A dynamic testing method for flexible thin film materials

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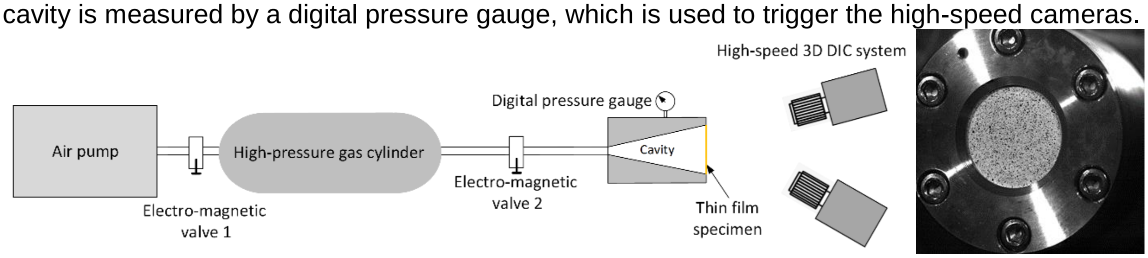
Abstract: The present work developed an experimental system based on inflation system for dynamic testing of thin film materials. Using this system, dynamic deformation of specimen was measured using high-speed 3D digital image correlation (DIC) system, and dynamic load history was measured using high-accuracy pressure gauge. The material parameters were identified using the virtual fields method (VFM). Compared with the current testing method, the present method easily achieved different loading on thin films. Moreover, the wrinkle of specimen during the loading stage was effectively avoided.

Introduction

Owing to the features of light weight, and easy folding, flexible thin film materials are increasingly used in aerospace engineering, for instance, the solar sail and deployable antenna use the flexible thin films materials [1]. These devices are folded inside the rocket cabin before launching and are unfolded when arriving at the scheduled orbit, involving local high-strain-rate deformation during the unfolding process. The numerical modelling of unfolding process of such devices for the reliability design requires accurate material parameters at different strain rates. However, it is well known that many materials in thin film form behave differently from their bulk counterparts [2]. Therefore, it is necessary to carry out dynamic tests of the thin films. So far, different methods were developed to carry out the mechanical tests of such films, e.g., Grünwald et al. used laser ultrasound technique measured Young's modulus and Poisson's ratio of thin film. However, this technique is restricted to measure the elastic parameters and requires complex optical system [3]. He et al. investigated Young's modulus of Kapton film using a micro uniaxial tensile testing and DIC system [4]. However, due to extreme weak compressive strength of flexible film, the specimen is easily wrinkled, leading to high measurement error. Moreover, these methods cannot be used to carry out dynamic testing of thin film. In the present study, a dynamic testing system for flexible thin films was developed. Moreover, the wrinkle of specimen during loading can be effectively avoid.

Experimental setup and measurement

The experimental system for dynamic testing of thin film materials is consisting of a dynamic inflation system and a 3D-DIC system, as illustrated in Fig. 1a. The compressive gas in the cylinder is rapidly released into the cavity where the thin film specimen is sealed at the exit. Different initial pressure in the cylinder achieves different strain-rate loading on the specimen. Dynamic deformation of the specimen is measured by the high-speed 3D-DIC system. The pressure in the cavity is measured by a digital pressure gauge, which is used to trigger the high-speed cameras.



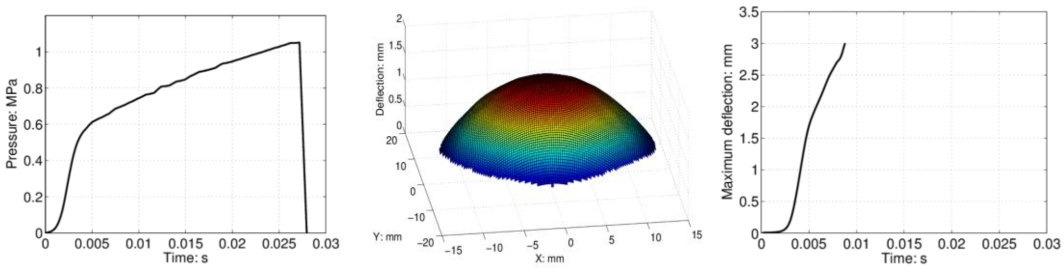
(a) (b)

Figure 1 Dynamic testing system for thin film materials. (a) Schematic. (b)Specimen fixed on the cavity.

A specimen with dimension of (Ø30 mm$\times$ 0.05 mm) was fixed on the cavity and tested using above experimental system, as seen in Fig. 1b. The initial pressure in cylinder was 1.5 MPa. The pressure history in the cavity was measured by the pressure gauge at a speed of 100 kHz. The images of the specimen was acquired using the high-speed cameras at 10,000 fps (896×848 pixels). During the DIC processing, the subset and step sizes were set to 21×21 and 5 pixels, and in-plane and out-of plane strain can be obtained.

Results analysis

Fig. 2a shows the pressure history in the cavity. It can be observed that the specimen was ruptured when the pressure reached around 1.05 MPa. Using the DIC method, out-of-plane displacement of specimen was obtained, as illustrated in Fig. 2b. When displacement is very large, the correlation fails and DIC calculation would be inaccurate. Fig. 2c shows the maximum out-of-plane displacement in each fields during the early stage of loading.



(a) (b) (c)

Fig. 2 Pressure and out-of-plane displacement. (a) Pressure in cavity (b) Out-of-plane displacement of specimen (c) Maximum out-of-plane displacement of specimen.

Using full-field deformation fields and the related force or pressure, it is possible to identify the material parameters using some inverse strategies. In the present work, the VFM was used, which is based on the principle of virtual work without inertial effect consideration as [5]

$$\int_{V_m} \boldsymbol{\sigma} : \boldsymbol{\varepsilon}^* dV = \int_{S_m} \boldsymbol{T} . \boldsymbol{u}^* dS \quad (1)$$

where $\boldsymbol{\sigma}$ represents the Cauchy stress tensor containing the unknown constitutive parameters, $\boldsymbol{T}$ the pressure acting on the boundary surface S_m, $\boldsymbol{u}^*$ and $\boldsymbol{\varepsilon}^*$are the virtual displacement and virtual strain fields. Eq. 1 is established based on the plane stress assumption. Although, for the present case, data in the global coordinate system does not fulfils this assumption; however, it is satisfied in the local coordinate system. Therefore, strain fields should be transformed into the local coordinate system before the parameter identification [6]. Elastic and plastic parameters can be identified using the VFM method.

Conclusion

The present work developed an experimental system for dynamic testing of thin films. Compared with the current method, the wrinkle of specimen during the loading stage can be effectively avoid. Moreover, different strain-rate loading on the thin films can be achieved. Using the VFM method, elastic and plastic parameters can be identified from the full-field deformation measurements. More details about this work will be presented on the conference.

References

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