ATTACH STRUCTURE ASSY MLI	MB-4	EXTERIOR
SRS (SUPPLEMENTAL REBOOST, FORMERLY WASTE GAS SYSTEM) MLI		EXTERIOR
MISCELLANEOUS MLI	MB-4	BOTH
MLI ON UTILITY LINE UMBILICALS	MB-4	INTERIOR
MLI ON WASTE GAS LINES	MB-4	EXTERIOR
TRUSS SEGMENT 5 (PORT SEGMENT 3)		
MLI ON MISCELLANEOUS ORUS	MB-8	BOTH
UHF ANTENNA MLI (C&T)	MB-8	EXTERIOR
MLI ON UTILITY LINE UMBILICALS	MB-8	INTERIOR
MLI ON WASTE GAS LINES	MB-8	EXTERIOR
TRUSS SEGMENT 6 (PORT SEGMENT 2)		
MLI ON WASTE GAS LINES	MB-9	EXTERIOR

Table I. WP-II MLI (cont'd)

SYSTEM/ELEMENT DESCRIPTION	FLIGHT	INTERIOR OR EXTERIOR TO STRUCTURE
TRUSS SEGMENT 7 (PORT SEGMENT 1)		
MLI ON MISCELLANEOUS ORUS	MB-10	EXTERIOR
MLI ON WASTE GAS LINES	MB-10	INTERIOR
SARJ MLI	MB-10	EXTERIOR
PROPULSION MODULE MLI (2 PMS)	MB-9	INTERIOR
TRUSS SEGMENT 8 (STBD OTBD SEGMENT)		
MISCELLANEOUS MLI	MB-14	BOTH
TRUSS SEGMENT 9 (PORT OTBD SEGMENT)		BOTH
MISCELLANEOUS MLI	MB-17	
PRESSURIZED BERTHING MODULE		
PBM 1	MB-5	INTERIOR
PBM 2	MB-7	INTERIOR
MOBILE TRANSPORTER		
MT MLI (ON RADIATOR MOUNTED COMPONENTS-2 RADIATORS)	MB-1	EXTERIOR
TEST-MT ENERGY STORAGE SUBSYSTEM MLI (MOVED TO MT AT MB-6)	MB-4	EXTERIOR
MRS (MOBILE REMOTE SERVICER) MLI	MB-8	EXTERIOR
AIRLOCK		
AIRLOCK PRESSURE SHELL MLI	MB-7	INTERIOR
AIRLOCK BOXES-ESET(2) (EQUIPMENT SETS ON CREW LOCK)	MB-7	
NODE 2 (AFT PORT NODE)		
MLI ON 3 END CONE HXS	MB-5	
MLI ON WATER LINES/UMBILICALS IN END CONE	MB-5	INTERIOR
MLI ON AMMONIA LINES/UMBILICALS IN END CONE	MB-5	INTERIOR
OTHER MLI (ANTENNAS?, CAMERAS?)	MB-5	EXTERIOR
MLI ON UTILITY LINES/UMBILICALS	MB-5	INTERIOR
NODE 1 (AFT PORT NODE)		
MLI ON 3 END CONE HXS	MB-11	
MLI ON WATER LINES/UMBILICALS IN END CONE	MB-11	INTERIOR
MLI ON AMMONIA LINES/UMBILICALS IN END CONE	MB-11	INTERIOR
OTHER MLI (ANTENNAS?, CAMERAS?)	MB-11	EXTERIOR
MLI ON UTILITY LINES/UMBILICALS	MB-11	INTERIOR

TABLE I. WP-II MLI (CONT'D)

SYSTEM/ELEMENT DESCRIPTION	FLIGHT	INTERIOR OR EXTERIOR TO STRUCTURE
NODE 4 (FWD PORT NODE)		
MLI ON 1 END CONE HXS	MB-21	
MLI ON WATER LINES/UMBILICALS IN END CONE	MB-21	INTERIOR
MLI ON AMMONIA LINES/UMBILICALS IN END CONE	MB-21	INTERIOR
OTHER MLI (ANTENNAS?, CAMERAS?)	MB-21	EXTERIOR
MLI ON UTILITY LINES/UMBILICALS	MB-21	INTERIOR
NODE 3 (FWD STBD NODE)		
OTHER MLI (ANTENNAS?, CAMERAS?)	MB-21	EXTERIOR
MLI ON UTILITY LINES/UMBILICALS	MB-21	INTERIOR
LAB-A MODULE		
MLI ON 2 END CONE HXS	MB-6	EXTERIOR
MLI ON WATER LINES/UMBILICALS IN END CONE	MB-6	EXTERIOR
MLI ON AMMONIA LINES/UMBILICALS IN END CONE	MB-6	EXTERIOR
MLI ON UTILITY LINES/UMBILICALS	MB-6	INTERIOR
HAB-A MODULE		
MLI ON 2 END CONE HXS	MB-16	EXTERIOR
MLI ON WATER LINES/UMBILICALS IN END CONE	MB-16	EXTERIOR
MLI ON AMMONIA LINES/UMBILICALS IN END CONE	MB-16	EXTERIOR
MLI ON UTILITY LINES/UMBILICALS	MB-16	INTERIOR
JEM MODULE		
MLI ON 2 END CONE HXS	MB-12	EXTERIOR
MLI ON WATER LINES/UMBILICALS IN END CONE	MB-12	EXTERIOR
MLI ON AMMONIA LINES/UMBILICALS IN END CONE	MB-12	EXTERIOR
MLI ON UTILITY LINES/UMBILICALS	MB-12	INTERIOR
ESA MODULE		
MLI ON 2 END CONE HXS	MB-13	EXTERIOR
MLI ON WATER LINES/UMBILICALS IN END CONE	MB-13	EXTERIOR
MLI ON AMMONIA LINES/UMBILICALS IN END CONE	MB-13	EXTERIOR
MLI ON UTILITY LINES/UMBILICALS	MB-13	INTERIOR
LAB-B MODULE		
MLI ON UTILITY LINES/UMBILICALS	MB-19	INTERIOR
HAB-B MODULE		
MLI ON UTILITY LINES/UMBILICALS	MB-20	INTERIOR
FLIGHT SUPPORT EQUIPMENT (FSE)		
LAUNCH AND ASSEMBLY MLI	ALL	EXTERIOR

TABLE II. THERMO-OPTICAL PROPERTIES MEASUREMENTS OF SEVERAL BETA CLOTH MATERIALS

MATERIAL / TREATMENT	SOLAR ABSORPTANCE (α)	EMITTANCE (ε)	TRANSMITTANCE (τ)
MBO 135-027 BETA AS RECEIVED, WITH TEFLON	0.24	0.91	NA
MBO 135-027 BETA AFTER 48 HOURS IN CTA, @ 1 TORR, 300 WATTS (TEFLON REMOVED)	0.22	0.89	NA
BETA CLOTH FROM CHEMICAL FABRICS CO. BEFORE TEFLON WAS APPLIED	0.25	0.89	NA
SHELDAHL G41450 AS RECEIVED (GLASS SIDE) TEFLON REMOVED (GLASS SIDE)	 0.31 0.17	 0.81 0.67	NA
CHEMGLAS 250/ SHELDAHL 1200 Å ALIMINUM BETA SIDE ALIMINUM SIDE	0.02 0.31 0.25	 0.90 0.13	NA
CHEMGLAS 250/SHELDAHL 1200 Å ALUMINUM (AFTER AO EXPOSURE- 4 SAMPLES) BETA SIDE ALUMINUM SIDE	 0.29 (AVG) 0.29 (AVG)	 0.89 (AVG) 0.15 (AVG)	0.02
CHEMGLAS 250/SHELDAHL 1200 Å ALUM (AFTER AO EXPOSURE- TAPE LIFT ON AL)			0.10

TABLE III. TEARING STRENGTH RESULTS OF AS RECEIVED ALUMINIZED MBO135-027 BETA CLOTH (ALUMINIZED CHEMGLAS 250).

SAMPLE NO., WARP	W1	W2	W3	W4	W5	W6	W7	AVERAGE
TEARING STRENGTH, G	2100	2100	2100	2000	2000	2000	2000	2042.8
SAMPLE NO., FILL	F1	F2	F3	F4	F5	F6		AVERAGE
TEARING STRENGTH, G	2700	2400	2400	2400	2500	2200		2433

TABLE IV. TEARING STRENGTH RESULTS OF ALUMINIZED MBO135-027 BETA CLOTH (ALUMINIZED CHEMGLAS 250), WITH ALMOST ALL TEFLON REMOVED.

SAMPLE NO., WARP	W1	W2	W3	W4	W5	W6	W7		AVERAGE
TEARING STRENGTH, G	1000	950	925	950	740	860	780		886.4
SAMPLE NO., FILL	F1	F2	F3	F4	F5	F6	F7	F8	AVERAGE
TEARING STRENGTH, G	1050	1275	825	1175	900	1060	875	1250	1051.2

TABLE V. BETA CLOTH UV TEST AT NASA LaRC (XENON LAMP SOURCE-CUT OFF AT 180 NM)

CHANGE IN SOLAR ABSORPTANCE (α)			
ESH (2 SUNS)	FORM F	ZS	FORM GW
0	0.29	0.32	0.31
200	0.30	0.32	0.32
400	0.32	0.32	0.32
800	0.34	0.33	0.32

FORM F- FABRIC SEWN IN A GRID PATTERN WITH METALLIC THREAD (2% SILICONES BY WEIGHT)

FORM GW- FABRIC WITH AN INTERNALY WOVEN GRAPHITE YARN IN A 6 X 4 INCH GRID PATTERN (.22% SILICONES BY WEIGHT)

ZS- DEVELOPMENTAL FABRIC PREPARED BY CHEMFAB FOR USE ON DOD/SHUTTLE PROGRAM (NO SILICONES, BUT NOT FLEXIBLE ENOUGH FOR PAYLOAD BAY INSTALLATION)

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13. ABSTRACT *(Maximum 200 words)*
MLI blankets for SSF must comply with general program requirements and recommendations for long life and durability in the low-Earth orbit (LEO) environment. Atomic oxygen and solar ultraviolet/vacuum ultraviolet are the most important factors in the SSF natural environment which affect materials life. Two types of Beta cloth (Teflon coated woven glass fabric), which had been proposed as MLI blanket covers, were tested for long-term durability in the LEO environment. General resistance to atomic oxygen attack and permeation were evaluated in the high velocity atomic oxygen beam system at Los Alamos National Laboratories. Long-term exposure to the LEO environment was simulated in the laboratory using a radio frequency oxygen plasma asher. The plasma asher treated Beta cloth specimens were tested for thermo-optical properties and mechanical durability. Space exposure data from the Long Duration Exposure Facility and the Intelsat Solar Array Coupon were also used in the durability assessment. Beta cloth fabricated to Rockwell specification MBO 135-027 (Chemglas 250) was shown to have acceptable durability for general use as an MLI blanket cover material in the LEO environment while Sheldahl G414500 should be used only in locations which are protected from direct Ram atomic oxygen.

14. SUBJECT TERMS
multi-layer insulation blanket, Chemglas 250, Sheldahl G414500, MLI blanket covers, Beta cloth, atomic oxygen, LEO environment

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