

INFLUENCE ON POLYMER MATRIX COMPOSITE EXPOSED TO SPACE ENVIRONMENT

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Polymer matrix composites such as carbon fiber reinforced plastic (CFRP) are lightweight materials which have good mechanical properties and are applied widely as basic structural materials for spacecraft, especially reusable launch vehicle. However the degradation data of the CFRP after exposed in space environment for long period was not obtained in ground experiment. Therefore understanding the process of degradation for CFRP is very important to maintain structural reliability. In this study we evaluate the two heat resistant CFRP which are candidates for the reusable launch vehicle.

Keywords: CFRP, Polycyanate, Polyimide, Delamination, Micro crack

1. Introduction

Composite materials such as CFRP were applied to spacecraft especially reusable launch vehicle (RLV) more and more because of their high specific strength and specific elasticity. However effective data have not obtained although polymer matrix is degraded by space environment factors such as electron beam, ultra violet ray, high vacuum, thermal cycle and atomic oxygen, effective data were very few for difficulty of simulating space condition (Fig.1).

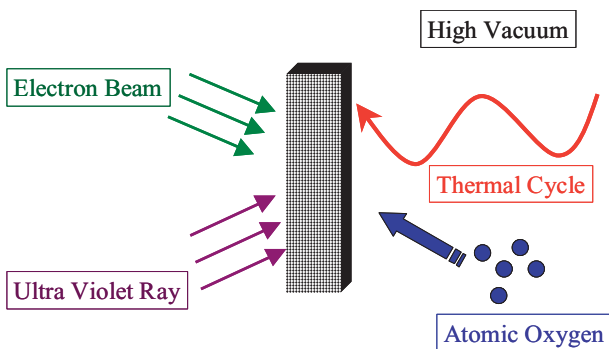


Fig.1 Space environmental factors to composite material

It is possible to conduct an experiment under each environment condition, but the experiment which includes all space environment factors is very difficult to conduct. Moreover it is known that the results which are obtained by simultaneous condition and sequential condition are different. The material experiments conducting under the actual space environment give us very important data for space development (Fig.2)

In case of RLV, the structure bears large mechanical and thermal load repeatedly. Therefore material degradation data under the space environment factor is very essential.

In this study we, Fuji Heavy Industries LTD. (FHI), selected two heat resistant materials which are the candidates for RLV structure, offered for the MPA&SEED experiment and evaluated surface and internal quality of the materials using 5 evaluation method

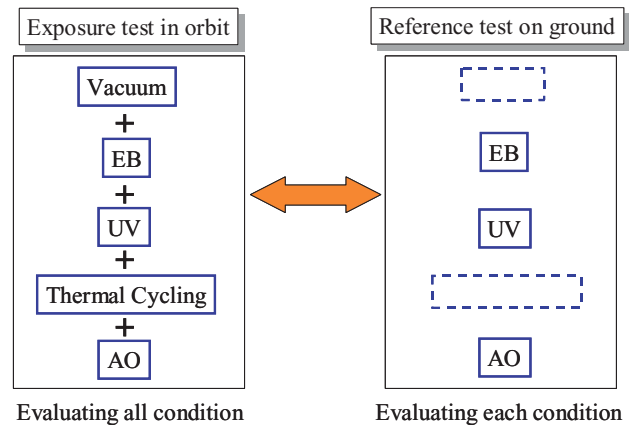


Fig.2 Difference of experiment condition between in orbit and on ground

2. Material Properties

Two heat resistant composite materials are evaluated in the experiment. One is YS90A/RS-3 which consist of pitch based carbon fiber and polycyanate resin, and the other is IM600/PIXA which consist of PAN based carbon fiber and the thermo plastic polyimide resin.

2.1 CF/Polycyanate

CF/Polycyanate (CF/PC) is more durable in heat condition compared with epoxy based CFRP using pitch based high tensile modulus carbon fiber and Polycyanate heat resistant resin named YS90A. CF/PC has good heat cycle durability because of low micro crack.

The properties of the material are following.

- Fiber: YA90A, High tensile modulus carbon fiber.
- Resin: RS-3, Polycyanate resin.
- Resin composition: Thermo set resin with cyan group (CN).
- Main characteristic:
 - 1) Low out gas
 - 2) Low micro crack
 - 3) Heat resistant temperature : 190°C
(Tg : 206~254)

2.2 CF/Polyimide

CF/Polyimide (CF/PX) is high heat resistant composite using PAN based carbon fiber and polyimide, which is one of the highest heat durable resin

The properties of the material are following.

- Fiber: IM600, High strength carbon fiber.
- Resin: PIXA-M, Polycyanate resin.
- Resin composition: Thermoplastic polyimide resin with imide group (NHO2)
- Main characteristic:
 - 1) Resistance to high temperatures
(thermal deformation temperature : 220、Tg : 240)
 - 2) High resistance to radiation
 - 3) High CAI strength

2.3 Specimens size and exposure period

The specimen size for the each material is 17mm sq. and 3mm thickness. The specimens were exposed out of ISS Russian service module on three different periods (10, 28, 46months). In addition, ground experiments which were applied space environment factors such as electron beam, ultraviolet ray, and atomic oxygen were conducted separately as reference experiment.

For each space environment factor, the specimens were irradiated for 0.5 and 1.0 year in orbit equivalent.

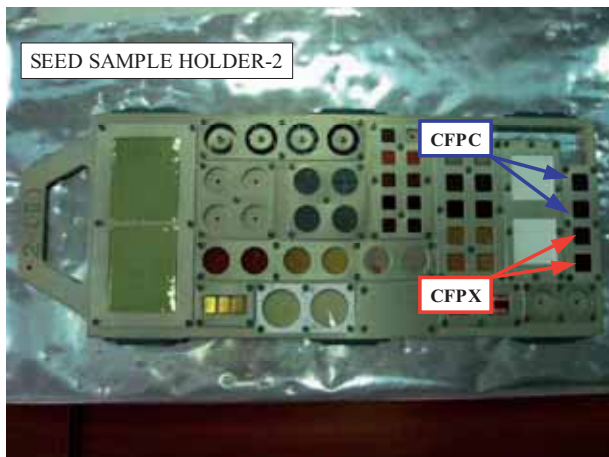


Fig.3

3. Evaluation

3.1 Evaluating method

Following observations were conducted in order to evaluate the specimens which were unexposed any condition, exposed in space environment and irradiated space environment factors.

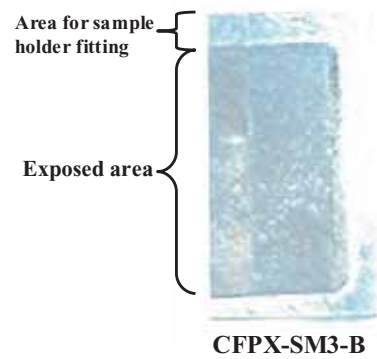
1. Visual Observation (VO)
2. Microscope Observation (MO)
3. Cross section Observation (CO)
4. Ultra Sonic Observation (USO)
5. Fourier Transform Infrared Spectroscope (FT-IR)

In the evaluation methods, VO and MO were conducted in order to obtain surface condition of the materials. CO and USO were conducted to get the internal data and FT-IR is for the data of composition change on the surface of the materials. The details of the evaluation are described in following next item.

3.2 Visual Observation

From results of VO, surface fading of the space-exposed specimens and atomic-oxygen-irradiated specimens were confirmed. Fig.4 shows the fading area of CFPX exposed for 46months. This picture is not clear to find changes. But the surface lost luster and changed to brawn color in the area exposed in space environment while the area for sample holder fitting had luster clearly and was not find any change. In addition, the surface of exposed area is rougher than that of the area for sample holder fitting.

In consideration of the above results, we think that the fading was caused by atomic oxygen in the space environment.



CFPX-SM3-B

(46 months exposed)

Fig.4 Fading of CFRP

3.3 Microscope Observation

Further research in the surface degradation we conducted microscope observation (MO). The MO results of CF/PC and CF/PX were shown in Fig.5, Fig.6. The rough surface was observed in either of the two materials under the condition of space environment exposure and atomic oxygen irradiation. On the other hand, any change was not observed among the unexposed and EB and UV irradiation


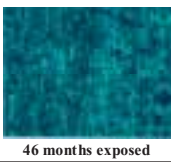
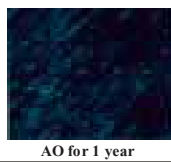
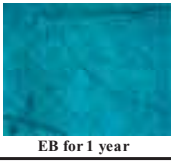
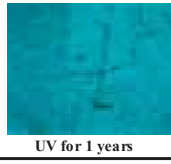
			
Unexposed			
	The surface is rougher than that of unexposed test piece.		The surface is rougher than that of unexposed test piece.
46 months exposed		AO for 1 year	
	No difference was observed.		No difference was observed.
EB for 1 year		UV for 1 years	

Fig.5 Results of CFPC for MO

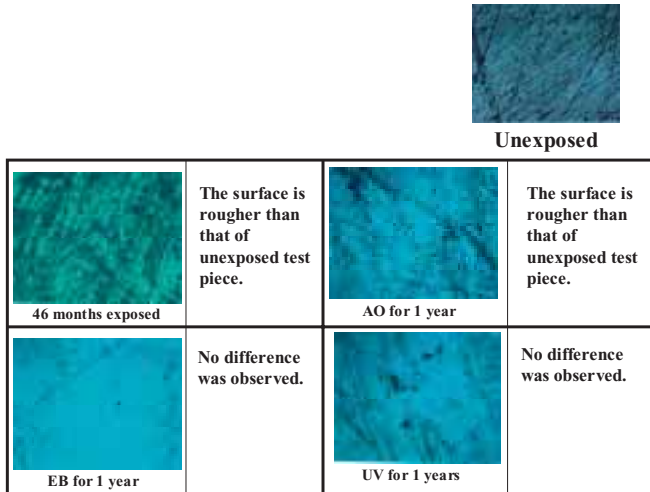


Fig.6 Results of CFPX for MO

3.4 Cross section Observation

Cross section Observation (CO) was conducted in order to research on the internal quality such as micro crack and delamination. Table 1 shows the result of counting the numbers of cracks and delamination. The delamination was observed in all CFPC including the unexposed specimen. Therefore we think that the delamination was generated for manufacturing process.

Cracks were not observed in CFPC. This result supports the characteristic of this material that micro cracks were very low.

On the other hand, many cracks were observed in CFPX which was made using thermoplastic polyimide. Thermoplastic polyimide resin is thought as ductile material. And the results are not same compared with a prior prediction.

In consideration that the space environment factor in which the number of cracks is the largest is EB condition, it is thought that the cracks were generated because the resin became brittle by EB that permeated into the internal and changed the polymer composition of the specimen.

Table1 The numbers of cracks and delaminations

Material	Environment	Crack	Delamination
CFPC	10 months	0	1
	28 months	0	1
	46 months	0	0
	EB for 1 year	0	1
	AO for 1 year	0	1
	UV for 1 year	0	1
	Unexposed	0	1
CFPX	10 months	0	0
	28 months	1	0
	46 months	7	0
	EB for 1 year	9	0
	AO for 1 year	3	0
	UV for 1 year	5	0
	Unexposed	0	0

Fig.7 and Fig.8 show the picture of CO for CFPX exposed for 46months in orbit and AO irradiation 1 year equivalent.

Supporting the result of VO, resin damage and carbon fiber without resin was observed on the surface of the specimen in Fig.7, Fig.8

Resulting from CO, the roughness of the CFRP surface was caused by AO.

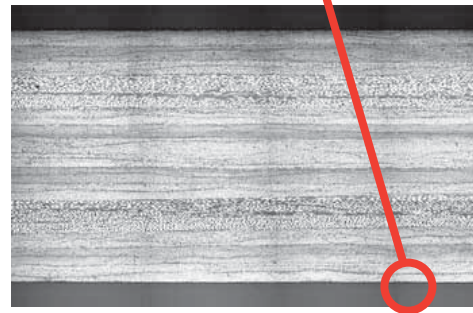
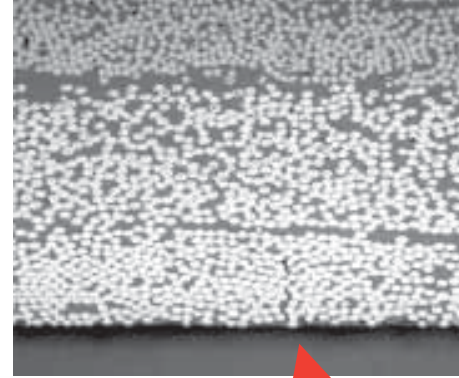


Fig.7 CFPX 46 months exposed

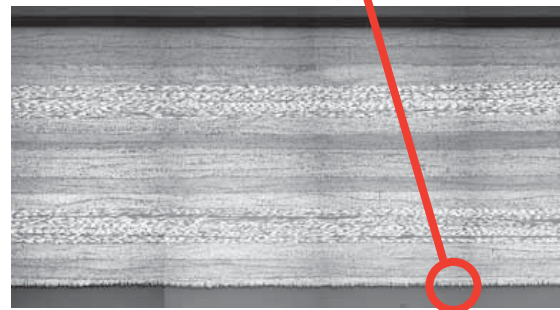
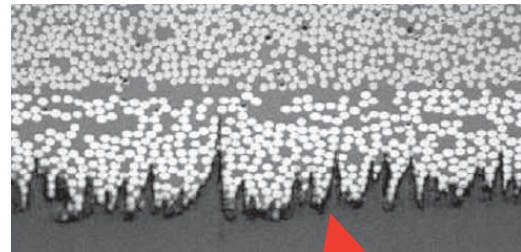


Fig.8 CFPX AO for 1 year

3.5 Ultrasonic Observation

Ultrasonic Observation (USO) is the general inspection method using aerospace composite parts for quality assurance.

In this study, USO was conducted in order to detect foreign objects and delamination.

Fig.9 and Fig.10 show the results of CFPC. The indication which exists directed to fiber was observed in all results including unexposed specimen. Although no clear indication was observed except the small delamination indication, clear trend among unexposed, space exposed and space environment factor was not found by using USO.

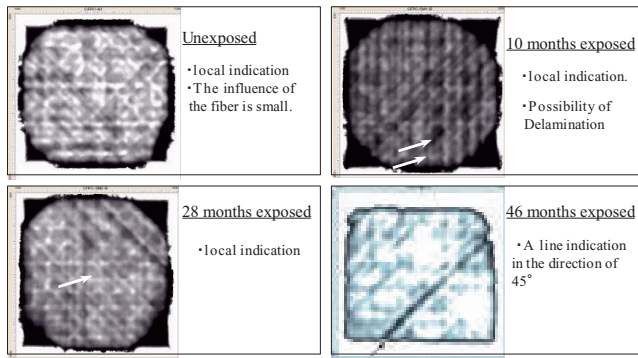


Fig.9 Result of CFPC for 4 period in orbit

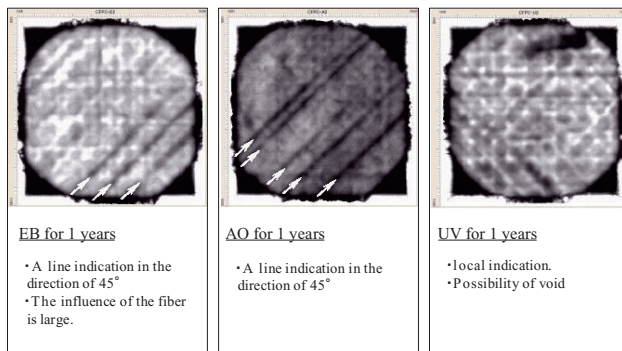


Fig.10 Result of CFPC irradiated space environment factors

The same trend was obtained in the results of CFPX. Fig.11 and Fig.12 show the results of CFPX.

No indication was observed in the specimen exposed for 46 months in orbit, although the indication which exists directed to fiber was observed in the results including unexposed specimen.

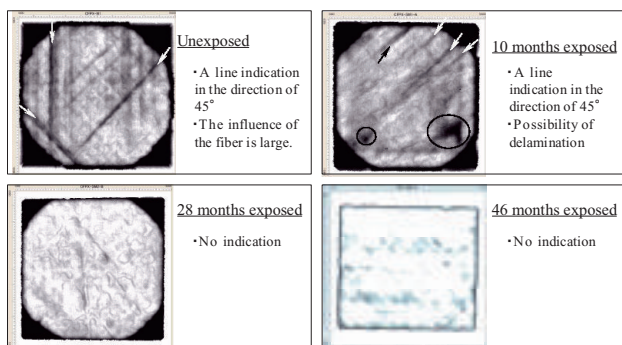


Fig.11 Result of CFPX for 4 period in orbit

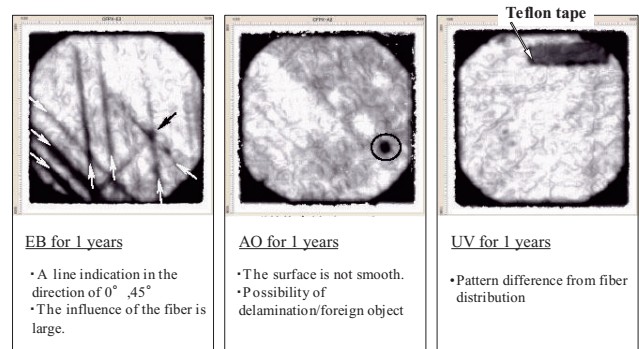


Fig.12 Result of CFPX irradiated space environment factors

3.6 Fourier Transform Infrared

Fourier Transform Infrared (FT-IR) spectroscopic analysis is the chemical analyzing method, and can get the resin degradation by measuring a organic composition change.

Fig.13 to 16 show the FT-IR results for CFPC and Fig.17 to 20 show the results for CFPX. In these graphs blue, orange, green, pink line show the unexposed, 10 months, 28 months, 46 months in orbit respectively.

Fig.14 to 16 also show the results of AO, EB, and UV respectively. In these graphs blue line shows the result of unexposed specimen. In the same way, orange and green line shows the result of equivalent irradiation for 0.5 year and 1.0 year respectively.

Same trend was confirmed in the result of CFPC and CFPX. As compared Fig.15 with Fig.16 and Fig.19 with Fig.20, no change of organic composition was found.

On the other hand, the sharp peak which indicates organic composition was low and almost disappear the result for 46 months in orbit and 1 year equivalent AO irradiation. The results show degradation of resin especially in CFPC.

In the result for 46 months in orbit, indication of ozone compound was found. But the phenomenon was not seen in the results of AO. I think this phenomenon to be the combined effect of the space environment, but the mechanism of the generation is not elucidated

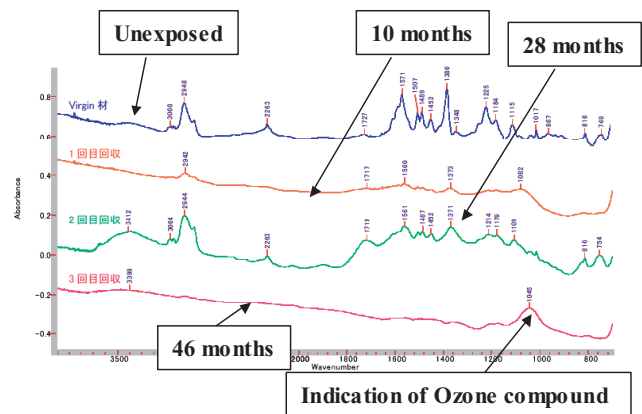


Fig.13 FTIR for CFPC in orbit

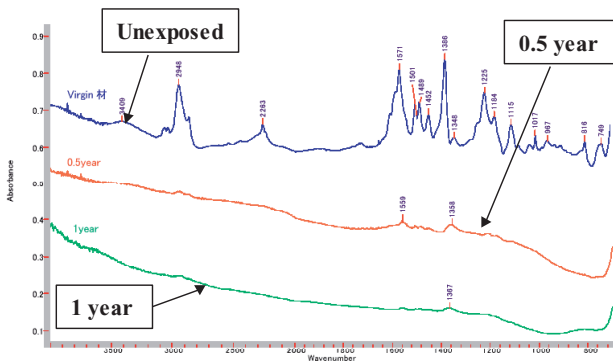


Fig.14 FTIR for CFPC AO irradiation

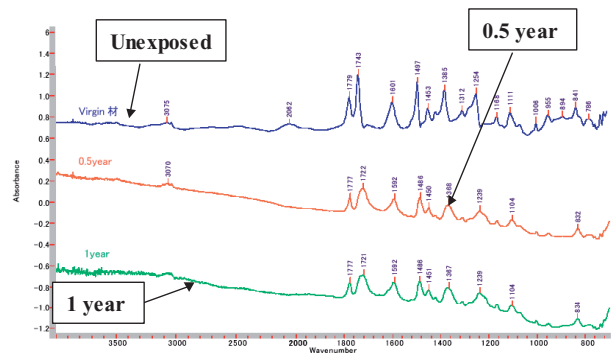


Fig.18 FTIR for CFPX AO irradiation

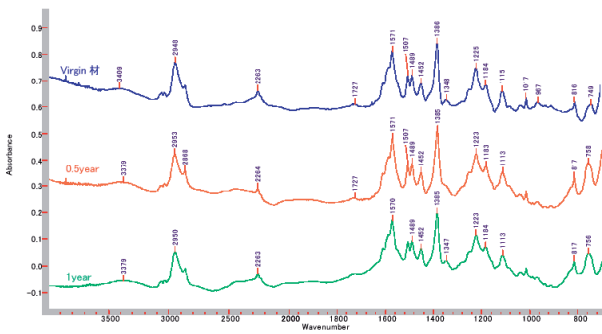


Fig.15 FTIR for CFPC EB irradiation

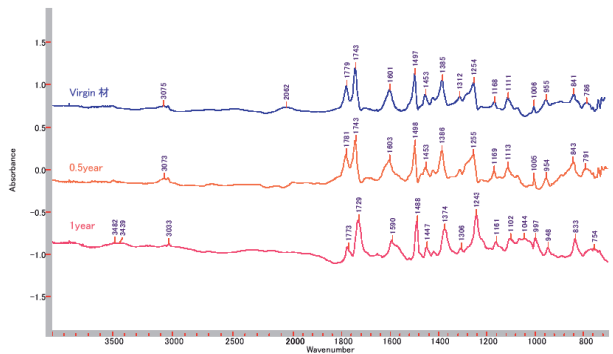


Fig.19 FTIR for CFPX EB irradiation

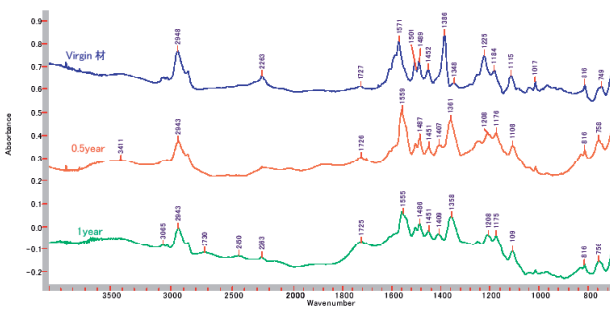


Fig.16 FTIR for CFPC UV irradiation

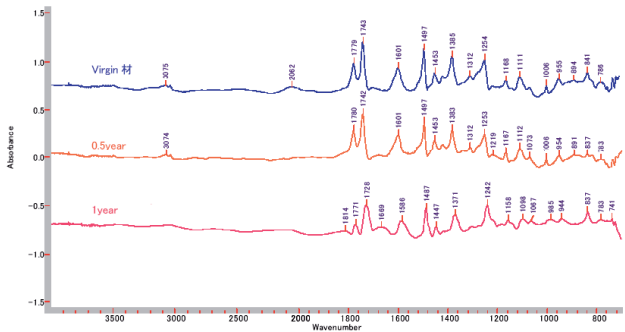


Fig.20 FTIR for CFPX UV irradiation

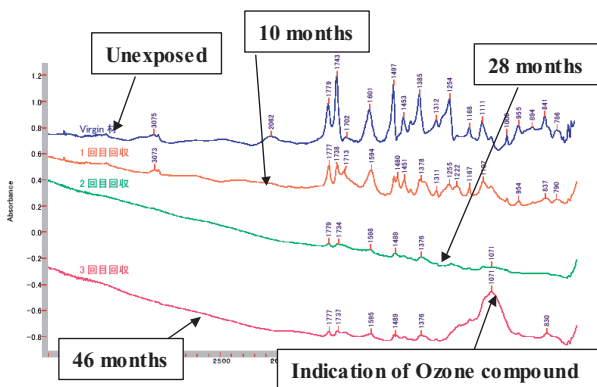


Fig.17 FTIR for CFPX in orbit

4 Summary

In the Space environment exposure experiment two kinds of composite materials which are candidates for future spacecraft were evaluated as follows.

As a result of visual and optical microscope inspection, resin damage and carbon fiber without resin were observed on the exposed surface for each specimen. We think that AO gives main influence for the lack of resin because the same result was observed in the reference experiment of AO.

The clear degradation of the resin was not observed in the internal structure for each materials and conditions as a result of ultrasonic inspection and cross section observation.

As space environment exposure period became long, the resin degradation and the ozone compound were observed from the results of FT-IR.