https://ntrs.nasa.gov/search.jsp?R=19940026540 2020-06-16T12:37:46+00:00Z

N94- 31045

SPACECRAFT MATERIALS: COMPARISON BETWEEN FLIGHT RESULTS OBTAINED ON LDEF AND MIR

Jean-Claude Guillaumon
CNES CT/TE/AE/MT/TH
18 Avenue E. Belin, 31055 Toulouse cedex (France)
Phone: (33) 61 27 39 53, Fax (33) 61 27 40 99

Alain Paillous
ONERA / CERT / DERTS
2 Avenue E. Belin, 31055 Toulouse cedex (France)
Phone: (33) 61 55 71 19, Fax (33) 61 55 71 69

SUMMARY

Two flight experiments dedicated to the study of the performance of materials in space have been carried out. Material samples have been exposed passively to low-Earth orbit (LEO) environment, then retrieved for laboratory study. The first experiment was conducted in the framework of the FRECOPA project and was flown on the trailing edge of the Long Duration Exposure Facility (LDEF) (exposure to vacuum and ultraviolet (UV) radiation for 5.5 years). The experiment COMES was installed outside of the MIR space station during an extravehicular activity; it was exposed to vacuum, O-atoms, and UV radiation for 1.1 year; and it was brought back to Earth by cosmonauts. The difference in exposure conditions and the use of transparent filters protecting some samples of COMES enable to differentiate the effects of UV radiation and oxygen atoms. The degradations of several thermal control coatings (paints, metalized polymeric films with and without ITO), structural materials, and optical components have been observed, measured, and compared after these two flight experiments. This paper summarizes various "lessons learned" that can be used to identify aspects of space aging, to orientate future research in this field, and to assist in spacecraft design.

INTRODUCTION

Various types of materials are used on satellites and space stations: structural materials (polymeric films, bulk polymers, composites), thermal control coatings (paints, second surface mirrors), optical components (windows, mirrors, lenses), etc. For all of them, there exists the problem of stability in a space environment and, more precisely, an understanding of the mechanisms involved in their degradation and of the long-term evolution of their properties.

The space environment is complex. Spacecraft materials are subjected to the effects of its different components which sometimes act alone but usually simultaneously. The space environment parameters met on low orbit are vacuum, solar UV radiation, micrometeoroids and space debris, atomic oxygen (AO), and deep thermal cycles.

In practical terms, research for material selection and qualification always makes use of space environment simulations which usually involve setting up very expensive, highly specialized equipment in the laboratory. The opportunities of retrieving materials which have really sojourned in space are rare, but they should always be taken as they provide invaluable data on effective degradations in space. Materials retrieved from space highlight the effects of synergy between the different environmental components and enable the researcher to evaluate the validity of the ground simulations.

The CERT/ONERA and the CNES were associated in two onboard experiments where a large number of specimens were exposed to a space environment in an LEO and then brought back to Earth for a laboratory study of their degradation. One of the experiments was carried by the NASA's LDEF satellite; the other was placed on the outer surface of the MIR space station during the Franco-Russian ARAGATZ flight. The resulting data have been used to identify aspects of space aging, to orientate future research in this field, and to assist in spacecraft design.

DESCRIPTION OF THE EXPERIMENTS

The AO 138-6 FRECOPA Experiment on LDEF

A part of the experiment was located directly at the surface of the FRECOPA tray and was exposed to the LDEF environment during all stages of the mission. It consisted of a total of 24 samples, 20 by 20 mm each. The other part of the experiment (Figure 1) was located inside a vacuum tight canister which was opened 15 days after placing in orbit and then closed again in space after 9 months; 30 samples were mounted in the canister. The AO 138-6 Experiment has been described in several reports (ref. 1–3).

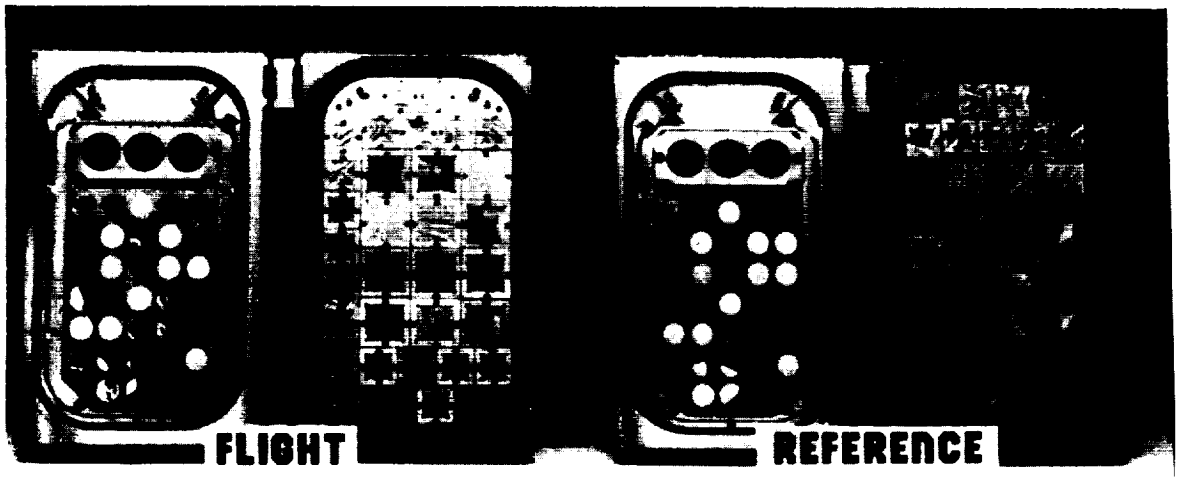


Figure 1. Sample-holder of Experiment AO 138-6 in the FRECOPA canister; comparison of the samples after flight to reference samples.

LDEF was a three-axis satellite, stabilized by gravity gradient. It had a circular orbit with an inclination of 28°; the initial altitude was 426 km and during capture 330 km. The total mission duration was 2,015 days. Because of its position on side three of the LDEF, the AO 138-6 experiment did not receive any oxygen atoms during the mission, with the exception of a short period during the

capture when it received a fluence evaluated at 1.32 10^{17} atoms cm^{-2}. The solar illumination was 11,110 equivalent Sun hours (esh) for the samples located on the tray and only 1,448 esh for the samples inside the canister. The particular irradiation dose (mainly due to the electron flux) was weak: 3×10^5 rads. The number of temperature cycles was 34,000 with temperatures within the ranges shown in Table 1.

Table 1. Range of estimated sample temperatures in typical lighting conditions.

Position	Conditions	Maximum temperature (°C)	Minimum temperature (°C)
Tray		49 to 63	–43 to –52
Canister	open	67 to 85	–33 to –40
Canister	closed	65 to 82	–20 to –26

The COMES Experiment on MIR

The COMES experiment (Figure 2) consisted of four panels which were deployed by an astronaut in space outside of MIR with the possibility of exposing samples on both sides, conventionally identified as "V" and "R." It included several modules on both sides.

V Side:

A total of 113 samples (20- by 20-mm squares or circles of 25 mm in diameter) had their central areas exposed to the space environment, without mechanical stress (20 mm in diameter). Among them, eight groups consisting of four identical samples of the same material were used to distinguish the effects of different space environment constituents, i.e.:

- exposure to all of the parameters (UV, AO, vacuum, temperature)
- exposure behind a 1-mm thick silica filter transmitting solar radiation with a wavelength greater than 190 nm (thus including most of the solar UV radiation)
- exposure behind a 1-mm thick optical filter only transmitting wavelengths greater than 360 nm
- exposure behind a metal disk, painted white and protecting the sample against the effects of AO and UV radiation.

In addition, six samples of polymeric films were exposed to the space environment while maintained under traction by a spring, and six samples of composite materials with an organic matrix underwent bending stress.

R Side:

Thirty-two samples were exposed without mechanical stress.

COMES is described in references 3 to 5. A total of 85 different materials were exposed on this experiment.

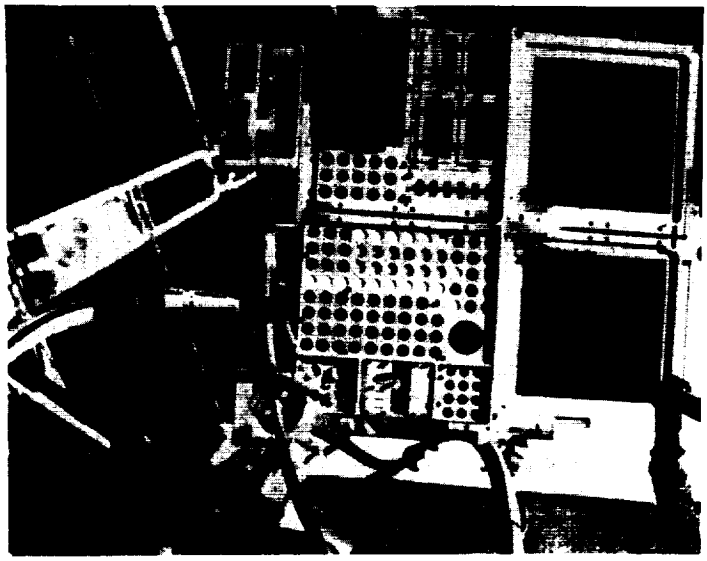


Figure 2. The COMES ARAGATZ experiment on board MIR; the photograph shows the face V.

During the flight, the MIR station followed an orbit located between 350 and 425 km in altitude, inclined at 51.6°. It should be noted that the orbit was transferred to more than 400 km in altitude from October 4, 1990, on, in order to continue the MIR flight in an automatic mode since there was no longer a crew aboard. On January 11, 1990, after having spent 392 days in space outside of the MIR, the COMES experiment unit was refolded during an extravehicular activity of cosmonauts; then it was stored aboard the station until October 2, 1990, at which date it was returned to Earth.

As the Russian team of the experiment had not provided much information on the attitude of the station during exposure of the COMES experiment, it is difficult to ascertain exactly the amount of sunlight received by each side of the experimental unit. However, after analysis of the data from the "Microcalorimeter" experiment, also mounted on the COMES panels, it may be estimated (ref. 6) that the V side received a solar UV dose of 2,850 esh and the R side 1,900 esh. For the same reasons, it was not possible to calculate, by means of the MSIS-86 environment model, the fluence of oxygen atoms accumulated by each of the two sides of COMES during the mission. Nor was it possible to determine whether the oxygen atoms had been received more for a particular inclination to the surfaces. On the basis of the erosion measured on samples of Kapton™ polyimide and Terphane™ polyethylene terephtalate arranged over the surface, it may be estimated that the fluences received were probably between 3.6 10^{20} and 5.9 10^{20} atoms cm^{-2} on the R side,* and between 3.7 10^{18} and 7.3 10^{19} atoms cm^{-2} on the V side.† It should however be pointed out that: (a) whereas the fluences appear to be rather uniform on R, this is probably not the case on V; and (b) these values have probably been underestimated, since a strong contamination, in particular by silicones, was detected on the samples on both sides. This must have protected the surfaces, at least partially, against AO. The temperature estimates of the sample holders on COMES, which may be made using thermal modeling, indicate that, in the case of the hottest exposure, the average temperature of the sample holders on the V side is probably of the order of +10 to +30 °C and that of the R side of the order of +50 to +60 °C. In the case of the coldest exposure (experiment unit in the shadow of the station), the temperature was determined for both sides to be between –60 and –70 °C.

---

* On the basis of the measurement of the decrease in mass of five samples, taking a reactivity of 3.0 10^{-24} cm^3 $atom^{-1}$ for the Kapton™, and 3.4 10^{-24} cm^3 $atom^{-1}$ for the Terphane™.

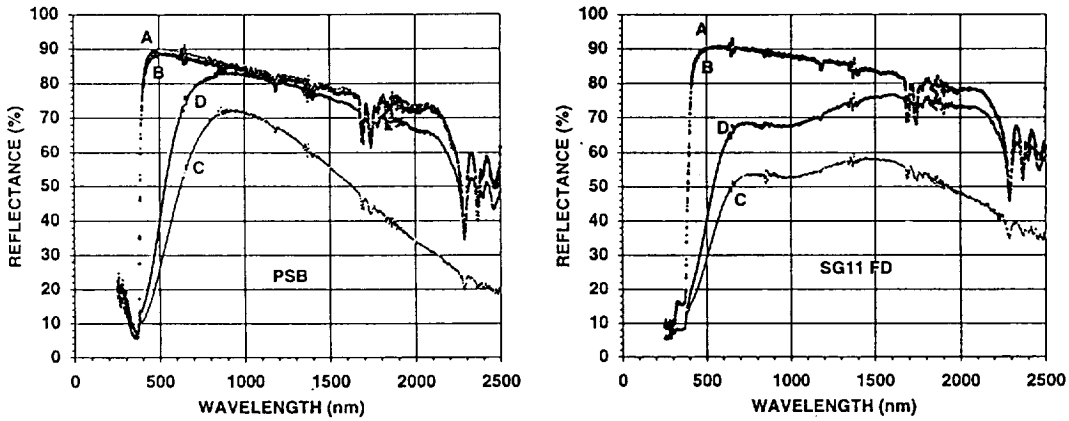
† On the basis of the measurement of the decrease in mass of eight different samples.

LESSONS FURNISHED BY THESE EXPERIMENTS

Validity of the Results

These experiments on LDEF and MIR are complementary: FRECOPA on LDEF gave an exposition to UV only; COMES on MIR gave an exposition where UV and AO were present simultaneously. On the other hand, the conditions of exposure on MIR (in particular, the UV and AO doses) are less well defined and a high surface contamination was observed (see below). This must be taken into account when comparing the results.

It is important to point out that they are based on measurements made after modification of the optical and mechanical degradations during the inevitable return of the specimens. More or less complete recovery of degradations caused by irradiation in a vacuum were noted when most of the polymers or white paints were returned to the air. An example of the importance of this phenomenon can be seen in Figure 3. On the other hand, there may be a postirradiation evolution following a peroxidation of the free radicals which are still trapped at the end of irradations, which helps to understand the progressive deterioration on the ground of samples recovered after the STS flights. This problem must, therefore, always be born in mind when using the data from these onboard experiments to forecast material behavior during an eventual future mission.



(A) in air, before irradiation,
(B) in vacuum, before irradiation,
(C) in vacuum, after combined irradiation with UV (6,250 esh), electrons (2.5 10^{15} electrons cm^{-2} s^{-1} of 400 keV) and protons (5 10^{15} protons cm^{-2} s^{-1} of 45 keV, 5 10^{14} protons cm^{-2} s^{-1} of 240 keV),
(D) after 5 days in air, postirradiation.

Figure 3. In air recovery of the white paints PSB and SG11 FD after combined irradiation with UV and particles in vacuum.

Synergy

Generally, in LEO it was found that there was much synergy of action of the different parameters of the natural and induced environments (UV, AO, thermal cycles, micrometeorites and

debris, and contamination). This is shown, for example, by the results of tests to separate the effects of different environmental components which were carried out on MIR.

For the COMES experiment, Table 2 shows the deteriorations in the solar reflectance of different samples exposed to different environments (see above), i.e. for the same samples:

- an exposure to all of the parameters: UV solar radiation (including far UV), AO, vacuum, and the temperature
- an exposure to UV radiation with a wavelength greater than 190 nm, to the vacuum and to the temperature
- an exposure to radiations with a wavelength greater than 360 nm, to the vacuum and to the temperature
- an exposure to the vacuum and to the temperature.

Table 2. Solar reflectance degradation ΔR_s of coatings on the V side of COMES, for different space environment conditions ΔR_s = final R_s – initial R_s.

Material	UV + At. Ox.+ vacuum ΔR_s	UV (λ >190 nm) ΔR_s	UV (λ>360 nm) ΔR_s	Vacuum ΔR_s
PCBZ	–0.01	–0.01	–0.01	+0.01
PSG 120 FD	–0.04	–0.03	0.00	0.00
A 276	–0.01	–0.14	0.00	+0.01
PCB 119	–0.01	0.00	+0.01	+0.01
SG 11 FD	–0.04	–0.01	0.00	0.00
PSB	0.00	0.00	+0.01	0.00
Kapton™ HN 50 µm	–0.03(*)	0.00(*)	0.00(*)	0.00(*)
FEP 25 µm	–0.05(*)	0.00(*)	0.00(*)	0.00(*)
FEP/Al 50 µm	–0.03	0.00	+0.01	+0.02

(*) ΔT_s: Variation of solar transmittance.

The Kapton™ HN and the Teflon™ FEP suffer deterioration under the combined effect of AO and UV radiation. As may be observed, the deterioration generally found on the white paints is relatively low, whether submitted to the complete environment or under UV.†† The A 276 paint is an exception. It suffers very strong deterioration under UV with a wavelength greater than 190 nm, but on the other hand its solar reflectance is stable under UV + AO. In the case of this paint, it has been confirmed that the AO decreases the extent of damage which would be experienced under UV radiation acting alone, as had been clearly shown by many observations on LDEF. On the R side of COMES which received the most oxygen atoms, the solar reflectances of the A276 paint and the PCB 119 even seem to have increased following the flight (Table 3). The PSG 120 FD and SG 11 FD paints, on the other hand, appear to deteriorate more under UV + AO than under UV radiation alone.

In certain cases, AO may counterbalance certain effects of UV irradiation acting alone. This is confirmed on MIR by the fact that exposition to space cured damage caused to specimens of PCB-Z and PCB-119 by preflight UV preirradiation on the ground (Table 4). This behavior is not general.

†† It should be remembered that the degradations considered here are those recorded after the samples have been returned to the air; those which might have been observed in orbit would have been different.

Table 3. Variations of solar reflectance and emissivity of various samples after their flight on FRECOPA/LDEF and COMES/MIR with $\Delta R_s = R_{s\ final} - R_{s\ initial}$ and $\Delta\varepsilon = \varepsilon_{final} - \varepsilon_{initial}$.

				AO 138-6 FRECOPA		AO 138-6 FRECOPA		COMES-ARAGATZ		COMES-ARAGATZ	
Type	Material	R_s initial	$\varepsilon_{initial}$	Canister ΔR_s	Tray ΔR_s	Canister $\Delta\varepsilon$	Tray $\Delta\varepsilon$	Face V ΔR_s	Face R ΔR_s	Face V $\Delta\varepsilon$	Face R $\Delta\varepsilon$
White paint	A276	0,75	0,877	-0,24		-0,005		-0,01	+0,03	+0,005	+0,036
White paint	S36	0,81	0,856	-0,04	-0,08	-0,001	-0,001				
White paint	PV100	0,78	0,865	-0,08		-0,001					
White paint	PSB	0,83	0,895	-0,05	-0,01	-0,001	-0,003	-0,01		-0,003	
White paint	SG11 FD	0,82	0,854					-0,04	-0,01	-0,005	-0,005
White paint	PSG 120 FD	0,80	0,876	-0,07		-0,002		-0,04	-0,02	0,000	-0,002
White paint (conductive)	PCB-Z	0,78	0,872	-0,04		0,000		-0,01	-0,02	+0,006	+0,003
White paint (conductive)	PCB-T	0,72	0,815	-0,10		0,000					
White paint (conductive)	PCB 119	0,79	0,861					-0,01	0,01	+0,008	+0,006
Black paint	PU1	0,03	0,885	+0,04		-0,002		+0,06	+0,06	+0,032	+0,032
Black paint	Z306	0,04	0,906	+0,035				+0,06		+0,026	
Black paint	Cuvertin 306	0,03	0,910					+0,03		+0,025	
Black paint	VHT SP102	0,05	0,860	+0,013		+0,001					
Black paint	HT650	0,03	0,873	0,01		-0,001					
Black paint	Electrodag 501	0,04	0,791					+0,02		+0,014	
Black paint	L300	0,05	0,843	+0,035		-0,013					
Black paint	PNC	0,08	0,796	+0,02		-0,040					
Black paint (conductive)	PUC	0,07	0,757					+0,03	+0,01	+0,127	+0,119
Aluminum paint	PSG173	0,69	0,317	-0,08		-0,006		-0,06		-0,009	
Aluminum paint (conductive)	PAC	0,73	0,275					-0,21		-0,024	
Coating	Alodine	061	0,050					+0,01		+0,020	
Black anodisation	PSS-703	0,09	0,874					+0,01		0,000	

Curiously, the solar reflectance of paint A276, preirradiated on the ground, continues to degrade in a LEO environment containing atomic oxygen.

Table 4. Effects of the MIR LEO environment on solar reflectance R_s of paints preirradiated with UV to 2,200 esh under vacuum in laboratory ΔR_s = final R_s – initial R_s.

Material	Preirradiation with UV	Initial R_s	ΔR_s
PCB-Z	no	0.77	–0.01
	yes	0.72	+0.03
PCB119	no	0.79	–0.01
	yes	0.74	+0.03
A276	no	0.75	–0.01
	yes	0.55	–0.03

Moreover, the LDEF and the STS flights results show generally that degradation of Teflon™ FEP depends on the relation between the quantities of AO and UV radiation received. On MIR, it was seen that on face V of COMES, the reactivity of FEP seems to have been very close to that of polyimide Kapton™ (FEP erosion exceeding 1 μm compared to a maximum Kapton™ erosion of 2.2 μm and an average of 0.7). On the other face, R, it seems to conform to that measured on LDEF** or STS flights (FEP erosion between 1.1 and 1.8 μm compared with a Kapton™ erosion of 11 to 17 μm). A similar anomaly was also noted for the black polyurethane paints PU1 and PUC which, on the two faces of COMES on MIR, were eroded by 3 to 4 μm whereas it is estimated that AO fluence was 10 times less on face V. The high level of contamination on MIR prevents us, perhaps, from drawing a definitive conclusion about these anomalies but they seem to indicate that precise, local ambient conditions greatly influence degradation.

Table 5. Erosion of FEP, polyimide, and PET films after exposure to LEO on MIR.

Position	Material	Number of samples	Minimum erosion (μm)	Maximum erosion (μm)	Average erosion (μm)
Side R	Polyimide	3	10.7	16.7	14.6
	PET	2	18.8	20.0	19.4
	FEP	3	1.1	1.8	1.5
Side V	Polyimide	9	0.11	2.2	0.5
	PET	4	0.18	1.3	0.5
	FEP	4	0.8	1.1	1.0

The exact synergy of the observed effects is difficult to understand. It may depend on the relative intensity of the elements involved (UV radiation, oxygen atoms, and contamination) and also on whether they are or are not simultaneous. We do not know how important is the fact that LDEF

** 10 to 13 percent of that of the Kapton™ polyimide.

received AO essentially during the last days of the flight. Damage kinetics during the flights is unknown for most of the LDEF and COMES experiments. We must, therefore, bear in mind that variations in solar activity, attitude, and orientation may influence the importance and nature of damage.

Temperature

With respect to the samples used in the FRECOPA AO 138-6 experiment, it may, however, be observed (Table 6) that almost all of the degradations measured following the flight on samples contained in the canister were greater than what might have been predicted on the basis of ground simulation of solar UV irradiation, with ex situ measurements. In addition, the differences between the degradations recorded for the samples located in the canister and those located on the external tray were relatively slight in spite of a much greater solar illumination on the tray (11,100 esh) than for the canister samples (1,450 esh).

Table 6. Ratio between solar reflectance changes in the FRECOPA canister and those after UV-irradiation at laboratory (ex situ measurements after 1,450 esh in vacuum).

Material	Ratio
PSB	1.8
S36	2.0
PSG 120	2.5
A-276	0.9
PCB-T	1.2
FEP	1.2
Aluminized Kapton™	3.0
Conductive aluminized Kapton™	1.1
Beta cloth	1.0

There are three possible interpretations for the excessive deterioration of the samples contained in the canister:

(1) A more significant contamination of the samples in the FRECOPA canister: measurements made by SIMS or RBS show a very slight contamination of these samples by a contaminant containing silicium, with a layer thickness probably less than 50 Å. Tests carried out at DERTS (ref. 7) on materials precontaminated by VCM products of silicon origin before their irradiation with UV and particles at room temperature indicate that the increased solar absorption due such thicknesses of pollutant is less than 0.01. This means that contamination cannot be the main cause of the observed differences.

(2) A deficiency in the quality of solar simulation applied, especially in the case of radiation with wavelength less than 200 nm. If this were the case, the deterioration would have been much more significant for the tray samples compared to those placed in the canister.

(3) An influence of temperature cycles undergone in space. This interpretation is the most likely according to thermal-vacuum tests undertaken on the ground which show (Table 1) that the maximum temperatures were almost 20 °C greater for the samples in the canister, and that they might thus reach +85 °C. The irradiation on the ground was carried out under standard conditions close to the ambient temperature. Deterioration under the effects of radiation is most likely greatly increased for the highest temperatures.

It is not, however, possible to know if the influence of a higher temperature on the specimens in the canister was felt more during the period when it was open than during the 4 years it was kept closed. There is little published literature in this field, and it does not permit a correlation between the importance of the degradation of the thermal control coatings and their irradiation or postirradiation temperature. In these conditions, laboratory studies seem indispensable in order to clarify this point for material irradiated by UV radiation and/or AO. This would probably permit a better choice of the conditions for simulation tests designed to predict behavior in a mission for a given thermal cycle profile.

Contamination

As was mentioned above, the samples retrieved after the FRECOPA flight on the trailing edge of LDEF seem to have been submitted to a rather low level of contamination (about 50 Å for a product containing silicon) compared with what has been published about other experiments on LDEF. This is probably due to the preconditioning in vacuum to which the specimens were subjected in the laboratory before their integration, to the conditions selected for this treatment, and to the design chosen for the whole FRECOPA experiment. The same precautions were taken for the COMES specimens on MIR. Nevertheless, a high degree of contamination by various products was noted on the surfaces of this experiment. Figure 4 shows at least three different types of contaminants on a silica surface. Through the microscope, we can see circular marks, probably droplets, on different types of specimens and various types of defects which are branching out. It should be noted that these defects, whose size varies between a few micrometers and several hundred micrometers, were observed only on electrical insulating material on COMES. Some certainly correspond to crystalline growth forms (Figure 5). Other defects (Figure 6) seem to resemble the arboresences known as Lichtenberg figures which are caused by an electrical breakdown resulting from charged particle irradiation of the dielectrics. Other causes could be imagined as an explanation for these ramified defects which are still being studied.

Figure 4. Surface contamination on silica after flight on MIR.

Figure 5. SEM study of crystal growth figures on a polyimide surface after flight on MIR.

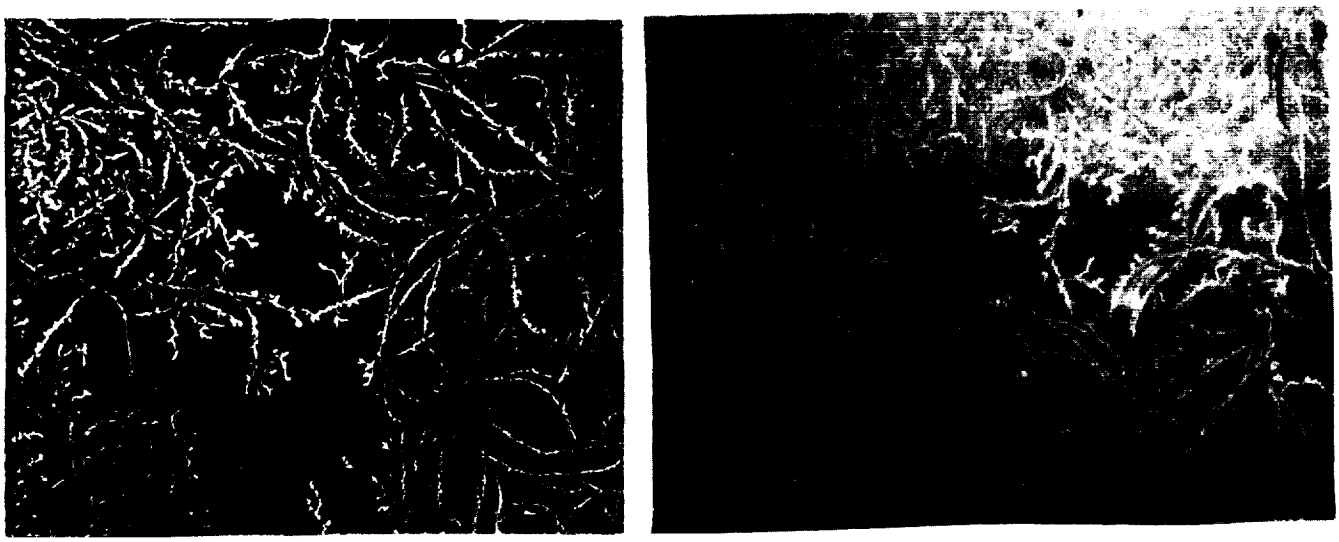


Figure 6. Unidentified defect on surface of a PES film after flight on MIR.

For these contaminants, it is difficult to define the origin, the moment at which they appeared, and the length of application. We must not forget that the experiment was also stored in the humid interior atmosphere of the MIR after exposure to space, with possible consequences for the samples. This leads us to think that the contamination observed on LDEF is very certainly much lower and less varied than that which will be obtained on a larger manned space station, subject to extravehicular and internal activity and serviced by regular visits by space shuttles.

Effects of an LEO Environment on Different Classes of Materials

Detailed results of the COMES and FRECOPA experiments have been published in various reports (ref. 1–5) giving details of variations in mass, optical reflection or transmission (spectral and solar), and emissivity. In this paper, we shall examine a few major facts.

A certain number of materials (aluminum, gold, and, above all, silver, OSR, alumina, or MgF_2 coatings) present slight but significant increases in weight after exposure on MIR—typically between 0.05 and 0.2 mg. This may correspond to oxidation but also, at least in part, to an accretion of contaminants. For example, a coating of silicon oxide (coming from AO oxidation of silicone products) with a specific mass approximately equal to 2.1 g cm^{-3} could correspond to an increase in mass of 0.10 mg if it were 1,500 Å deep on the surface of the exposed part of the specimens.

Contrary to a widely-held idea, according to which exposure to a space environment does not cause a variation in surface emissivity ε, many specimens presented quite clear changes[§] in this property. The erosion noted has been relatively low; as a result, the emissivity values did not decrease because of a reduction in the thickness of the emissive layer of an SSM, for example. In the case of conductive SSM's, polymer films, polyurethane, or carbon paints, an increase of ε was noted as a consequence of an irregular attack of the surface on a microscopic scale. An increase can also be noted for metallic materials which may oxidize; silver (included in the PAC conductive paint) and, to a much lower degree, gold and anodizations. As surface temperature depends on the relation α/ε, it is essential to know, for the thermal control coatings, the variations in both parameters α and ε in function of the time spent in LEO.

Even though no systematic measurements were made, the diffuse component of the optical reflection or transmission of the materials studied had visibly increased. This may have an important consequence on, for example, the design of optical equipments and baffles.

As already mentioned, it seems that the presence of AO sometimes (but not always, however) brings about a decrease in the damage caused by UV irradiation on solar reflectance. However, the behavior of the different classes of white paint in an environment which includes simultaneously UV radiation and AO is not the same. In order of decreasing stability, we find paints with a silicate binder, with a silicone binder, and finally those with a polyurethane binder. These latter should be proscribed for LEO usage.

All black paints have been undoubtedly bleached by exposure to LEO, more on MIR than on the trailing edge of LDEF (perhaps because of a synergistic action of UV radiation and oxygen atoms).

Aluminum paints deteriorated badly in a low orbit environment, as was proved by data from FRECOPA on LDEF (where they were subjected to UV only) and from COMES on MIR (where they were subjected to UV and AO). This result is surprising, bearing in mind the excellent stability of these paints noted during ground irradiation tests with UV radiation. It seems obvious that the reflectance spectrum of aluminum paints exposed on MIR was greatly modified. As analogous spectral modifications were also noted on solid aluminum and on VDA layers, it would seem that the aluminum underwent some sort of superficial chemical attack during the mission on MIR.

[§] Emissivity measurements were made with a Gier & Dunkle DB100 reflectometer.

Unlike the thermo-optical properties, the mechanical properties (elastic modulus and damping, T_g) measured after the mission on face V of the COMES experiment, using a Polymer Lab DMTA1 thermomechanical dynamic analyzer, do not seem to have been greatly modified on the FEP and Kapton™ films. It would seem, therefore, that there is no mechanical degradation due to UV irradiation in the bulk of the film even though it must be remembered that these measurements were made during exposure to air and that there may have been some form of degradation recovery because of this. Only a residual elongation was noticed on all films which had been exposed in mechanical tension.

Generally, polymer films and organic matrix composites exposed on COMES were eroded and, for prolonged exposition in LEO, in conditions where they are exposed to AO, need to be protected by a thin superficial layer of a stable material. According to our measurements, it is possible to say that the ITO and VDA layers, and the silicone overcoatings, have proved to be effective in this role (providing they were uniform in thickness and without holes).

On the organic matrix composites exposed on COMES, an important weight loss (0.12 to 1.2 percent of the initial mass in the exposed zone) was noted. This does not correspond to the real erosion, which was observed by optical means and remains low. It is the result of long-term outgassing in space vacuum, despite the preconditioning in a dry atmosphere carried out before integration.

If the silica or cerium glass OSR and the FK52 glass presented good stability, it must be mentioned that an antireflection optical coating showed signs of considerable spectral changes; this was also true for the MgF_2 coatings on aluminum which have already been mentioned. On the other hand, the anodizations resisted well.

CONCLUSION

To summarize, the important alterations in properties noted in LEO for very varied materials confirm the need for great care to be taken during their selection for use in a given mission.

In-flight results should not be used indiscriminately and, even if they indicate good behavior, should not be considered as a qualification for general use in a space environment or even, more particularly, in a LEO environment.

Most of the degradation observed in space is the result of a synergistic action between various parameters which define a space environment. HEO and GEO environments possess their own specific conditions due to fluxes of charged particles. Even in LEO, degradation depends on precise local conditions of exposure (intensity, simultaneity and proportion of UV radiation and AO) and use (thermal cycles). The problems must, therefore, be studied for each individual case.

Moreover, the data obtained after exposure of the specimens to vacuum and their return to the air (which is the case for most data at present available) are to be used with the greatest possible precaution as they do not take possible air recoveries into account. They can be used only if they are supported by simulation experiments carried out in the laboratory. In any case, simulations using UV irradiation and oxygen atoms simultaneously, in controlled conditions, are needed for an evaluation of the performance of a new material or one which is destined for a particular function, and also to determine the exact mechanisms of damage.

Contamination has been observed to be very general on a satellite. Associated with various environmental parameters, it affects the behavior of surfaces and the nature and extent of damage. It has very varied origins and can appear at practically any stage of a mission. In most cases, it plays an important part in the degradations which have been observed in surface properties. Bearing in mind the oxidation caused to many substances by AO, standardized VCM criteria are obviously no longer enough to be representative of the outgassing of materials in LEO and to allow their selection for use in a space environment. Some serious thought is required in this field.

REFERENCES

1. Guillaumon, J.C., and Paillous, A.: "Experiment AO 138-6, Spacecraft Thermal Control Coatings." Proceedings of the First LDEF Post-Retrieval Symposium, Kissimmee, FL, June 2–6, 1991.

2. Guillaumon, J.C., and Paillous, A.: "Project FRECOPA, Experience AO 138-6, Revetments de Control Thermique." Note CERT-ONERA-DERTS CR/LDEF/06, July 1991.

3. Guillaumon, J.C., Marco, J., and Paillous, A.: "Flight and Laboratory Testing of Materials in Low Earth Orbit." Proceedings of the Fifth International Symposium on Materials in a Space Environment, Mandelieu, France, September 16–20, 1991, pp. 27–42.

4. Guillaumon, J.C., and Paillous, A.: "ARAGATZ. Rapport final sur l'Expérience COMES-Echantillons." Note CNES, July 1992.

5. Paillous, A., and Oscar. H.: "ARAGATZ. Expérience COMES-Echantillons: étude des échantillons exposés à l'espace en traction." Note DERTS-CERT-ONERA, CR ARAGATZ COMES/05, August 1992.

6. Subias, M.: "Expérience Microcalorimètres, Compte-Rendu des mesures effectuées en vol. Note CNES 90/TE/AE/MT/TH n° NT118.

7. Marco, J., and Paillous, A.: "Long-Term Tests of Contaminated OSR's Under Combined Environment." Proceedings of the Third European Symposium on Spacecraft Materials in Space Environment, ESTEC Noordwijk, The Netherlands, October 1–4, 1985, p. 245.