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Quasi-static and Dynamic Poisson's Ratio Evolution of Hyperelastic Foams

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Abstract

Poisson's ratio of soft, hyperelastic foam materials such as silicone foam is typically assumed to be both a constant and a small number near zero. However, when the silicone foam is subjected to large deformation into densification, the Poisson's ratio may significantly change, which warrants careful and appropriate consideration in modeling and simulation of impact/shock mitigation scenarios. The evolution of the Poisson's ratio of foam materials has not yet been characterized. In this study, radial and axial measurements of specimen strain are made simultaneously during quasi-static and dynamic compression test on a silicone foam. The Poisson's ratio was found to exhibit a transition from compressible to nearly incompressible based on strain level and reached different values at quasi-static and dynamic rates.

Keywords: silicone foam, Poisson's ratio, Kolsky bar, material behavior

Introduction

Hyperelastic foams such as silicone foam characteristically exhibit a non-linear elastic stress-strain response when subjected to large compressive deformation. Because hyperelastic foams have excellent energy absorption capability and can experience full recovery following impact loading, such foams are used in shock, vibration, and thermal isolation schemes. With increasing efforts to model shock isolation, accurate computational models require the experimental input of intrinsic material parameters that must be measured at relevant loading rates. While compressive and tensile stress-strain response under quasi-static and dynamic loading rates are often characterized, Poisson's ratio is another important parameter to describe the volume compressibility of a material. Poisson's ratio is often treated as a constant for different materials. At small strains, foams may be treated as compressible solids. However, since the response of hyperelastic foam is highly nonlinear at large deformation and drastically hardens after densification, Poisson's Ratio has been found to vary with specimen strain [1, 2] and cannot be treated as a constant. Under large deformation into densification, the Poisson's ratio of foam materials may approach a nearly incompressible rubbery state. Limited information on the transition of compressibility of foam materials is available in the literature. Because the properties of hyperelastic foams are dependent upon temperature, stress state, and strain rate, etc, the Poisson's ratio may not be assumed to be a constant over all loading rates. In this study, the Poisson's ratio of a hyperelastic silicone foam was experimentally measured under quasi-static and dynamic loading rates at large deformation into densification. The quasi-static and dynamic Poisson's ratios were compared to understand rate effects. These results can be used to improve rate-dependent material models of hyperelastic foams subjected to large deformation at low or high strain rates.

Experiments and Results

Experimental measurement of Poisson's ratio at quasi-static rate was conducted with a custom setup while measurement at dynamic rates was conducted using a Kolsky compression bar. At quasi-static rates, a laser-based radial displacement sensor was used to capture the radial deformation. At high strain rates, a high-speed camera was used to image the deformation from which radial and axial strain measurements were taken. Frame rates for dynamic experiments ranged from 250,000 frames per second (FPS) for to 650,000 FPS depending on strain rate.

Using axial and radial strains obtained during experiments, the Poisson's ratio was calculated and are shown as a function of engineering strain along with the engineering stress-strain behavior in Fig. 1. At quasi-static strain rate, the Poisson's ratio had a nearly constant value of 0.22 until axial engineering strain of 0.5, then drastically increased to another constant value of 0.47 at axial engineering strain of 0.6 or larger. At high strain rate, Poisson's ratio started with a constant value of 0.21 until an axial engineering strain of approximately 0.45 was reached, whereupon a transition occurred over axial engineering strains of 0.45 and 0.55. Above an axial engineering strain of 0.55, the Poisson's ratio reached another constant value of 0.43. Under both quasi-static and dynamic strain rates, the transition in Poisson's ratio coincided with the onset of densification. Although significant strain rate effect in Poisson's ratio was not seen, some difference was observed. While experimental error might contribute to such a difference, another possibility is that under dynamic compression the silicone foam may be subjected to lateral confinement caused by radial inertia stress after densification. The difference could also be linked to a strain rate effect on densification.

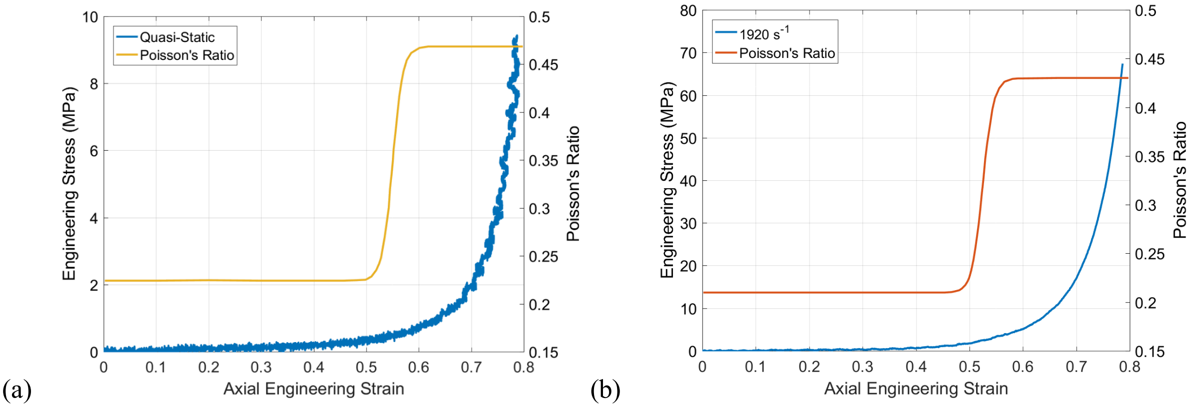

Figure 1. (a) quasi-static stress-strain and Poisson's ratio, (b) dynamic stress-strain and Poisson's Ratio

Summary

In this study, the strain-rate dependent behavior of Poisson's ratio for a hyperelastic silicone foam material was explored. Quasi-static and dynamic compression experiments were conducted and the Poisson's ratio was calculated using the radial-axial true strain relationship of the material and was described using a Boltzmann sigmoidal function. At low axial engineering strain at both strain rates, the material was compressible and had a value of approximately 0.21-0.22. The material underwent a transition in Poisson's ratio that coincided with the onset of densification and reached a value of 0.47 for quasi-static and 0.43 for dynamic rate. This shows that the Poisson's ratio of hyperelastic foams must be represented as a function of densification and may result in a significant change of radial inertia behavior under dynamic compression which must be adequately addressed in material models of foams.

References

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