Dynamic mechanical properties of flexible polydimethylsiloxane subjected to impact loading

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Abstract

This paper presents the experimental study on the dynamic mechanical properties of the flexible polydimethylsiloxane (PDMS) species through axial compressive impact loading testing by using a split Hopkinson pressure bar (SHPB). Meanwhile, dynamic responses are investigated by finite element method simulation. The strain rate effect and dynamic responses on the flexible PDMS under impact loading are discussed in details. It can be seen that the dynamic stresses of flexible PDMS increase with the increase of impact loading and strain rate. All the dynamic compressive stress-strain curves show similar characteristics under various impact loading. The dynamic stress-strain behavior of the flexible PDMS has apparent strain rate effect. In addition, the dynamic responses occur mainly in the impact loading direction. The amplitudes of dynamic displacement, velocity and acceleration responses on the flexible PDMS increase as the strain rate increase. The displacement responses occur earlier for the bigger strain rate. The velocity responses appear a kind of platform area. The acceleration responses oscillate sharply. These preliminary findings are believed to build the foundation for future research on the impact mechanical properties of flexible electronic devices and provide design guidelines for flexible devices in engineering practice.

1. Introduction

Flexible and stretchable inorganic electronics have received considerable attention in both industry and academe for their applications in electronic products, medical field, and ductile battery devices, mainly including foldable silicon integrated circuits [1], electronic eye camera [2-5], multifunction medical catheter, electronic skin [6,7], and extensible flexible human health detector. Compared with the organic electronics, flexible and stretchable inorganic electronics are fabricated with the inorganic semiconductor functional elements and flexible substrates. Therefore, flexible and stretchable inorganic electronics possess excellent electrical and mechanical properties and exhibit highly elastic behavior when subjected to large deformation.

As the key component, the flexible substrate determines the mechanical performance of the flexible inorganic electronics. The ideal substrate should be physically and thermally stable to make it suitable for all applications. Among all the possible candidates, polydimethylsiloxane (PDMS) has been widely adopted as a substrate material for manufacturing lab-on-a-chip and micro total analysis systems， due to its hyperelasticity and biocompatibility. A considerable number of studies have been conducted on the mechanical properties of PDMS to date. On the aspect of static and quasistatic mechanical properties of PDMS, there are many literatures for reference. However, to the authors' best knowledge, most of these studies focused on the quasistatic response, while minimal attention was given to dynamic mechanical properties and responses of the soft PDMS for impact protection of stretchable device subject to impact loading.

In this study, we utilize an SHPB experimental device to investigate the dynamic behavior and response of soft PDMS for impact protection of stretchable device. The strain rate effects and dynamic response of flexible PDMS subject to impact compression loading are discussed. The dynamic responses of flexible PDMS are also presented in terms of the finite element method (FEM).

2. Dynamic behavior and respnses of flexible PDMS

The dynamic compressive stress-strain curves of the flexible PDMS samples obtained by SHPB testing and FEM simulations are plotted in Fig.1. It can be seen that dynamic stresses increase with the increase of impact loading. All the dynamic compressive stress-strain curves show similar characteristics. It is a nearly linear region where the axial strain is less than 4%. Then the stress stays nearly constants with increasing strain until the strain reaches ~15%. Again, the stresses are increased with increasing the strain. At the earlier of loading, the dynamic strains obviously increase with the slight increase of dynamic stresses, while the dynamic strains slightly increase with the strong increase of dynamic stresses at the mid-term of loading, until the peaks of dynamic stresses appear. There is a significant increase in the stress level at a given strain of the PDMS as the strain rate is increased from about 5000 s−1 to 7700 s−1 range. The dynamic stress-strain behavior of the flexible PDMS is clearly strain rate dependent. It can be also seen that the simulated results are in good agreement with those of SHPB testing. Therefore, the FEM model shown in section 2.2 can be used as simulating the dynamic responses of flexible PDMS furthermore.

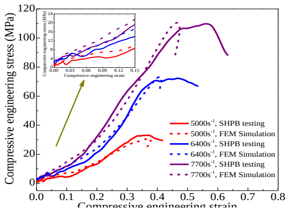

Fig. 1 Stress-strain relations of the 3.12 mm-thick PDMS sample by SHPB testing and FEM simulation at different strain rates.

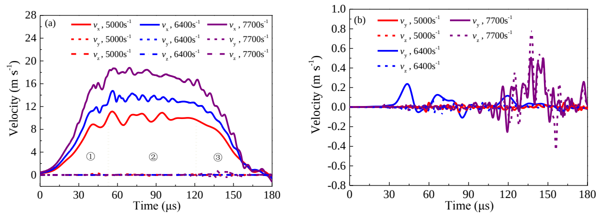

Fig. 2 Velocity responses of central point on the surface of PDMS in the (a) X-axis; Y-axis and Z-axis directions; (b) Y-axis and Z-axis directions in FEM simulation.

Fig. 2(a)–(b) show that the amplitudes of velocity response are bigger in the X-axis direction than those of the Y-axis and Z-axis directions. The velocity responses appear a kind of platform area, the amplitudes of which keep almost unchanged for a long response time. The response amplitudes increase clearly with the increase of strain rate in the X-axis direction. While, the velocity responses occur later at the Y-axis and Z-axis directions, which are in the state of oscillation.

3. Concluding remarks

The dynamic mechanical properties of flexible PDMS samples under impact compression are investigated by SHPB testing and FEM simulation. The strain rate effect, stress wave velocity, and dynamic responses on impact loading are discussed in details. It can be seen from the experimental testing and simulation results that the dynamic stresses of flexible PDMS samples increase with the increase of impact loading and strain rate. All the dynamic compressive stress-strain curves show similar characteristics under various impact loading. At the earlier of loading, the dynamic strains obviously increase with the slight increase of dynamic stresses, while the dynamic strains slightly increase with the strong increase of dynamic stresses at the mid-term of loading, until the peaks of dynamic stresses appear. Clearly, the dynamic stress-strain behavior of the flexible PDMS has a strain rate effect.

References

[1] D. H. Kim, J. H. Ahn, W. M. Choi, Stretchable and Foldable Silicon Integrated Circuits, Science, 320 (2008) 507-511.
[2] H. C. Ko, M. P. Stoykovich, J. Song, A Hemispherical Electronic Eye Camera Based on Compressible Silicon Optoelectronics, Nature, 454 (2008) 748-753.
[3] I. Jung, J. Xiao, V. Malyarchuk, C. Lu, M. Li, Dynamically Tunable Hemispherical Electronic Eye Camera System with Adjustable Zoom Capability, Proc. Natl. Acad. Sci. U. S. A., 108 (2011) 1788-1793.
[4] Y. M. Song, Y. Xie, V. Malyarchuk, J. Xiao, Digital Cameras with Designs Inspired by the Arthropod Eye, Nature, 497(2013) 95-99.
[5] S. I. Park, Y. Xiong, R. H. Kim, P. Elvikis, Printed Assemblies of Inorganic Light-Emitting Diodes for Deformable and Semitransparent Displays, Science, 325 (2009) 977-981.
[6] R. C. Webb, A. P. Bonifas, A. Behnaz, Y. Zhang, Ultrathin Conformal Devices for Precise and Continuous Thermal Characterization of Human Skin, Nat. Mater., 12 (2013) 938-944.
[7] S. Xu, Y. Zhang, L. Jia, K. E. Mathewson, Soft Microfluidic Assemblies of Sensors, Circuits, and Radios for the Skin, Science, 344 (2014) 70-74.