Mechanical Property of Polyimide Film in Space Radiation Environments

Zicai Shen\textsuperscript{a,*}, Yuming Liu\textsuperscript{b} and Wei Dai\textsuperscript{c}

Beijing Institute of Spacecraft Environment Engineering, No.104, Youyi Road, Haidian District, Beijing, China(100094)

Email: \textsuperscript{a}zicaishen@163.com, \textsuperscript{b}lyming2005@126.com, \textsuperscript{c}daiwei0018@163.com

Abstract. The mechanical property of polyimide film (PI) in electron, proton, near ultraviolet and far ultraviolet was studied by \textsuperscript{\Phi}800 combined space radiation test facility of Beijing Institute of Space Environment Engineering, the degradation of mechanical property of polyimide film was tested by Electronic tensile testing machine. The tensile strength and the rupture elongation of polyimide film decrease with the increase of electron or proton radiation, while tensile strength and the rupture elongation of polyimide film decrease firstly and then increase with near ultraviolet irradiation.

1. Introduction

As the progress of space science and technology, the spacecraft structure and weight becomes larger and larger. Restricted by efficient room and carry mass of delivery, the preparation and launch of traditional space structure encounters tremendous difficulty. So improvement of spacecraft function and efficiency in restricted carry mass is an important way for spacecraft design. Deployment structure is excellence in cheap cost, small storage bulk, light weight, high reliability, and can realize some special capability which traditional structure cannot.

Space deployment structure can be used in lunar base, deployment solar battery, solar sail, sunshield of next generation space telescope and so on, and films are important compose of this structure [1-7].

Film usually exposed on the surface of spacecraft and their mechanical property will degrade severely in space environments [8-11], which induces atomic oxygen (AO) in low earth orbit (LEO), orbital thermal cycling, micrometeoroids, orbital debris, and space radiation environments such as electron, proton, near ultraviolet (NUV), far ultraviolet (FUV) et al. Among of these space environments, radiation environments can damage the molecular bond of polyimide films, and results in the degradation of mechanical properties of it. So it is essential to study the mechanical degradation of spacecraft film in space radiation environments, and its results will give help to the design of spacecraft and to promote the reliability of spacecraft in orbit.

In this paper, the mechanical property of polyimide film in space radiation environments such as electron, proton and NUV was studied by \textsuperscript{\Phi}800 combined space radiation test facility of BISSE separately [12], and then their mechanical property evolution was analyzed and compared.
2. Test scheme

2.1. Sample preparation
The test samples are PI film, and its thickness is 25μm, besides samples used in proton irradiation is 50μm. It was cut into special sample with 150mm length and 15mm width, and the edge of sample must smooth and without any small gap.

2.2. Test parameters
The test samples irradiated by electron generated by electron gun with energy of 40keV, and the fluencies at which to test their mechanical properties is $0, 1 \times 10^{15} \text{e/cm}^2, 3 \times 10^{15} \text{e/cm}^2, 5 \times 10^{15} \text{e/cm}^2, 7 \times 10^{15} \text{e/cm}^2, 10 \times 10^{15} \text{e/cm}^2$ separately. The proton generated by proton sources with energy of 45keV was used as irradiation energy, and the fluencies is $0, 1 \times 10^{14} \text{p/cm}^2, 3 \times 10^{14} \text{p/cm}^2, 5 \times 10^{14} \text{p/cm}^2, 7 \times 10^{14} \text{p/cm}^2, 10 \times 10^{14} \text{p/cm}^2$ separately. For NUV irradiation tests, the samples were irradiated by mercury xenon lamp with energy of 1000W, the NUV exposure is 0ESH, 100ESH, 200ESH, 300ESH, 500ESH, and 1000ESH separately, and the acceleration factor is 4. The facility was internally surrounded by a cold shroud which was kept at about -35°C by a (freezer). Because of this, the samples were fixed on a metal sample mount whose temperature was maintained at about 20°C. The system was kept at a vacuum better than $3.0 \times 10^{-3} \text{Pa}$ by a turbo-molecular pump backed up by a mechanical pump.

3. Mechanical property analysis

3.1. Electron irradiation effect
The rupture elongation and tensile strength of PI films radiated by electron are illustrated in Figure 1 and Figure 2.

![Figure 1](image-url)  
Figure 1. Tensile strength of polyimide in different electron fluencies.
Figure 2. Elongation of polyimide in different electron fluencies.

From Figure 1 and Figure 2, it can be seen that the rupture elongation and tensile strength of PI film increases in the beginning and then decreases with fluencies of electron.

The relation between rupture elongation and irradiation fluence was fitted to the function of

\[
y = 28.89 + 36.61 \exp\left(-\frac{x}{5.20}\right)
\]

Here, \(y\) is rupture elongation, \%; \(x\) is fluence, \(10^{15} \text{e/cm}^2\).

The relation of tensile strength and irradiation fluence was fitted to the function of

\[
y = 150.54 + 52.18 \exp\left(-\frac{x}{3.29}\right)
\]

Here, \(y\) is tensile strength, Mpa; \(x\) is fluence, \(10^{15} \text{e/cm}^2\).

From fitting analysis, it can be seen that the rupture elongation and tensile strength of PI film both exponentially decreased with increasing irradiation fluence.

3.2. Proton irradiation effect

The tensile elongation test were performed after the PI film samples were exposed to the proton irradiation at fluence of \(0, 1\times10^{14} \text{p/cm}^2, 3\times10^{14} \text{p/cm}^2, 5\times10^{14} \text{p/cm}^2, 7\times10^{14} \text{p/cm}^2, 10\times10^{14} \text{p/cm}^2\) respectively and the results are illustrated in Figure 3 and Figure 4.

Figure 3. Tensile strength of polyimide in different proton fluencies.
From Figure 3 and Figure 4, it can be seen that the rupture elongation and tensile strength of PI film decreases with fluencies of proton.

The relation between rupture elongation and irradiation fluence was fitted to the function of

$$y = 48.035 + 11.861 \exp\left(-\frac{x}{3.352}\right)$$  

(3)

Here, $y$ is rupture elongation, %; $x$ is fluence, $10^{14}$/cm$^2$.

The relation between tensile strength and irradiation fluence was fitted to the function of

$$y = 222.435 + 29.714 \exp\left(-\frac{x}{3.497}\right)$$

(4)

Here, $y$ is tensile strength, Mpa; $x$ is fluence, $10^{14}$/cm$^2$.

From fitting analysis, it can be seen that the rupture elongation and tensile strength of PI film both exponentially decreased with increasing irradiation fluency.

3.3. NUV irradiation effect

After the NUV irradiation test at different exposure of 0, 300ESH, 500ESH, 800ESH, 1600ESH, the tensile elongation tests are performed. The rupture elongation and tensile strength are illustrated in Figure 5 and Figure 6.

Figure 4. Elongation of polyimide in different proton fluencies.

Figure 5. Tensile strength of PI in different NUV irradiations.
From Figure 5 and Figure 6, it can be seen that the rupture elongation and tensile strength of PI film decreases in the beginning and then increases with exposure of NUV.

The relation between rupture elongation and NUV irradiation fluence was fitted to the function of

$$y = 64.96 - 40.39 \exp\left(-\frac{x}{372.74}\right) \quad (x>300)$$  \hspace{1cm} (5)

Here, y is rupture elongation, %; x is exposure, ESH.

The relation between tensile strength and NUV irradiation exposure was fitted to the function of

$$y = 199.20 - 55.27 \exp\left(-\frac{x}{572.33}\right) \quad (x>300)$$  \hspace{1cm} (6)

Here, y is tensile strength, %; x is exposure, ESH.

From fitting analysis, it can be seen that the rupture elongation and tensile strength of PI film both exponentially increase with increasing irradiation exposure of NUV.

4. Conclusions

Different space radiation environments have different effect on the mechanical properties of PI film. The tensile strength and the rupture elongation of PI film radiation by electron increase firstly and then exponentially decrease, but these mechanical properties of PI film radiated by proton only exponentially decrease. For NUV irradiation, the mechanical properties of PI film decrease firstly and then increase with near ultraviolet exposure.

5. References

[1] A. D. Joyce, K. G. Kim, A. T. Jacqueline, Mechanical properties degradation of Teflon FEP returned from the Hubble Space Telescope, NASA/TM- 1998- 206618 (1998)1-11.
[2] L. A. Michael, L. C. Harry, M. K. David, et al, Design and flight testing of an inflatable sunshield for the NGST," AIAA, 2000-1797(2009)1-9.
[3] M. S. Grahne, D. P. Cadogan, C. R. Sandy, Development of the inflatable shield in space (ISIS) structure for the NGST program, IAF paper, IAF00-1104,(2000)1-11.
[4] G. Charles and P Humphrey, Developments and activities in solar sail propulsion, AIAA, 2001-3234(2001)1-20.
[5] W. G. Nathan and I. C. James, Deployment modeling of an inflatable solar sail spacecraft, AIAA, 2006-6336, (2006)1-15.
[6] Lichodziejewski, D. and Cassapakis, C., "Inflatable power antenna technology," AIAA, 1999-1074, (1999)1-11.
[7] Larry, L., Hamid, H., Michael, L.T., Dynamic characterization of an inflatable concentrator for solar thermal propulsion, J. Spac. & Rock. 40 (2003)24-27.
[8] Dennis, A. R., John, W. C., Lawrence, B. F., Electron, proton, and ultraviolet radiation effects on thermophysical properties of polymeric films, J. Spac. & Rock. 39 (2002) 833-838.
[9] David, E., Mary, H., Whitney, H., Perry, G., Georgy, W., Willian, H., Characterization of candidate solar sail material exposed to space environmental effects., AIAA, 2004-1085, (2004)1-10.
[10] S. Hiroyuki and Y. Ichiro, Degradation of Mechanical properties of polyimide film exposed to space environment, Journal of spacecraft and rockets. 46(2009) 15-21.
[11] E. F. James, R. Edward, Low-Energy Electron Effects on Tensile Modulus and Infrared Transmission Properties of a Polypyromellitimide Film, NASA-TM-81977, (1981)1-15.
[12] W.Q. Feng, Y.G. Ding, D.K. Yan, et al. Combined low-energy environment simulation test of geosynchronous satellite thermal control coatings. J. Spac. & Rock. 46 (2009)11-14.