

# LONG TERM FLIGHT PERFORMANCE OF HIGH DIFFUSE REFLECTANCE Ag/TEFLON COVERINGS FLOWN ON CANADIAN MOBILE SERVICING STATION, MSS

J. I. Kleiman<sup>(1)</sup>, Z. Iskanderova<sup>(1)</sup> and J. Antoniazzi<sup>(2)</sup>

<sup>(1)</sup> -Integrity Testing Laboratory Inc., Markham, Ontario, Canada, Tel: (905) 415-2207; e-mail: [ekleiman@itlinc.com](mailto:ekleiman@itlinc.com)

<sup>(2)</sup> -MDA, Brampton, Ontario, Canada, Tel: (905)-790-2800; e-mail: [joe.antoniazzi@mdacorporation.com](mailto:joe.antoniazzi@mdacorporation.com)

## ABSTRACT

A texturing surface modification process was developed for Silver-Teflon thermal protection coverings that were applied to a camera and light equipment on the International Space Station using an adhesive. The developed treatment that involves an ion-beam texturing process that changes the appearance of the surface in a controlled manner from a metallic-like and shiny to complete milky-white appearance reduced dramatically the specularly of Silver-Teflon thermal control films without significantly affecting their thermal optical properties. The space hardware covered with the textured Silver-Teflon was exposed to the open space environment between June 2002 and June 2006 and delivered back to MDA around November 2006. Remarkable performance was demonstrated by the treated Ag/Teflon with the solar absorptance and total emittance values and the  $\alpha/\epsilon$  ratio remaining very close to the original values as measured before the flights.

## 1. INTRODUCTION

The International Space Station has a considerable amount of electronic equipment positioned on the outside of the station. Effective thermal control over such equipment is extremely important for normal operation of the station. For extreme thermal environments present in Low Earth Orbit, the standard radiative paints used on electronic boxes for thermal control may have too high an absorptivity. The use of Silver-Teflon film which has a lower absorptivity is a viable alternative. However, standard Silver-Teflon exhibits excessive glare due to the high specular reflection that can cause problems with cameras. Some of the cameras used on the Mobile Servicing System were designed and manufactured in Canada by MDA. Such cameras are used (among many other tasks) to locate targets attached or in close vicinity to equipment covered with the Silver-Teflon films.

A texturing surface modification process was developed for Silver-Teflon film by ITL in order to provide a matt finish [1,2]. This product was applied to MDA cameras

and lights on the International Space Station using an acrylic adhesive (3M 966). The developed treatment of Silver-Teflon surfaces reduced substantially the specularly of films by changing the morphological appearance of their surfaces by ion-beam texturing in a controlled manner from a metallic-like and shiny to complete milky-white appearance without significantly affecting the thermal optical properties [1].

The camera/light covered with the textured Silver-Teflon was launched with the Mobile Base Structure (MBS) on STS-111 in June 2002. The equipment was removed from MBS on June 2006 (which occurred between shuttle missions) and brought inside the ISS. Then it was stored inside the ISS until it was brought down on STS-115 (September 2006) and delivered back to MDA around November 2006. Remarkable performance was demonstrated by the treated Silver-Teflon with the solar absorptance and total emittance values and the  $\alpha/\epsilon$  ratio remaining very close to the original values as measured before the flights.

This paper presents some results on the performance of the surface-modified Silver-Teflon thermal control films in the prolonged exposure.

## 2. EXPERIMENTAL

All materials used in the present work were prepared from Teflon FEP purchased from Sheldahl<sup>1</sup>. An ion-beam vacuum system containing a linear ion-beam source and a large 58 cm diameter rotating drum to which the sample was mounted, providing a large surface area of 150 x 50 cm<sup>2</sup> for the ion beam exposure of the samples, was used for preparation of the textured material. A typical drum speed of 2 rpm was used in the experiments. High purity krypton gas was used for texturing the films. The chamber vacuum pressure of  $3 \cdot 10^{-2}$  Pa was maintained during the experiments at the above conditions. Typical etching rates of 0.015  $\mu\text{m}/\text{min}$  were achieved in rotational experiments under the described conditions. The details for the experimental set-up can be found elsewhere [1].

The back sides of Teflon samples were coated with a silver/Inconel reflecting coating. The textured surfaces, in accordance with the technical drawing requirements were coated with a 1300 Å SiO<sub>x</sub> layer<sup>ii</sup>.

Scanning electron microscopy (SEM) study of all samples was performed on a JEOL JSM-T300 model microscope. The surfaces of the polymer samples were coated with a thin layer of carbon to prevent charging.

The solar emissivity (or total emittance) ( $\epsilon$ ) of the samples was measured in accordance with the ASTM specification E-408 [3] using an infrared reflectometer manufactured by Gier Dunkle Instruments, Model DB100. The total and the diffuse optical reflectance as well as the solar absorptivity of the samples ( $\alpha$ ) were measured using a spectrophotometer (Beckman Instruments, Model DK-2a) equipped with an integrating sphere. The solar absorptivity in UV, visible, and the near-infrared (IR) ranges of the spectrum, covering the range 200-2450 nm was measured in accordance with the ASTM-E903 specification [4].

### 3. RESULTS AND DISCUSSION

#### 3.1 Texturing Process

The developed surface texturing process is based on ion-beam bombardment of the surface with noble gases. As a result of such treatment, the specularly of Silver-Teflon thermal control films can be reduced dramatically, with the surface morphology changing from metallic-like and shiny to complete milky, white appearance.

Ion beam texturing is a well known phenomenon [5]. Most ion sputtered fluoropolymer surfaces develop cone or spire-like features. The applications of ion beam textured polymers for adhesion improvement, biomedical applications, electrical properties changes, wettability properties changes, etc., was studied and described [6-8]. It was shown that depending on the ion beam power density and target temperature the etch rates of PTFE range from 3 to 1700  $\mu\text{m}/\text{h}$  [8].

An optimization of the process parameters allowed achieving a strong texturing effect. Fig.1 shows the total and diffuse reflectance of a 127  $\mu\text{m}$  thick Ag/Teflon after it was treated with Krypton ions. As can be seen from Fig. 1, most of the light was reflected as diffused, with the diffused reflectance almost equalling the total reflectance.

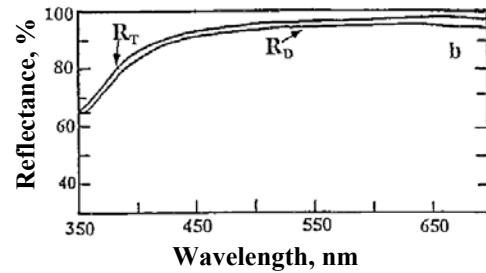


Fig.1. Total ( $R_T$ ) and diffuse ( $R_D$ ) reflectance measurements for a Ag/Teflon sample after an exposure to a Krypton gas ion-beam

The surface of the treated film attains rough morphology with well developed cone or spire-like features. Fig. 2 shows planar and cross-sectional SEM images of a sample after a forty hour exposure at optimized conditions.

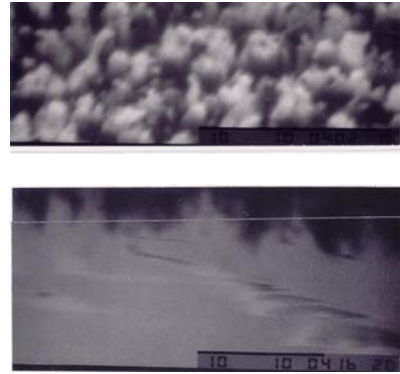


Fig. 2. Planar (a) and cross-sectional (b) scanning electron microscopy images of krypton ion-beam textured Teflon FEP after 40 hours of exposure. Magnification  $\sim 3,500\times$



Fig.3. Optical images of Ag/Teflon samples before (left) and after (right) treatment with the texturing process. Coins are placed in front of the samples to demonstrate the total loss of reflectance in the treated sample.

As a result of the treatment, the surface of the Ag/Teflon changed from a metallic-like and shiny to complete milky-white (Fig.3)

While the surface morphology of the treated sample underwent strong changes, the thermal optical properties of the surfaces practically remained unchanged (table I). As can be seen from table I, all thermal optical parameters underwent very little changes, providing the  $\alpha/\epsilon$  ratio of 0.09 as compared to 0.10 of the original material.

Table I: Summary of property changes in the textured Ag/Teflon sample.

Parameters	Teflon Original	Textured Teflon
Solar Absorptance ( $\alpha$ )	0.08	0.07
Total Emittance ( $\epsilon$ )	0.79	0.81
$\alpha/\epsilon$	0.10	0.09
Appearance	Shiny, grey-metallic	Mat, milky-white
Total Reflectance ( $R_T$ )	0.95	0.93-0.95
Diffuse Reflectance ( $R_D$ )	0	0.92-0.93

## 2.2 Hardware and Flight Details

The camera/light unit covered with the textured Ag/Teflon was launched with the Mobile Base Structure (MBS) on STS-111 in June 2002 (Fig.4). The equipment was removed from MBS on June 2006 (which occurred between shuttle missions) and brought inside the ISS. Then it was stored inside the ISS until it was brought down on STS-115 (Sept 2006) and delivered back to MDA around Nov 2006.



Fig.4. Image of a portion of the Canadarm2 with the camera and light on the tip of the Canadarm2. The insert shows the camera in greater details. The areas with Silver-coated Teflon are on the central part of the camera. The two side areas are blanketed.

The Ag/Teflon surfaces, immediately after return, had the same, complete milky-white appearance (Fig.5).



Fig. 5. Visual appearance of the camera CLPA S/N 206 (TVC S/N 209) (stored in a clean room at MDA) after delivery in November of 2006

Figure 6 shows the same camera after 8 months storage in the clean room.

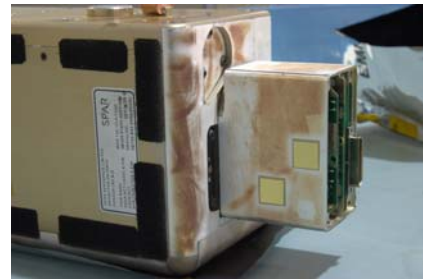


Fig. 6. Visual appearance of the camera CLPA S/N 206 (TVC S/N 209) (stored in a clean room at MDA) after an eight months storage.

The thermal optical properties of the textured Teflon surfaces were evaluated after the 8 months of storage. Table II presents the results of the solar absorptance and thermal emittance values as measured in the discolored regions on sides #2, 3, and 4 and side #1 that remained relatively milky-white after even the prolonged storage at MDA.

Table II: Thermal optical parameters of the textured Teflon as measured on the camera after return and storage of 8 months. The discolored regions were measured on sides 2 – 4 (see Figs 7 and 8)

Side #	Solar Absorptance, $\alpha$	Total Emittance, $\epsilon$	$\alpha/\epsilon$	
			Flight	Orig.
1	0.180	0.775	0.23	0.09
2	0.444	0.764	0.58	
3	0.248	0.803	0.31	
4	0.316	0.802	0.39	

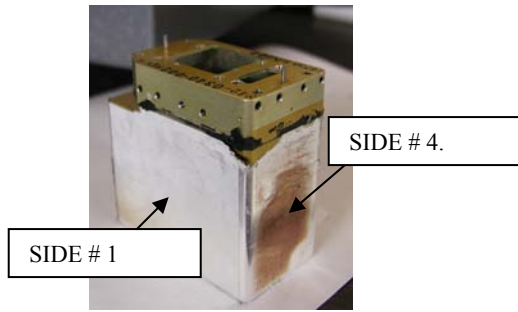


Fig.7. Visual appearance of the textured Teflon covering a camera surface after return to MDA from a space exposure and storage for ~ 8 months.

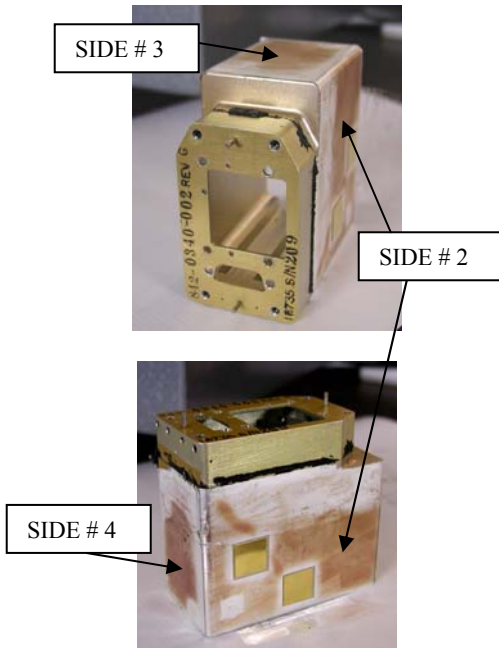


Fig. 8. Visual appearance of the camera (shown in two different positions) covered with the textured Teflon after return to MDA from a space exposure and storage for ~ 8 months.

A similar phenomenon of Teflon discoloration was observed in one of LDEF experiments that underwent 5.8 years of exposure to the LEO space environment [9]. It was noticed in the Thermal Control Surfaces Experiment (TCSE) samples on LDEF that the front thermal cover consisting of Sheldahl's 50  $\mu\text{m}$  (2 mil) thick Ag/FEP thermal control material glued with Y966 acrylic adhesive that in exposed to the space environment areas the material underwent a clear delineation and attained a diffuse whitish appearance with brown discoloration [9].

Based on the post flight analysis it was established that the brownish streaking was the result of a series of events, starting with the initial cracking of the silver/Inconel layer during application to the TCSE front thermal cover. Subsequent long-term exposure to thermal cycling and solar ultraviolet caused the brownish discoloration. The intensity of the brownish discoloration was found to be a direct function of the crack density that appeared to be caused by excessive handling or stretching [9].

The difference between the case observed in [9] and the one discussed in this paper is that the camera hardware when brought back to MDA did not exhibit the discoloration pattern (Fig. 5) attaining it only after a storage in a clean room (Fig.6).

Table III presents a comparative evaluation of the solar absorptance data for the sample flown on LDEF [9] and the MDA sample after a prolonged storage. As can be seen from table III, the solar absorptance values of the Ag-Inconel coated Teflon are much higher especially in regions with heavier discoloration.

Table III: Comparative evaluation of the solar absorptance data for the samples flown on LDEF and from MDA.

Sample		Solar Absorptance, $\alpha$	
		After storage or LEO flight	Original
MDA [Present work]	1	0.180	0.09
	2	0.444	
	3	0.248	
	4	0.316	
Ref.[8]	Low discoloration	0.10	0.08
	Strong discoloration	0.49	

As was mentioned above the Ag/FEP thermal control material used in the LDEF experiment had demonstrated surface erosion by atomic oxygen, attaining diffuse whitish appearance. On the other side, the textured Ag/Teflon material used on the cameras did not show visible signs of change in morphology upon return from orbit. It is plausible to suggest that the layer of  $\text{SiO}_x$  deposited after the texturing helped to prevent the AO erosion of the material in space environment. In addition, XPS analysis of a control and textured by krypton ion

beam surface of FEP Teflon indicated that as a result of the texturing, the surface of the treated Teflon becomes fluorine-rich (table IV), thus providing increased additional protection from atomic oxygen erosion. It should be noted that in order to evaluate the resistance of the Teflon FEP surfaces to LEO after texturing the samples were tested in the atomic oxygen beam facility at UTIAS. In all conducted tests, the morphology of the surfaces and the mass of the samples remained practically unchanged.

Table IV: Results from a general survey XPS analysis of a control and textured by krypton ion beam surface of FEP Teflon.

Sample	%F	%C	%O	F/C Ratio
Control	66.7	33.3	-	2.0
Kr-sputtered	69.7	30.3	-	2.3

#### 4. CONCLUSIONS

Large areas of Teflon FEP films were successfully textured in a continuous ion beam process using krypton as the ion source. Highly developed surfaces having milky mat appearance were produced, dramatically increasing the diffuse reflectance of the Teflon FEP films without substantially changing their thermal optical properties.

The camera/light units covered with the textured Ag/Teflon were successfully exposed to space on the ISS for a prolonged time while retaining their highly diffuse properties and the required thermal optical properties.

The discoloration effects observed on the textured Teflon after a prolonged storage, upon return of the camera/light equipment, could be associated with oxidation processes occurring in the epoxy used to attach the Silver-Teflon to the hardware and or the silver layer deposited on the back of the Teflon that could be initiated by the atmospheric oxygen.

As a result of the observed browning effect in storage upon return to Earth and taking into consideration the results reported in [9], MDA has now changed the method by which the Silver-Teflon film is installed. The essential element of this change is to ensure that the film is not bent in too tight a radius so that no micro-cracking occurs in the metal film. All bonded films are also

inspected using optical microscopy in order to ensure that no micro-cracks are present.

#### 5. ACKNOWLEDGMENTS

The authors would like to thank Dr. J. Golden for pointing them to the LDEF study paper by J.M. Zwiener, K.A. Herren, D.R. Wilked, L. Hummer and E.R. Miller [9]. The authors also wish to thank Dr. V. Issouпов for help with some thermal optical properties measurements

#### REFERENCES

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9. J.M. Zwiener, K.A. Herren, D.R. Wilked, L.Hummer and E.R. Miller, "Unusual Materials Effects Observed on the Thermal Control Surfaces Experiment" (S0069), in Proceedings of Symposium "LDEF-69 Months in Space", Kissimmee, Fla, June 2-8, 1991, NASA Conference Publication 3134, Part 3, pp.919-934, 1991

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i. The Teflon FEP material was purchased at Sheldahl

Inc., 1150 Sheldahl Road, North Field, Minnesota,  
55057, USA.

ii. The SiO<sub>x</sub> coating was deposited at Sheldahl Inc.

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