# Fracture of Unidirectional Tensioned Polyimide Films under Simulated Space Debris

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**Abstract:** Large space membrane structures using for functional surface of spacecraft (LSMS-FSS), such as film antennas and film solar concentrators, have important potential space applications for space based communications, imaging and energy transmissions. The large size and area lead to higher impact probabilities of space debris. This paper focuses on the fracture and damage of unidirectional tensioned polyimide films under hypervelocity impact. The films are pure polyimide, with the thickness of 8μm/12.5μm/25μm. The tension stress is adjusted from 0Pa to 5MPa. The 20J pulsed laser driven flyer (LDF) facility is used for generating simulated hypervelocity space debris with the diameter of about 1mm, and the velocity of about 5.9 km/s. Multiple impacts are achieved successively by moving the sample. By a serious of experiments, the effects of the films thickness are investigated, the contribution of tension stress is obtained, and the cumulative damage under multiple impacts at different locations is also analyzed.

**Keywords:** Polyimide film; tension stress; space debris; hypervelocity impact; fracture

## 1. Introduction

Large space membrane structures using for functional surface of spacecraft (LSMS-FSS), such as film antennas and film solar concentrators, have important potential space applications for space based communications, imaging and energy transmissions[1-6]. They have many prominent excellent performances including low areal density, high packaging efficiency, deployable and operating at high frequencies. At the same time, these structures are characterized by large area (up to tens or hundreds of meters), thin thickness (several to tens microns), and needing tension stress to maintain the high profile accuracy (less than the wavelength of microwave or light). Space debris plays important role on the service performance on orbit. The large size and area lead to higher impact probabilities of space debris, since they have to be exposed in the space environment. These film structures are vulnerable to small



*Proc. 7th European Conference on Space Debris, Darmstadt, Germany, 18–21 April 2017, published by the ESA Space Debris Office*
*Ed. T. Flohrer & F. Schmitz, (http://spacedebris2017.sdo.esoc.esa.int, June 2017)*

space debris, impact induces voids and cracks, and tension stresses exaggerate the damages which will destroy the structure integrity.

Experimental researches have been done on the hypervelocity impacts of polyimide films such as the solar sail and thermal control films[7-12]. Results show that the films tends to rupturing brittlely and forming a radial pattern under the hypervelocity impact of small space debris, and it is more obvious for the thinner films and lower temperature. However, the effect of the pre-stress on the fracture of the films needs to be further investigated. This paper focuses on the fracture of unidirectional tensioned polyimide films under hypervelocity impact.

## 2. Experimental procedures

The films are pure polyimide with the thickness of 8μm/12.5μm/25μm, and the size of 30mm×60mm. The unidirectional tension state is achieved by using a special designed clamp. The samples are fixed to two carbon fiber reinforced polymers (CFRP) beams at the two ends, which are tensioned by weights. The tension stresses are adjusted from 0Pa to 5MPa, below the yield stress of about 69MPa.

The 20J pulsed laser driven flyer (LDF) facility[13] at China Academy of Space Technology is used for generating simulated hypervelocity space debris or flyers. Schematic diagram of experiments illustrated in Fig.1. The size of the flyer is about 0.5mm×0.8mm or 0.5mm×1.2mm and the thickness is 8μm, see Fig.2. The impact velocity keeps the constant value of 5.9 km/s. Since the experiments are conducted in the atmosphere, the initial distance between the sample and the flyer is adjusted to about 1mm so in order to reduce the influence of the air. Multiple impacts at different locations are achieved by moving sample successively.

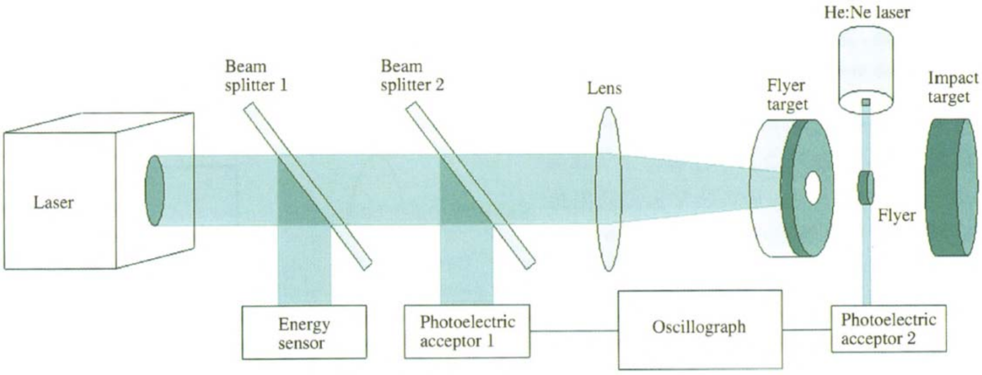



Fig.1 Schematic diagram of the laser driven flyer experiments[13]

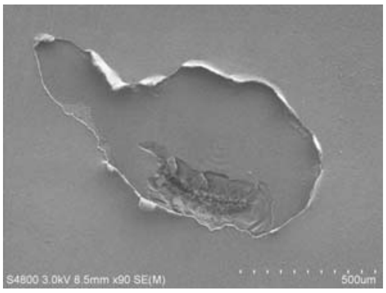
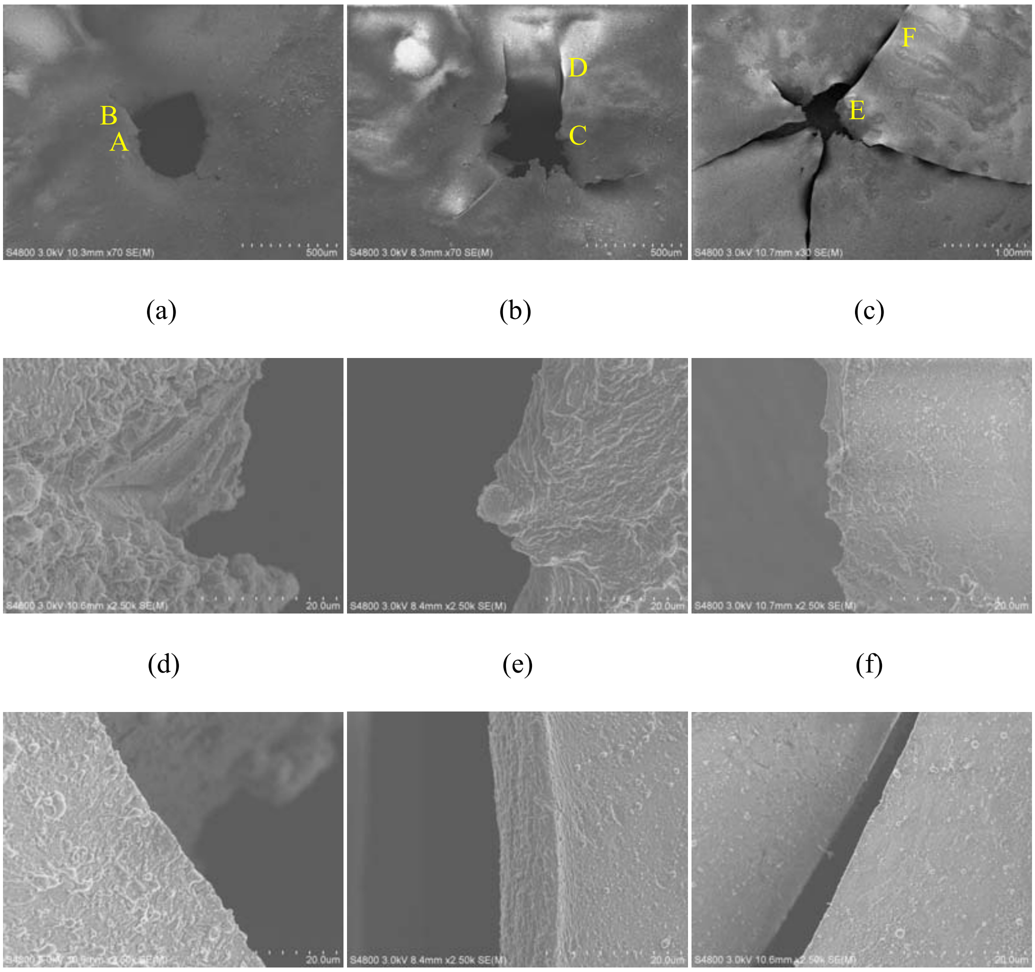



Fig.2 Morphology of the flyer target – a hole caused by a small flyer spalled from the glass basement

The morphology of the fractured surface of the sample due to the hypervelocity impacts is examined using a scanning electron microscope (SEM) of model S4800.

## 3. Results and discussion

Impact morphology and fracture modes of different polyimide films at the same tension stress of about 0.22-0.27MPa are demonstrated in Fig.3. Hypervelocity impact results in two distinct regions: the center impact region and the remote radial crack region. The materials at the center are sheared off, that leaves a void. There are several cracks in the remote radial crack region. It can be seen from the SEM images that, the center impact region shows ductile failure while the remote radial crack region shows brittle fracture. The void diameters of the three samples are almost the same, which is about 0.4-0.5mm and slightly smaller than the flyer. There are big differences at the radial cracks. Only two short cracks with the length of 0.2mm are in the 25μm thick film and the diameter of the region is about 0.8mm. Four cracks exist in the 12.5μm sample, the longest one is 0.5mm, and the region diameter arrives 1.2mm. The radial crack region extends to 4.7mm, which includes five long cracks with the length of 0.6mm/1.7mm/1.7mm/2.4mm/2.8mm. So the thickness plays important role on the fracture behavior of the film. The fracture region increases significantly with the decreasing film thickness. This is consistent with the results of Verker[8] and Zhao[9].



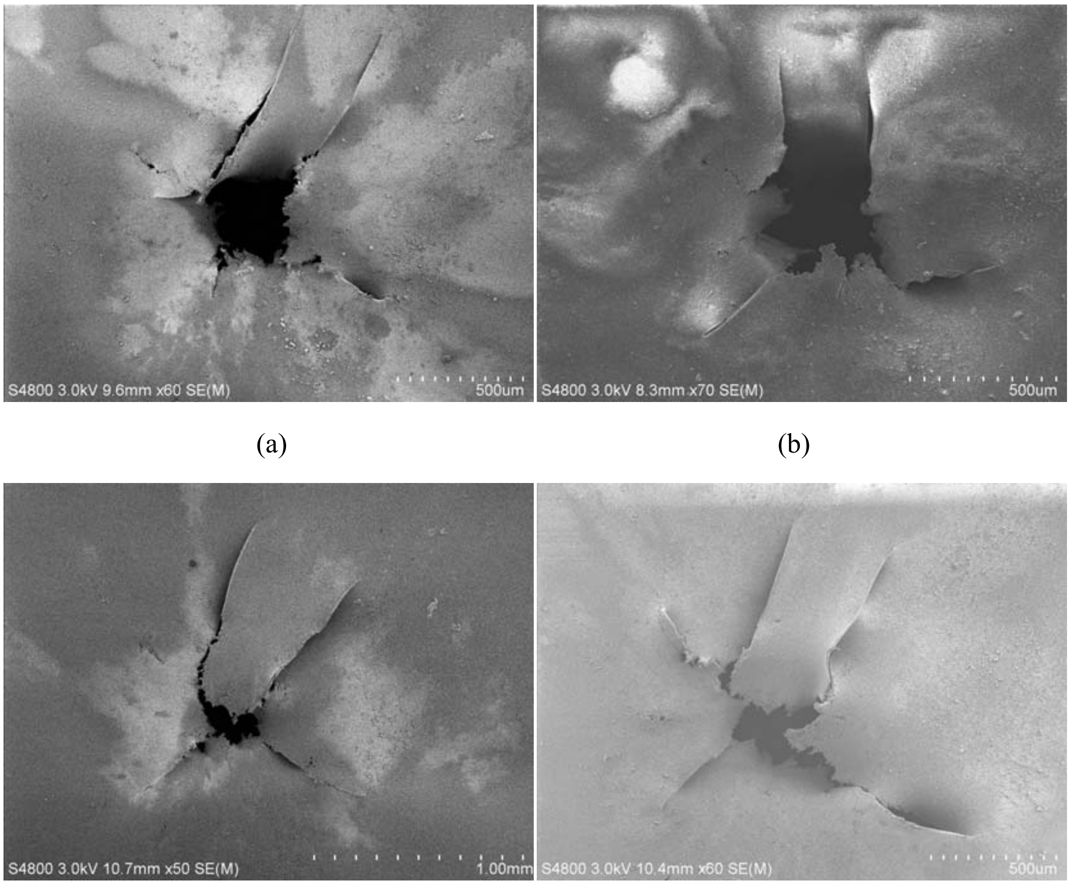

(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

Fig.3 Impact morphology and fracture modes of different polyimide films (flyer velocity of 5.9km/s): (a)25μm film with the tension stress of 0.27MPa; (b) 12.5μm film with the tension stress of 0.27MPa; (c) 8μm film with the tension stress of 0.22MPa; (d)region A; (e)region B; (f)region C; (g)region D; (h)region E; (i)region F

Fig.4 shows the fracture morphology of the 12.5μm polyimide films at different tension stress. When the stress increases from 0.06MPa to 5.24MPa, the shape and the size of the central impact region are very close. Number and orientation of the cracks are almost the same for the samples with different stresses. The size of the radial crack region increases slightly from 1.3mm to 1.6mm. Fracture is affected by the stress not very seriously under the current stress level.

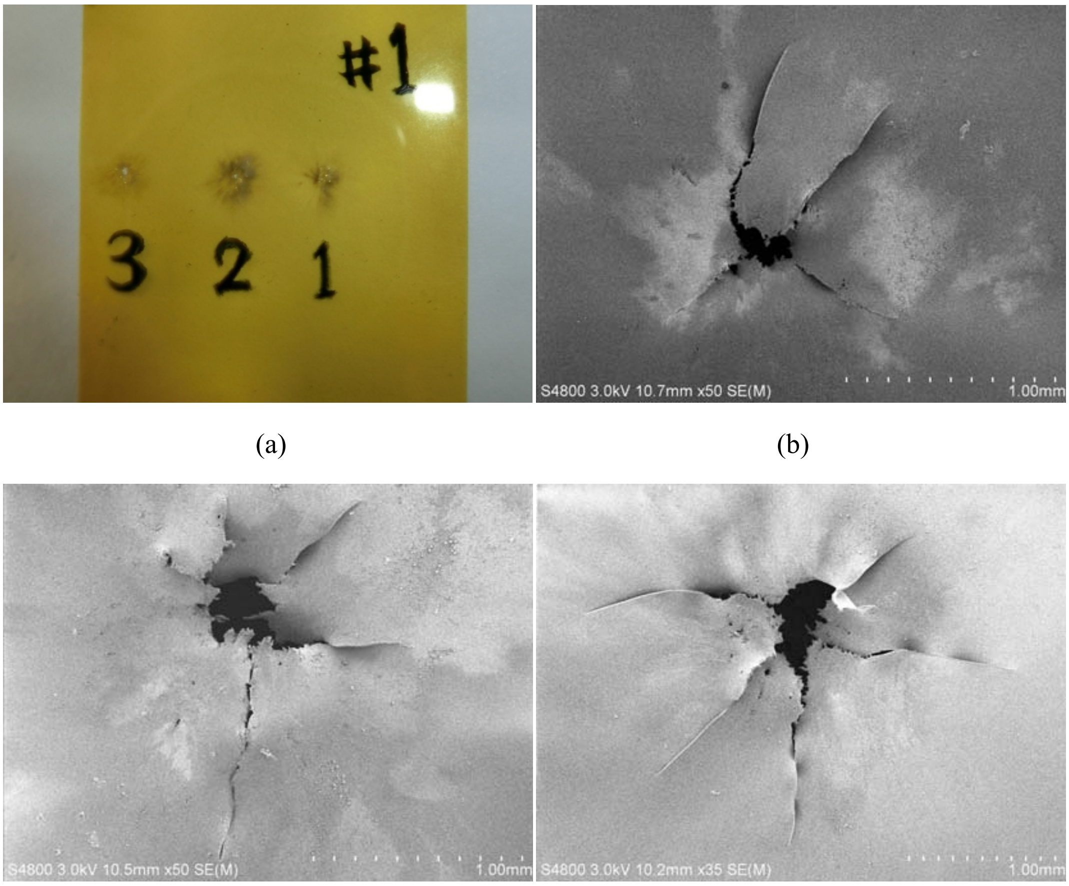



(a) (b)

(c) (d)

Fig.4 SEM images of the 12.5μm polyimide films at different tension stress (flyer velocity of 5.9km/s): (a)0.06MPa; (b)0.27MPa; (c)1.32MPa; (d)5.24MPa

The surface morphology of a 12.5μm-thick polyimide film impacted successively by 3 flyers at the velocity of 5.9km/s is illustrated in Fig.5. The first and the second impact site are 7mm apart, and the distance between the second and the third void is 8.5mm. Distribution of the cracks is different for the three impacts. Size of the fracture region is close, which is about 1.6mm and smaller than the above mentioned distances. Cracks from one impact site do not run through that of another site. That is to say, fracture from locations far enough hardly interacts with each other. It is suggested that cumulative damages induced by multiple impacts will not expand dramatically under the current conditions.




(a) (b)

(c) (d)

Fig.5 The surface morphology of a 12.5μm-thick polyimide film impacted successively by 3 flyers at the velocity of 5.9km/s: (a)three impacts on the sample; (b)the first impact; (c) the second impact; (d) the third impact

## 4. Conclusions

Fracture of unidirectional tensioned polyimide films impacted by the hypervelocity flyers are studied experimentally. Effects of film thickness, tension stress magnitude and impact times are discussed, and the results are summarized as follows:

(1) The central impact region shows a ductile fracture, and the remote radial crack region is characterized by brittle fracture.

(2) The fracture region especially the remote radial crack region increases significantly with the decreasing film thickness.

(3) For the 12.5μm-thick film, the fracture region extends slightly with the increases of the tension stress from 0 to 5MPa.

(4) When the distances between two different impact sites are larger than the fracture regions, cracks from the two sites do not run through another.


## Acknowledgements

This work was supported by the National Natural Science Foundation of China 11672361, 11402282, E050601 and the open foundation of the State Key Laboratory of Structural Analysis for Industrial Equipment, DUT.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