

SPACE ENVIRONMENT DURABILITY OF BETA CLOTH IN LDEF
THERMAL BLANKETS

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INTRODUCTION

Beta cloth performance for use on long-term space vehicles such as Space Station *Freedom* (S.S. *Freedom*) requires resistance to the degrading effects of the space environment. The major issues are retention of thermal insulating properties through maintaining optical properties, preserving mechanical integrity, and generating minimal particulates for contamination-sensitive spacecraft surfaces and payloads. The longest in-flight test of beta cloth's durability was on the Long Duration Exposure Facility (LDEF), where it was exposed to the space environment for 68 months.

The LDEF contained 57 experiments which further defined the space environment and its effects on spacecraft materials. It was deployed into low-Earth orbit (LEO) in April 1984 and retrieved January 1990 by the space shuttle. Among the 10,000 plus material constituents and samples onboard were thermal control blankets of multilayer insulation with a beta cloth outer cover and Velcro™ attachments. These blankets were exposed to hard vacuum, thermal cycling, charged particles, meteoroid/debris impacts, ultraviolet (UV) radiation, and atomic oxygen (AO). Of these space environmental exposure elements, AO appears to have had the greatest effect on the beta cloth.

The beta cloth analyzed in this report came from the MSFC Experiment S1005 (Transverse Flat-Plate Heat Pipe) tray oriented approximately 22° from the leading edge vector of the LDEF satellite (ref. 1). Figure 1 shows the location of the tray on LDEF and the placement of the beta cloth thermal blankets. The specific space environment exposure conditions for this material are listed in table 1.

The beta cloth in this study was impregnated with TFE Teflon™. Similar blankets are used as a static-free fabric liner in the shuttle cargo bay and are proposed for use on S.S. *Freedom*. Specifications for this cloth are a weave count of 87 by 62 with an uncoated areal weight of 5.5 to 6.7 oz/yd² (186.5 to 227.2 g/m²). The finished cloth contains 17 to 23 percent resin by weight.

Analyses were made on multiple specimens taken from various locations on the blanket including areas subject to AO and UV radiation impingement, areas shielded from incident AO, areas shielded from both AO and UV radiation, and control samples. Areas containing meteoroid/debris impacts were also removed and analyzed.

This report includes photographic evidence of changes in the beta cloth due to the space environment, thickness loss of the Teflon™, particulate contamination analysis, and evaluation of thermal properties. The Velcro™ and Dacron™ thread used to attach the beta cloth thermal blankets to the experiment tray are also analyzed.

PHOTOGRAPHIC OBSERVATIONS

The beta cloth blanket was relatively well preserved as noted during the postflight inspection. Further inspection using a black light for enhanced contrast provided some indication of space exposure effects. Under this illumination, the samples exposed to solar UV and only indirect AO were slightly darker than the control sample, and the AO-exposed samples were somewhat darker than these. This change is probably due to increased light absorption of the textured surface of eroded Teflon™ surface and of the exposed glass fiber matrix, rather than alteration of fluorescent properties.

Photographs taken with a scanning electron microscope indicate the change in beta cloth caused by space environment exposure. Figure 2 is of beta cloth removed from the folded underside of the blanket, protected from AO, radiation, and thermal cycling. The sample is intact. For comparison, Figure 3 is of beta cloth exposed to the leading edge environment, where Teflon™ erosion by impinging AO was most severe. However, the Teflon™ erosion did not release the embedded glass fibers. Teflon™ is visible between the fibers in areas shielded from direct impingement of AO. Erosion is evident to the extent seen. Figure 4 shows the fine erosion peaks typical of AO-eroded polymeric material at high magnification. Figure 5 is a still higher magnification SEM photo showing the remaining Teflon™ in the glass fiber weave. The AO erosion seemed to be limited to the first layer of glass fibers. The glass fibers prevented further erosion by staying in place and protecting the remaining Teflon™. Also, areas impacted by meteoroid and debris particles have pulled-up fibers, but these fibers remained in the matrix (Figures 6, 7).

After photographing the AO erosion, samples of beta cloth from the most heavily eroded areas were then turned upside down and photographed again. Figure 8 is of flight beta cloth, showing the underside that was protected from AO and UV radiation. Teflon™ in this matrix shows no erosion, which would only occur if AO were able to completely penetrate the beta cloth. Figure 9 is of beta cloth from the folded underside of the entire thermal blanket. This beta cloth looks very much like the original received from the manufacturer (Figure 10), with no cracking or loss of Teflon™. These photographs are of representative areas found on the beta cloth samples.

BETA CLOTH PROPERTY CHANGES

In beta cloth, the glass fibers are bonded with TFE Teflon™ to prevent fiber-to-fiber abrasion. AO erosion of the Teflon™ might result in the exposure of any loose glass fibers, leading to the generation of particulate contamination, and loss of thermal performance in the blanket. AO erosion data for TFE Teflon™ from LDEF Experiment A0171 (ref. 2), located at 38° off-RAM angle of incidence, provided a reactivity value of 2.0×10^{-25} cm³/atom from a thickness loss of 0.55 mils (14.0 microns). Based on these results and the estimated AO fluence incident on the beta cloth from LDEF Experiment S1005³ of 8.43×10^{21} atoms/cm², the predicted loss of TFE Teflon™ from the S1005 beta cloth is approximately 0.61 mils (15.5 microns).

Thickness measurements were taken on each of the four blanket samples using a micrometer. Samples taken from areas exposed to the leading edge space environment, areas shielded from direct AO, areas shielded from both AO and UV radiation, and control samples all had thicknesses in the range of 7.70 to 7.73 mils with no discernible systematic differences between the samples. This indicates that the fiberglass mat was not significantly affected by space exposure and that the actual

thickness loss of TFE Teflon™ cannot be measured directly. However, the thickness loss can be reasonably determined through weight change.

Samples of the same surface area were taken from various locations of the exposed area and the folded underside of the blanket and weighed. Assuming that the glass fiber particulate loss during flight is negligible and the density of TFE Teflon™ is consistent, the calculated average thickness loss of TFE Teflon™ is 0.24 mils (6.1 microns). This is in general agreement with the estimates based on SEM observations of apparent erosion and the remaining Teflon™ shielded by the glass fibers at the 22° off-RAM angle of AO incidence.

The beta cloth was also evaluated for sloughing. The samples were flushed with Freon™ over a Millipore filter collector. A soft brush was then used to wipe the beta cloth surface directly above another collector. The results from the sloughing are presented in Figures 9 to 12. These graphs show the number of particles of a particular size collected after the Freon™ flush and brushing. The largest dimension of the particle is counted. Control material from the manufacturer, beta cloth from the folded underside of the thermal blanket, and beta cloth fully exposed to AO and UV radiation were evaluated. SEM photos of similar samples with particulate contamination (Figures 2 and 3) agree with the sloughing results. The beta cloth exposed to AO had the least amount of particulate contamination, most likely due to erosion. The beta cloth from the folded underside of the thermal blanket was cleaner than the control sample, presumably as a result of preflight preparation.

Optical property measurements of the beta cloth were made using a Gier-Dunkle portable reflectometer model DB100 for infrared thermal emittance (ϵ) and portable reflectometer model MS251 for solar absorptance (α). The beta cloth manufacturer specifications require a nominal 0.8 minimum emissivity. Table 2 lists the sample exposure conditions and the optical property measurements taken. The measured variation in absorptivity and emissivity are considered to indicate no significant degradation in thermal performance.

VELCRO™ PROPERTY CHANGES

One problem that did occur with the thermal blankets was the degradation of the Dacron™ threads attaching the Velcro™ bonding strips to the blankets. Figure 13 reveals the deterioration of the Dacron™ exposed to AO. Although the blanket did not detach during flight, it came apart easily at this seam during deintegration of the experiment tray. For long-term LEO space use, this problem must be remedied with a change in thread to one that is not susceptible to AO erosion or a change in configuration to shield against AO attack. Figure 14 shows an intact seam which was shielded from direct AO by a heat pipe.

Figure 15 is of the observed bleaching effect of AO on the Velcro™. SEM photos of unexposed and exposed Velcro™ hooks (Figures 16 and 17) show the AO erosion. In some places, only nubs of nylon were left (Figure 18). The loops were similarly affected. In addition, the mechanical strength of the Velcro™ was degraded by space exposure. Peel tests on uneroded Velcro™ indicated a peel strength of 2.0 to 2.5 lb/in. Velcro™ that had been eroded and bleached had a peel strength of 1.2 to 1.7 lb/in.

CONCLUSION

Microphotographs indicate that the Teflon™ is removed by erosion from the outer surface of the beta cloth. The eroded Teflon™ surface has the characteristic morphology of polymeric materials exposed to orbital AO. However, evidence shows that the Teflon™ remained underneath the first layer of glass fibers, and the glass fibers remain in the matrix, protecting the underlying Teflon™. Minimal particulate generation and maintenance of thermal insulating properties were documented during this investigation.

While beta cloth's performance over a 30-year S.S. *Freedom* mission remains unqualified, beta cloth's performance in the near 6-year exposure on the LDEF provides the evidence for satisfactory retention of properties for extended space exposure. Beta cloth overlap of the Velcro™ is being recommended, and new materials and configurations are under consideration for replacement of Dacron™ as a result of degradation of these blanket elements. It is anticipated that with these changes, beta cloth thermal blankets will endure space environment exposure well beyond 6 years.

REFERENCES

1. NASA Conference Proceedings, First LDEF Post-Retrieval Symposium, Orlando, FL, June 2-8, 1991, presentation by David Shular, MSFC.
2. Whitaker, A.F., Finckenor, M.M., Kamenetzky, R.R.: "Property Changes Induced by the Space Environment in Polymeric Materials on LDEF." Submitted for publication to AIAA.

Table 1. Space environment exposure conditions of LDEF beta cloth.

• High Vacuum	- 10^{-6} to 10^{-7} Torr (estimated)
• UV Radiation	- 8,680 ESH (Estimated Sun Hours)
• Proton Fluence	- 10^9 p+/cm ² (0.05 to 200 MeV)
• Electron Fluence	- Range of 10^{12} e-/cm ² at 50 keV energy to 10^8 e-/cm ² at 3.0 MeV energy
• AO	- 8.17×10^{21} atoms/cm ²
• Micrometeoroid/ Space Debris	- 424 impacts >0.1 mm diameter craters per square meter
• Thermal Cycles	- ~32,000 cycles

Table 2. Beta cloth optical property measurements uncertainty ± 0.02 .

	<u>Vacuum</u> <u>Only</u>	<u>AO</u> <u>+UV</u>	<u>UV</u> <u>Only</u>
Absorptivity	0.22	0.22	0.23
Emissivity	0.89	0.89	0.89

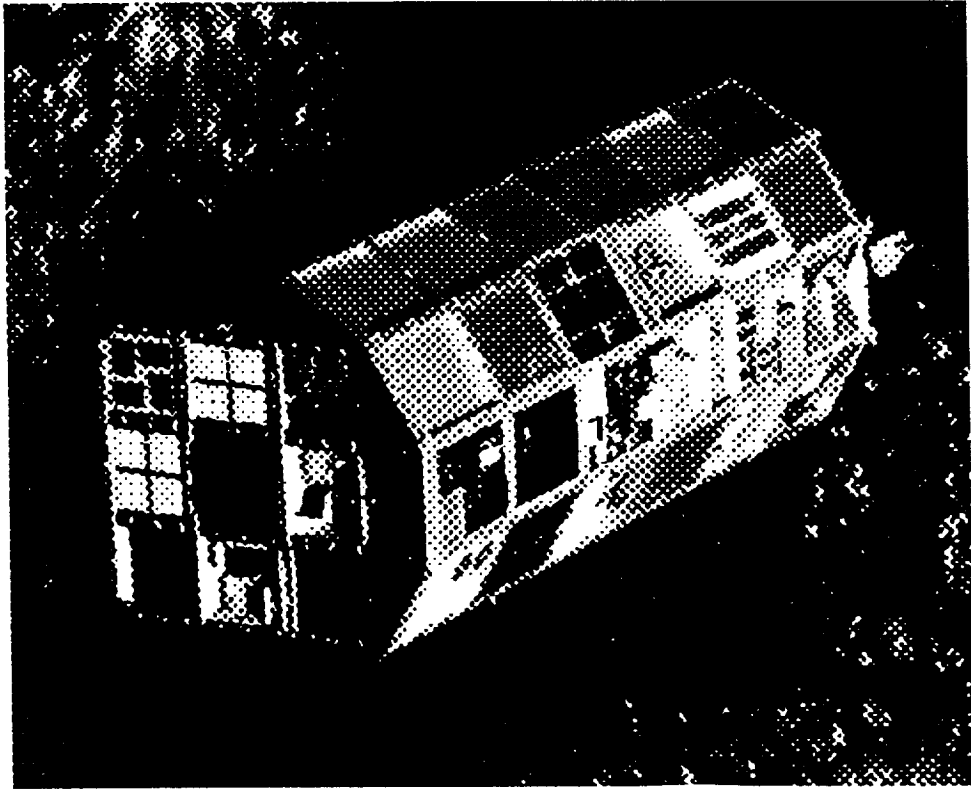
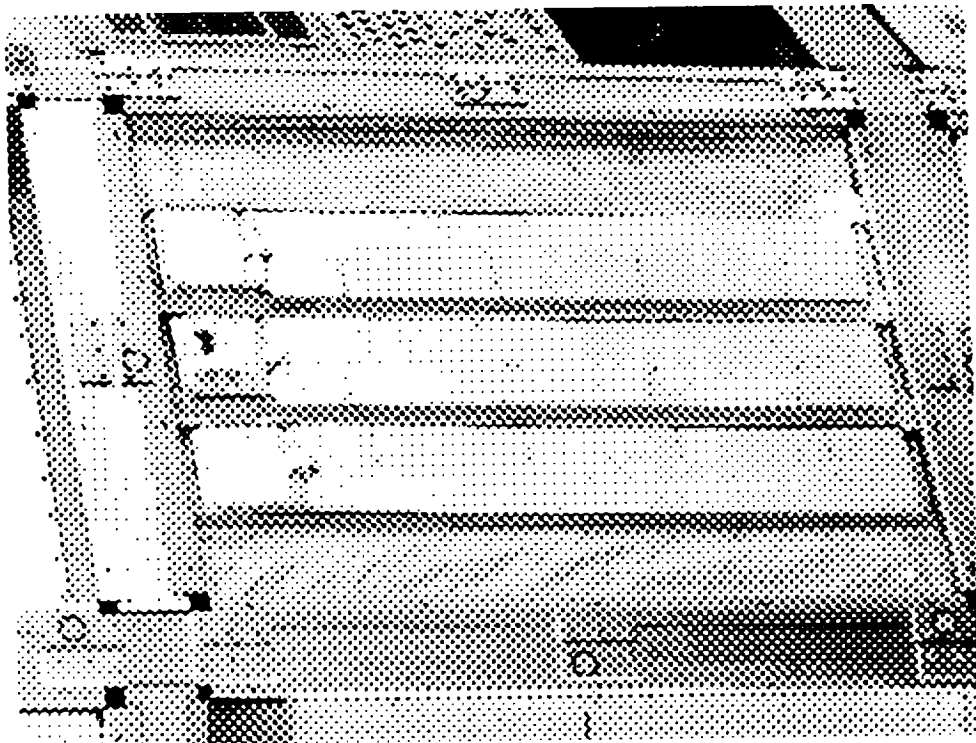


Figure 1. The LDEF.



S1005 experiment, Tray B10, transverse flat plate heat pipe experiment.

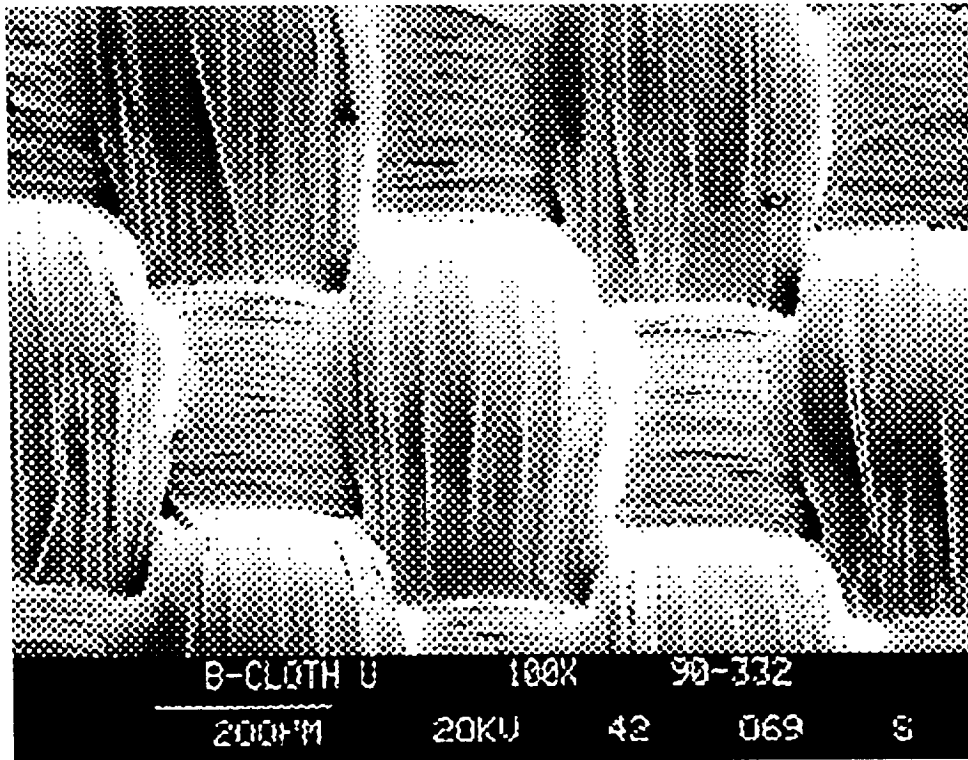


Figure 2. Beta cloth from folded underside of thermal blanket, protected from AO erosion.

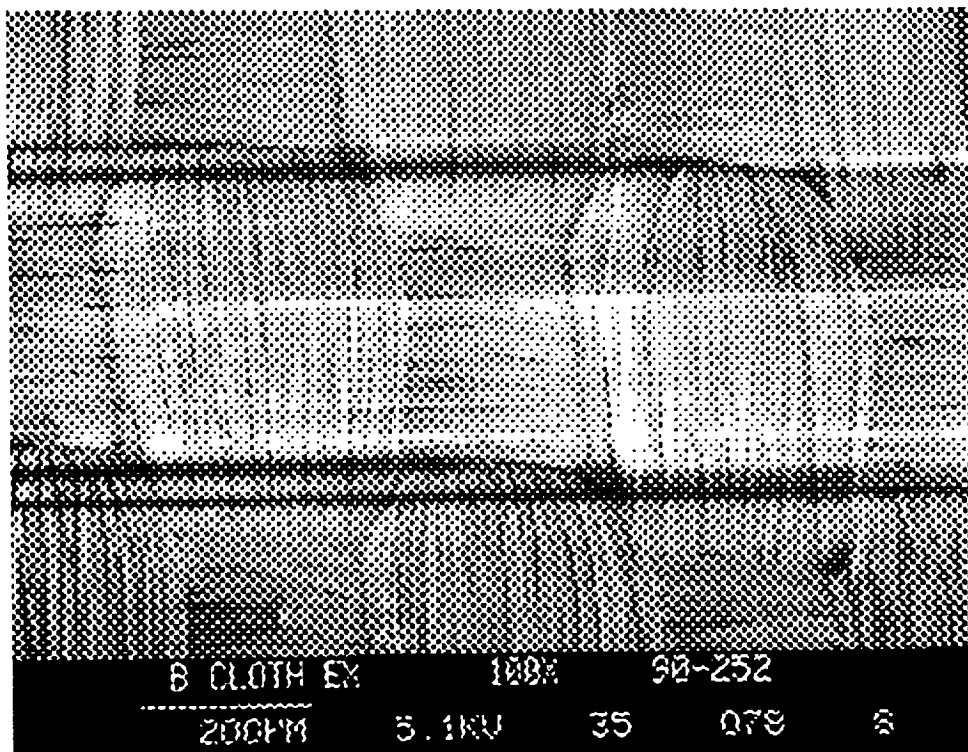


Figure 3. Beta cloth exposed to RAM environment.

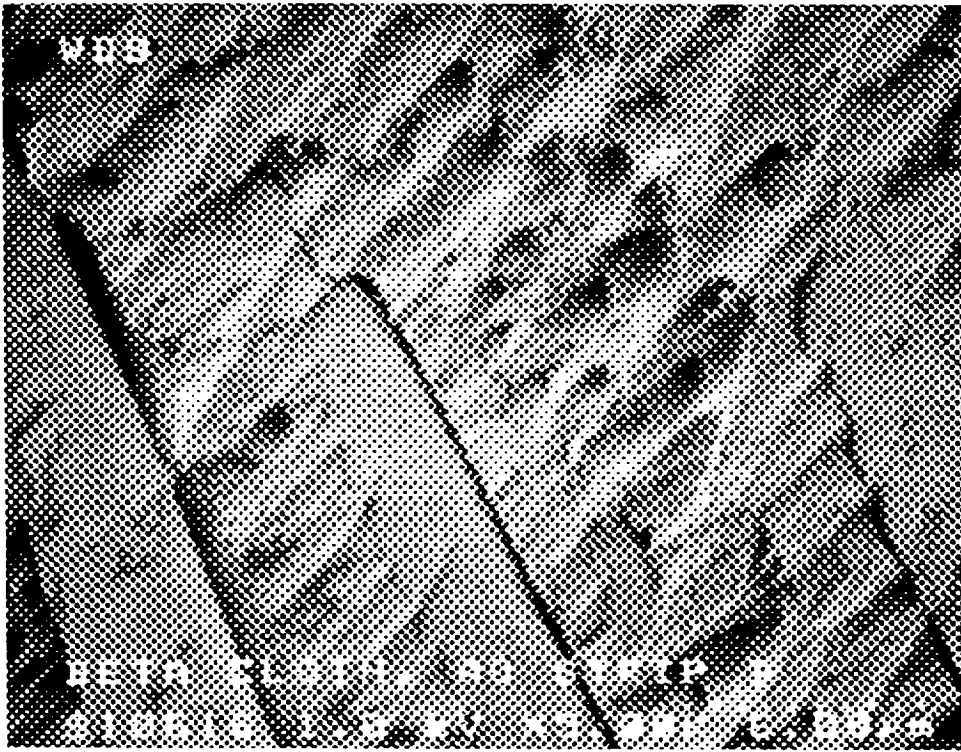


Figure 4. AO erosion peaks typical of Teflon™.

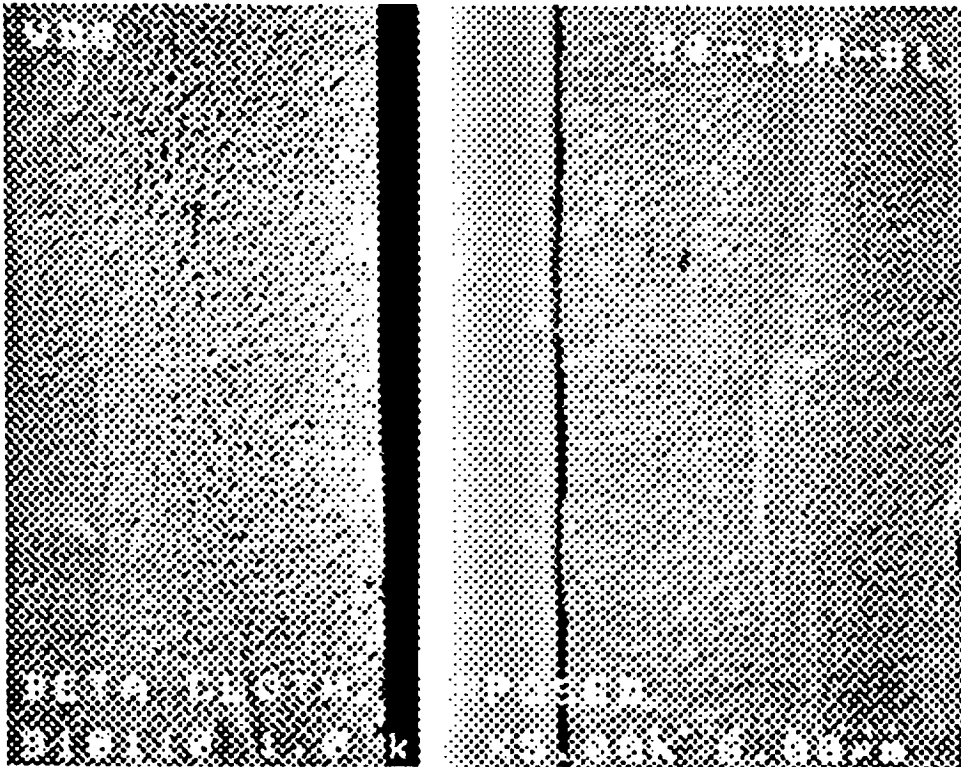


Figure 5. Remaining Teflon™ in glass fiber weave.

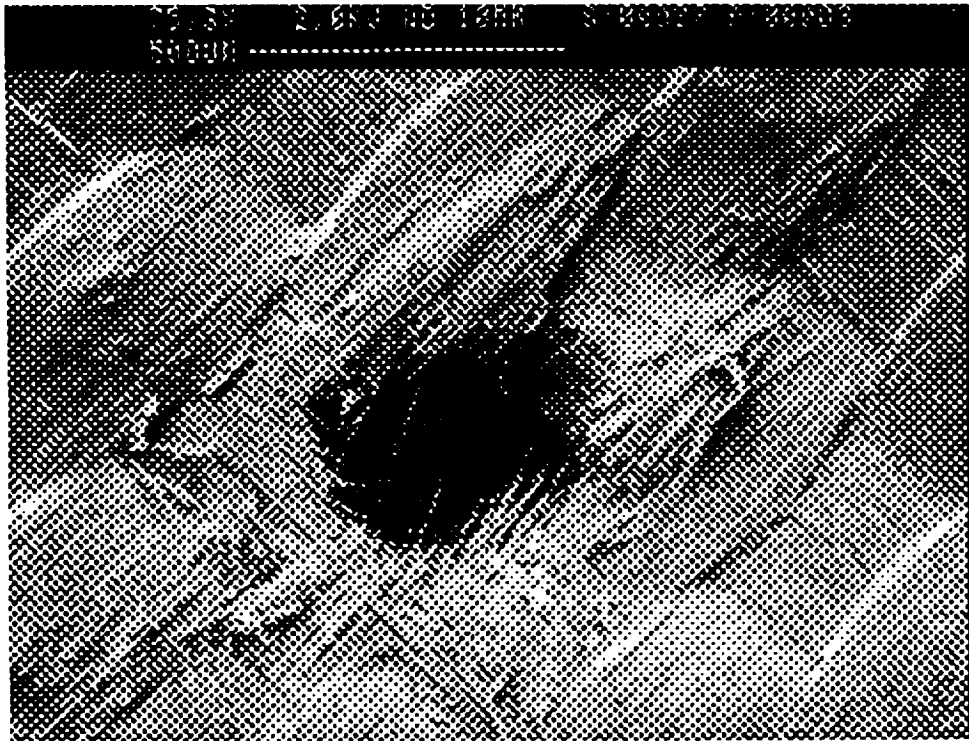


Figure 6. Meteoroid/debris impact in beta cloth.



Figure 7. Meteoroid/debris impact.

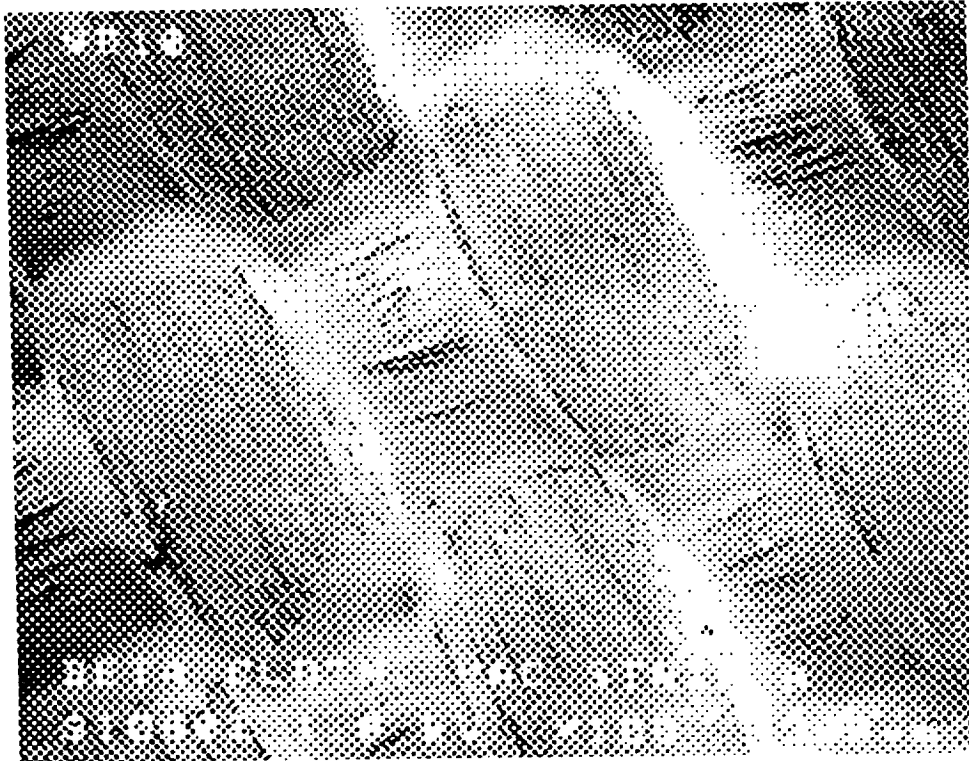
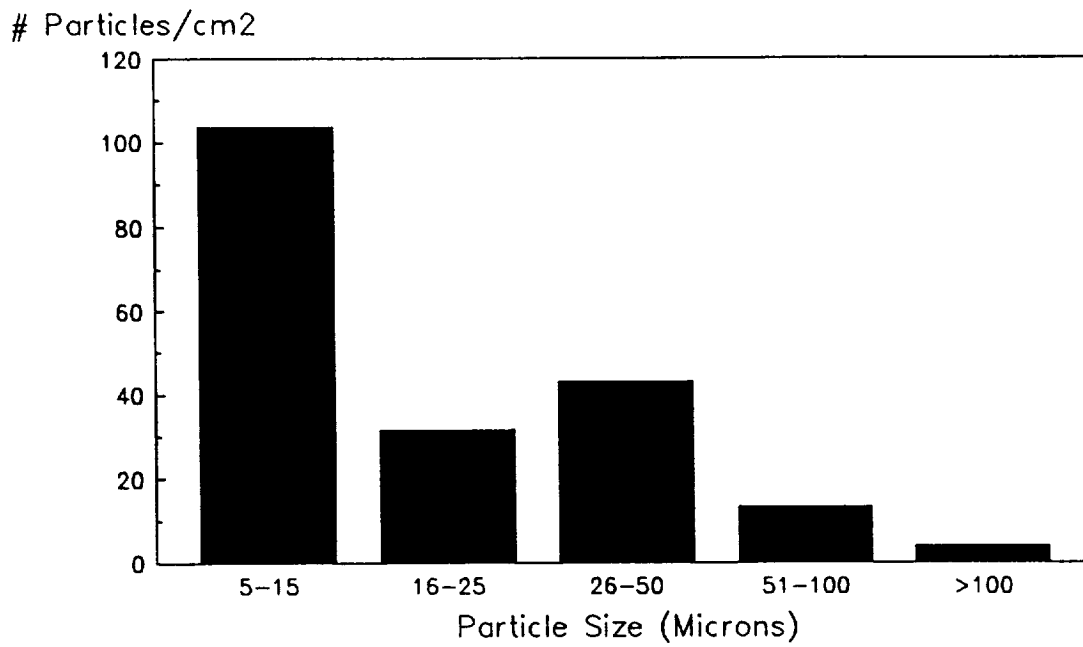


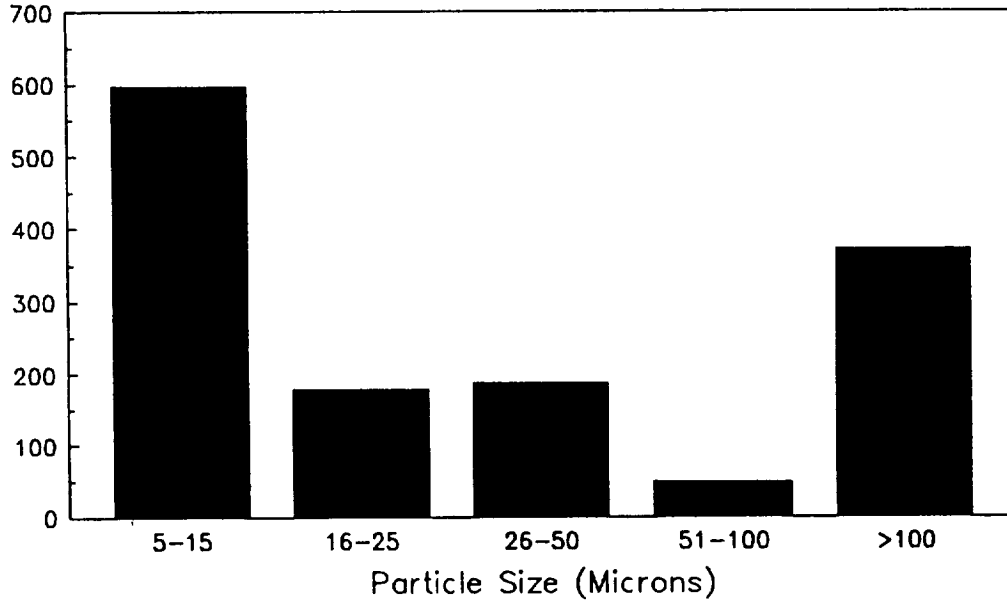
Figure 8. Underside of exposed beta cloth. No AO perforation visible.



Freon Flush and Surface Brushing

Figure 9. Beta cloth sloughing evaluation, AO and UV exposure.

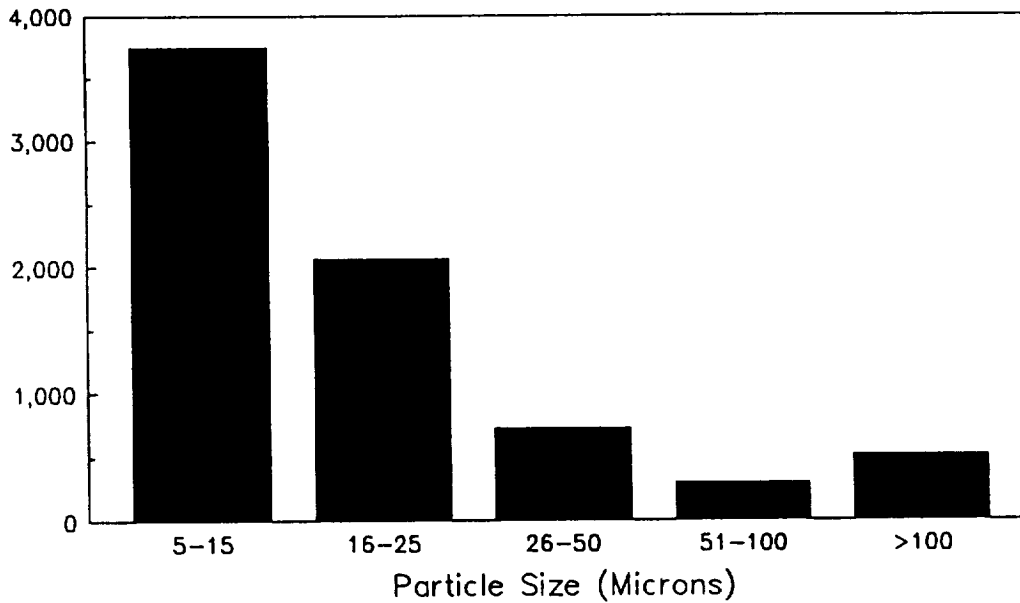
Particles/cm²



Freon Flush and Surface Brushing

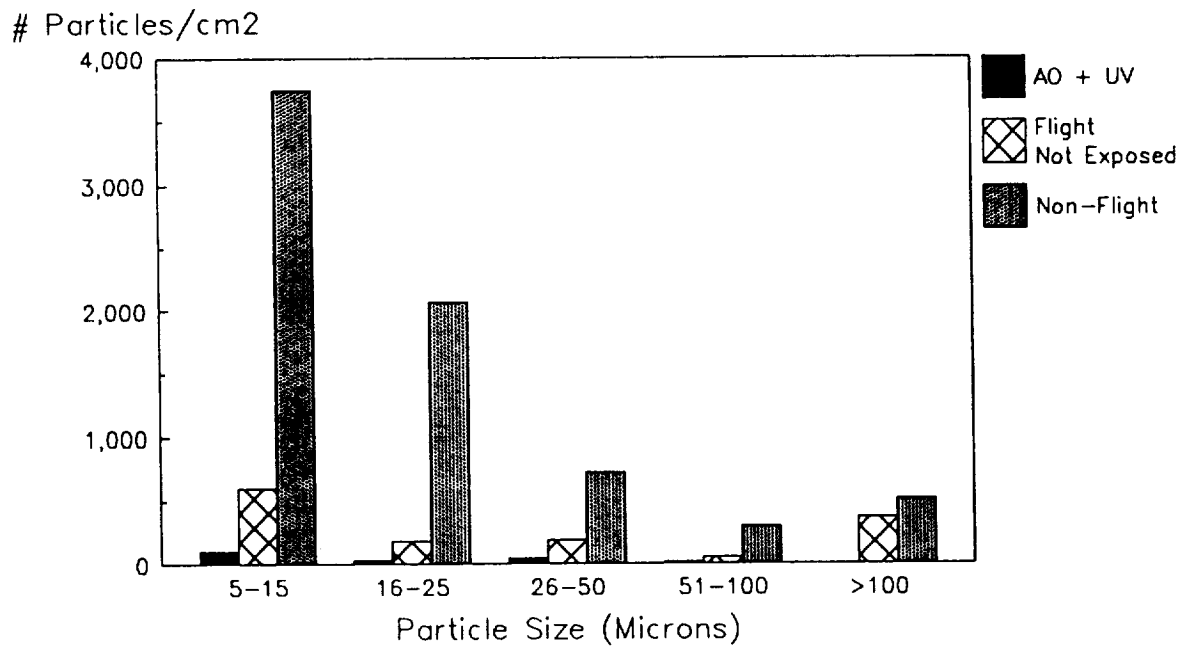
Figure 10. Beta cloth sloughing evaluation, flight beta cloth, not exposed.

Particles/cm²



Freon Flush and Surface Brushing

Figure 11. Beta cloth sloughing evaluation, nonflight beta cloth.



Freon Flush and Surface Brushing

Figure 12. Beta cloth sloughing evaluation, comparison chart.

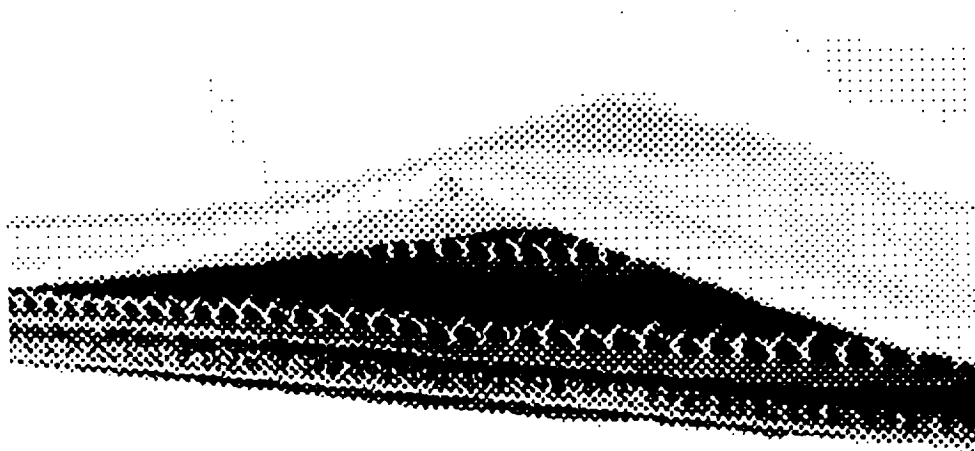


Figure 13. Velcro™ seam with failed Dacron™ thread.

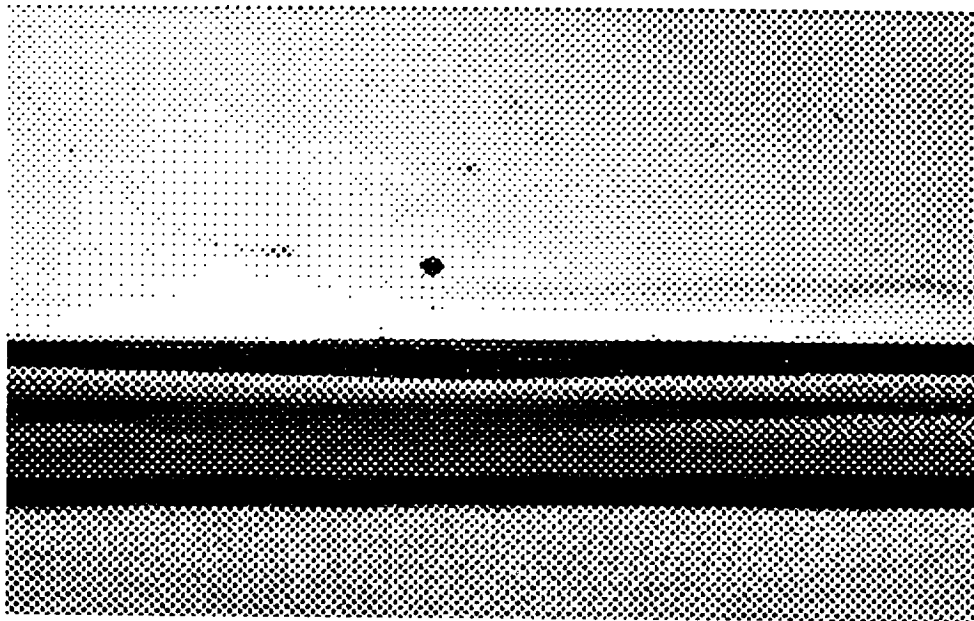


Figure 14. Intact seam shielded from AO.



Figure 15. AO bleaching of Velcro™.

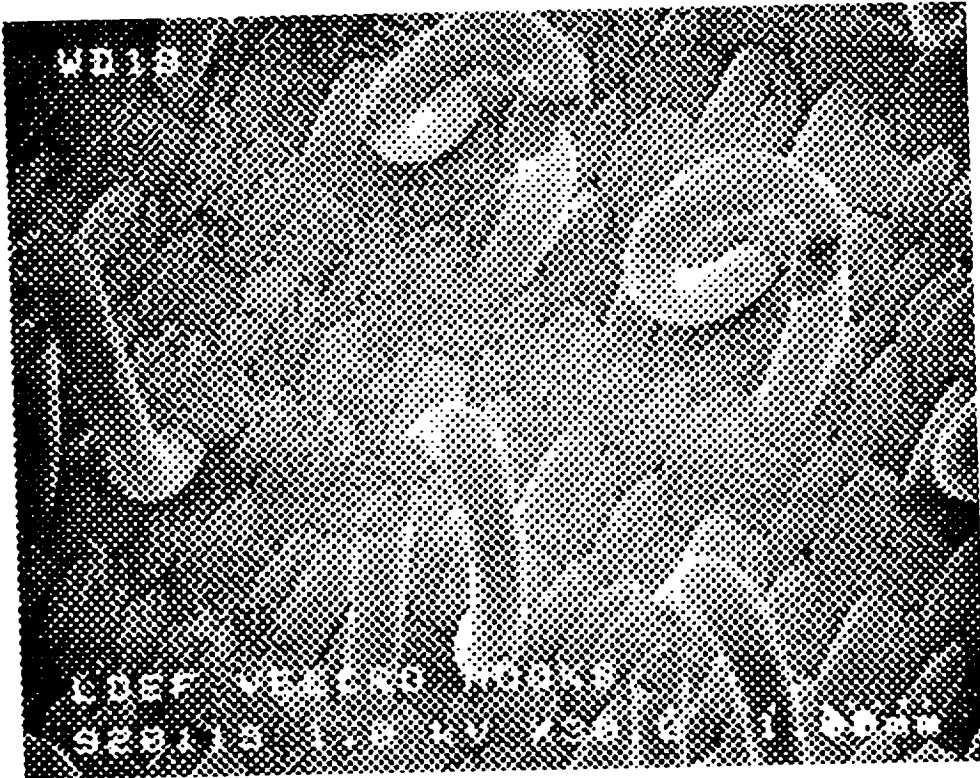


Figure 16. Unexposed Velcro™ hooks.



Figure 17. Velcro™ hooks eroded by AO.

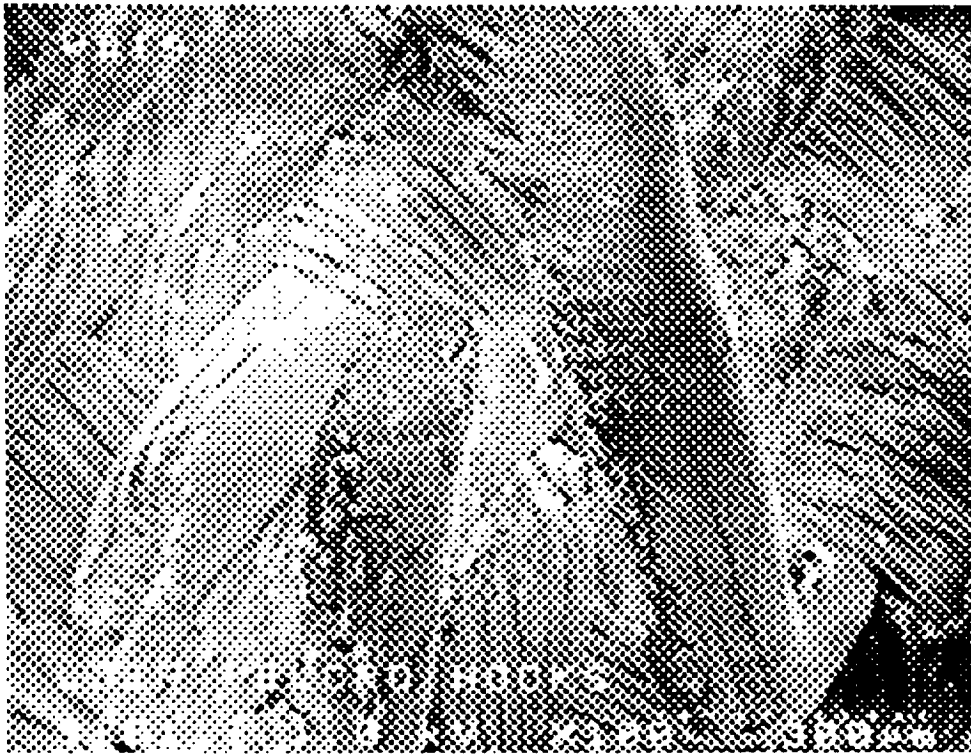


Figure 18. Higher magnification of eroded Velcro™.

