Degradation of Optical-properties of Thermal Control Coatings Under Space Low Energy Electrons

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Abstract

Thermal control materials is very important for spacecraft thermal control subsystem. The properties of the thermal control materials will undergo severe degradation in space environments, especially for optical properties. This paper describes a study of solar absorptance degradation of spacecraft thermal control materials under low energy electron irradiation. The test was intended to simulate space electron radiation environment in GEO for 15 years. The three energies of electron such as 40keV, 20keV and 10keV were accepted during irradiation test. The temperature of tested samples is controlled less than 30℃. The thermal control coatings includes ACR-1 conductive organic white paint, ITO coated aluminized Kapton film, ITO coated OSR, S781 organic white paint and SR107-ZK organic white paint. The degradation of solar absorptance of these samples was in-situ evaluated and compared with test results from different high energies and fluxes of electrons. The empirical model analyse of the degradation data was performed.

1. INTRODUCTION

The satellite would suffer rigorous space environments when it is in orbit, such as particle radiation, solar electromagnetic radiation, space debry, vacuum and so on. The satellite would be affected by these environment factors, especially the properties of surface materials would have large change, this change would affect the operation of the satellite directly or indirectly. For example, solar absorptance of thermal control coatings would increase under these environments, ultimately affect the function of thermal control subsystem.

solar absorptance is an important parameter of thermal control coatings. Temperature increase of satellite at the end of long term mission is mainly caused by the degradation of α_s of surface thermal control coatings under space environment. GEO is in the outer radiation belt. There are a great deal of low energy charged particles in the orbit. Low energy charged particles will deposit more energy in the surface layer. Low energy charged particles will damage surface properties seriously. So the degradation of thermal control coatings under GEO is especially concerned.

This paper describes a study of solar absorptance degradation of spacecraft thermal control materials under low energy electron irradiation. The test was intended to simulate space electron radiation environment in GEO for 15 years by several energies electron. The degradation of solar absorptance of these samples was in-situ evaluated and compared with test results from different high energies and fluxes of electrons.

The test was performed on a Low Energy Combined Environment Test Facility built by Beijing Institute of

Spacecraft Environment Engineering(BISEE). This facility can supply environments of medium energy electrons, low energy protons, NUV, FUV and vacuum. α_s or spectral reflectance or spectral transmittance or surface resistance or mechanical properties in-situ measurement for test specimen are equipped inside the facility. Fig.1 show the photograph of the facility.

Fig.1 Low Energy Combined Environment Test Facility

2. TEST CONDITIONS

2.1 Electron irradiation

GEO is in the outer radiation belt. The main source of electrons in GEO is radiation belt particles. The AE8 MAXmodel is used for the electron flux calculation. Fig.2 gives the differential flux spectrum of electron in GEO. We can see that the flux of low energy electron is very large,

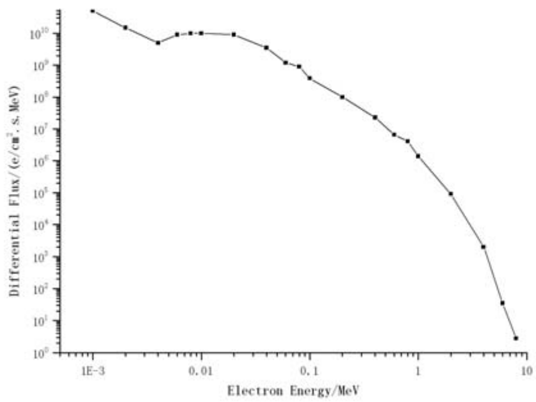

Fig.2 Electron differential flux spectrum in GEO

The duplication of space electron environment in ground is impossible, so two methods for simulating the radiation spectrum of charged particles are recommended in ISO-15856[1].

a) Use several beams of quasimonoenergetic charged particles with various energies. The spectrum is adjusted by proper choice of fluences of the separate radiation sources. Also (quasi)-monoenergetic spectra can be used to simulate most effects, for some others, such as induced conductivity or recovery a broad spectrum radiation is to be preferred.

b) Convert a monoenergetic beam to a number of quasimonoenergetic beams using a sectioned foil with the thickness varying from point to point. The thickness of the foil is about the size of free path of the particles and is determined by scattering and absorption characteristics of the foil.

The former method was applied in many ground simulation test. Stuckey and his participator used four or more energies electrons for simulating the dose profile of GEO radiation environment in the space environment test of materials for inflatable structures and Tedlar, as in [2] and [3]. Fig.3 shows the dose profile of simulation test and space environment in orbit.

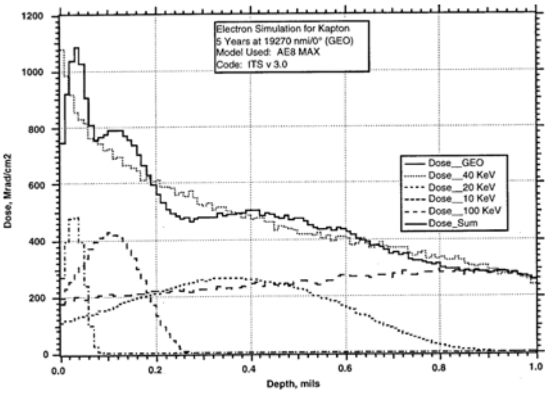

Fig.3 Predicted simulation dose profile and orbital dose profile in GEO

An electron radiation test of thermal control coatings was performed to simulate the electron environment effects of GEO for 15years. Three energies electron were used to simulate the dose profile of particle environment in GEO on materials. Table 1 gives the energy and fluences of electron in the simulation test. The simulated test dose profile and orbital dose profile in GEO is given in fig.4. The electron exposure were performed starting with the highest energy first and progressing successively to lower energies.

Table 1 The energy and fluence of electron in the simulation test

Electron energy (keV)	Electron Fluence (e/cm^2)
10	2.0×10^{15}
20	2.4×10^{15}
40	5.0×10^{15}

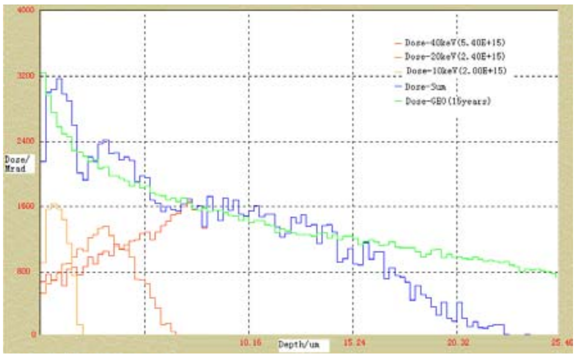

Fig.4 Predicted simulation dose profile and orbital dose profile in GEO

2.2 Temperature and vacuum

Temperature of samples was controlled by good thermal contact with metal plate support connected with a constant temperature circulator. The plate support is maintained at a specific temperature of 30 ℃ to ensure sample temperature less than 50℃. The facility's shroud temperature is controlled at less than -35℃ which ensure the sample temperature much higher than the shroud temperature. Vacuum systems are turbo molecular pump and mechanical pump. Vacuum is better than 3×10-3Pa during whole test period.

2.3 Cantamination control

Solar absorptance is a kind of surface properties which is sensitive to contamination. Contamination of test samples must be minimized to prevent the effects to test results. In this test ,we had several methods to control sample contamination such as low contamination vacuum system, cryogenic shroud , sample high temperature.

3. SAMPLES DISCRIPTION

The thermal control coatings tested included S781 white paint, SR107-ZK white paint, ACR-1 conductive white paint, ITO coated OSR, ITO coated aluminiumed Kapton. S781 white paint is a kind of organic paints with ZnO pigment and S781 silicone resin. SR107-ZK white paint's pigment is ZnO treated by potassium silicate and its binder is SR107 silicon rubber. ACR-1 conductive white paint is altered ZnO pigmented and its binder is crylic acid resin. These three paints is sprayed on aluminium substrate. Sample of aluminiumed Kapton is a Kapton (0.05 mm) film coated aluminium on one side and ITO on other side. The aluminiumed side was bonded on round aluminium substrate. OSR is a quartz plate(0.2mm) coated silver on one side and ITO film on other side. The aluminium substrate is 28mm in diameter. Three samples of one materials are mounted on target for irradiation test at the same time.

4 TEST RESULTS AND DISCUSSION

4.1 Test results

The solar absorptances for 3 samples of one material were measured and average value was taken as the α_s value for that material during each measurement. Table 2 ~ 6 show the test results of five materials.

Table 2 α_s Degradation of OSR under electron exposure

Electron fluence ($\times10^{15}e/cm^2$)	0	0.465	0.924	1.493	2.097
α_s	0.071	0.088	0.086	0.09	0.101
Electron fluence ($\times10^{15}e/cm^2$)	2.66	3.969	5.113	5.772	6.906
α_s	0.087	0.103	0.100	0.100	0.078
Electron fluence ($\times10^{15}e/cm^2$)	7.495	8.102	8.725	9.488	
α_s	0.098	0.085	0.091	0.093	

Table 3 α_s Degradation of ITO coated aluminiumed Kapton under electron exposure

Electron fluence ($\times 10^{15}e/cm^2$)	0	0.465	0.924	1.493	2.097
α_s	0.285	0.318	0.333	0.345	0.364
Electron fluence ($\times 10^{15}e/cm^2$)	2.66	3.969	5.113	5.772	6.906
α_s	0.36	0.374	0.383	0.378	0.363
Electron fluence ($\times 10^{15}e/cm^2$)	7.495	8.102	8.725	9.488	
α_s	0.379	0.365	0.365	0.372	

Table 4 α_s Degradation of S781 white paint under electron exposure

Electron fluence ($\times 10^{15}e/cm^2$)	0	0.465	0.924	1.493	2.097
α_s	0.222	0.239	0.242	0.244	0.249
Electron fluence ($\times 10^{15}e/cm^2$)	2.66	3.969	5.113	5.772	6.906
α_s	0.259	0.266	0.268	0.265	0.255
Electron fluence ($\times 10^{15}e/cm^2$)	7.495	8.102	8.725	9.488	
α_s	0.258	0.257	0.258	0.255	

Table 5 α_s Degradation of SR107-ZK white paint under electron exposure

Electron fluence ($\times 10^{15}e/cm^2$)	0	0.465	0.924	1.493	2.097
α_s	0.177	0.228	0.249	0.255	0.259
Electron fluence ($\times 10^{15}e/cm^2$)	2.66	3.969	5.113	5.772	6.906
α_s	0.259	0.266	0.282	0.266	0.251
Electron fluence ($\times 10^{15}e/cm^2$)	7.495	8.102	8.725	9.488	
α_s	0.266	0.25	0.258	0.253	

Table 6 α_s Degradation of ACR-1 conductive white paint under electron exposure

Electron fluence ($\times 10^{15}e/cm^2$)	0	0.465	0.924	1.493	2.097
α_s	0.297	0.305	0.312	0.314	0.315
Electron fluence ($\times 10^{15}e/cm^2$)	2.66	3.969	5.113	5.772	6.906
α_s	0.32	0.328	0.331	0.326	0.317
Electron fluence ($\times 10^{15}e/cm^2$)	7.495	8.102	8.725	9.488	
α_s	0.328	0.313	0.32	0.321	

The plotted curve of degradation datas of 5 materials is given in fig.5. As shown in the test results, ITO coated aluminiumed Kapton is most degradated and other four materials are less degradated.

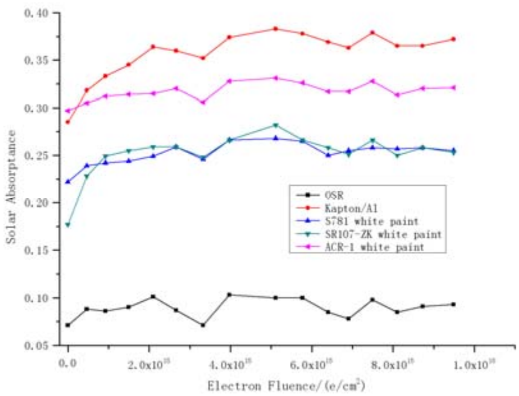

Fig.5 Curve of Degradation datas of five materials

4.2 Discussion

The range of low energy electron is short, for example, the range of 40keV electron is less than 25 microns. Hence thhe most part of energy of low energy electron is deposited in the materials surface and induced more damage to the material surface. The range of high energy electron is much more than low energy electron, the deposited energy is less and the damage to surface of materials is relatively less than low energy electron. The $\Delta\alpha_s$ of OSR in this study is 0.022, but up to $2.5\times10^{15}e/cm^2$ of 360keV electron exposure induced change of α_s is 0.001. The difference between two results is obvious. The $\Delta\alpha_s$ of ITO coated aluminiumed Kapton in this study is 0.087, but solar absorptance of this material under 1MeV electron exposure to $1\times10^{13}e/cm^2$ is not changed. Thus it can be seen that effect of low energy electron on thermal control coatings is bigger than high energy electron. So it is recommended that low energy electron is applied in ground simulation test.

5 EMPIRICAL MODEL

As shown in Fig.5, degradation trend of solar absorptance is slow-down as electron dose accumulates.That makes possible to use empirical model to extrapolate the test results. We applied a two-order exponential decaying formula empirical model for curve fitting. Fig.6 gives the results of curve fitting of results of 40keV electron exposure.

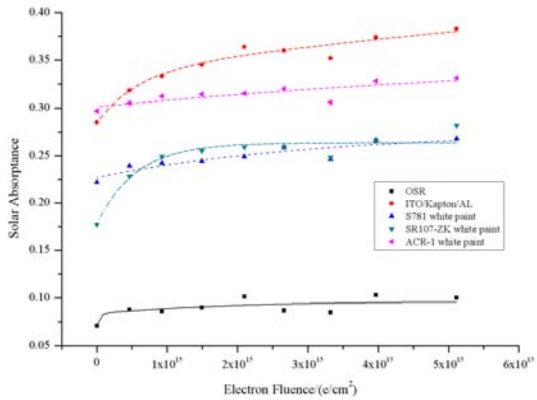

Fig.6 Curve fitting results and degradation data

From fig.6 we can seen that the curve fitting results of S781 white paint and ITO coated aluminiumed Kapton agreed with degradation data well, but there are difference between the curve fitting results and the degradation data of other three materials. This is partly due to the big discreteness of the degradation data.

6. CONCLUSION

The simulation test method of dose profile fitting is used in low energy electron radiation test that simulate the particle environment of GEO 15 years on several thermal control coating. The solar absorptance is measured in-situ. The test results are compared with the results of high energy electron radiation. The results show that the degradation of low energy electron radiation is much more than high energy electron. It is recommended that low energy electron is applied for ground simulation test. The method of dose profile fitting can be used for ground simulation test of space radiation environment. Empirical model is also used for curve fitting of degradation data, showing that the empirical model can use for curve fitting, but is not able to give a reliable extrapolated value.

7. REFERENCE

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