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Effect of Pre-Strain on Impact Energy Dissipation in Silicone Foam Using Frequency-Based Kolsky Bar Analyses

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Introduction

Silicone foams have been used in a variety of applications such as thermal isolation, vibration reduction, and shock mitigation materials [1-3]. Polymeric foams such as silicone foam exhibit significant effects from strain rate, temperature, and stress-state on the mechanical response [4, 5], which can consequently determine their shock mitigation performance against impacts, shocks, or explosions. Silicone foams can also be subjected to preload during assembly processes, which may also result in a change in shock mitigation performance of assembled components.

To maximize shock mitigation performance, it is generally best to maximize the shock energy absorption and minimize the transmitted force and acceleration. The total amount of energy that can be absorbed by a foam material is typically calculated using the area under the stress-strain curve prior to densification of the foam [4]. The main shortcoming of this method is that it does not provide any information regarding the sensitivity of absorbed energy to frequency, which is critical to predict the survivability and functionality of encapsulated components. Song and Nelson [6] used Kolsky compression bar techniques to develop a frequency-based analysis to study the frequency response of impact energy absorption of a polymethylene diisocyanate (PMDI) based rigid polyurethane foam. Their results showed that above a characteristic frequency of 1.5 kHz, nearly all impact energy was absorbed by the PDMI foam. While this experiment was conducted under uniaxial stress conditions, the characteristic frequency might depend on stress-state and preload conditions [6].

No experiments have been conducted to investigate pre-strain effect on shock mitigation in silicone foams, particularly in the frequency domain. Additionally, the influence of pre-strain under a multiaxial stress-state has not been investigated, which simulates preloads that may be imposed during the assembly process. In this study, a Kolsky compression bar has been modified with preload and passive triaxial confinement capabilities to study the energy dissipation behavior of a silicone foam subjected to multiple pre-strains. The silicone foam samples were laterally confined and pre-strained to different levels before dynamic loading. Frequency-based analyses [6] were applied to characterize the frequency response and shock mitigation capability of the silicone foam pad.

Materials and Specimens

The material investigated in this study was open cell silicone foam with a non-compressed density of 608 ± 21.85 kg/m^3. The silicone foam, which had an average cell size of ~0.5 mm, is a highly flexible and compressible foam material. Experiments were conducted at pre-strains of 0, 13, 23.3, and 33.5 % engineering strains, respectively. Three experiments were conducted at each condition. A specimen was also reloaded five times after an initial loading to determine the effect of repeated loading on the shock mitigation performance.

Given magnitudes Fourier transforms of the incident, reflected, and transmitted pulses, $B_i(f)$, $B_r(f)$, $B_t(f)$, respectively, the energy dissipation ratio δ(f) in the frequency domain is calculated using

$$\delta(f) = 1 - \frac{|B_t(f)|^2}{|B_i(f)|^2 - |B_r(f)|^2} \quad (1)$$

Results and Discussion

Silicone foam was found to dissipate energy across the full spectrum of input frequency. Figure 1 shows the frequency spectrum of energy dissipation ratio through the silicone foam pre-strained to 33.5% engineering strain. The initial energy dissipation ratio is 0.995 until a cutoff frequency of 2.65 kHz is reached, where the energy dissipation ratio is nearly 1, representing full dissipation. These results highlight the extreme efficiency of silicone foam at dissipating applied energy, even at low frequencies. While the boundary conditions and impact speed of the experiments on PDMI foam were different, Song and Nelson [6] showed less energy dissipation at low frequencies with an initial energy dissipation ratio of 0.87 and full dissipation reached 1.5 kHz. In other words, even though the silicone foam in this study was pre-strained to 33.5% engineering strain, silicone foam displayed much better shock mitigation across the frequency spectrum compared to the PDMI foam.

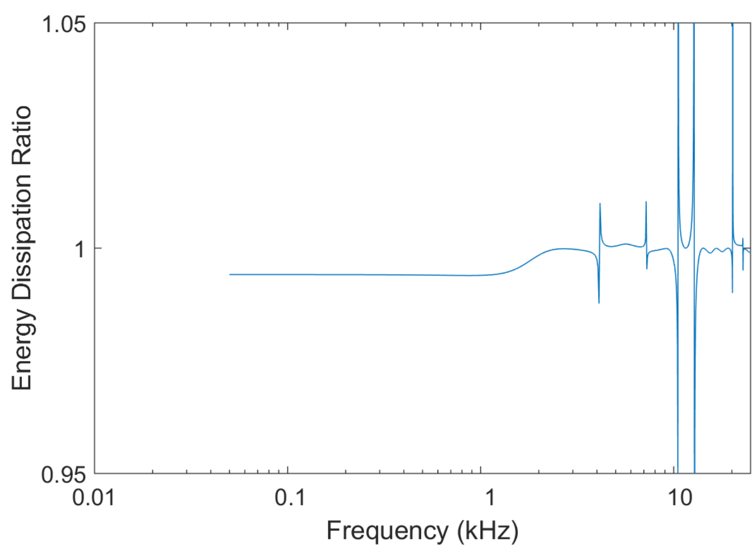

Fig. 1. Energy dissipation ratio of a 33.5% pre-strained silicone foam sample

As is shown in Fig. 1, when the silicone foam was pre-strained to 33.5%, 99.5% of the low-frequency energy was dissipated, whereas even smaller amounts of pre-strain were applied as is shown in Fig. 2. The total energy dissipation approaches 1 with reductions of pre-strain. It can also be observed that the cutoff frequency shifts with reductions of pre-strain; at 13% pre-strain, the cut-off frequency drops from 2.65 kHz to 2 kHz. Nearly all energy at all frequencies was dissipated when the silicone foam was not pre-strained.

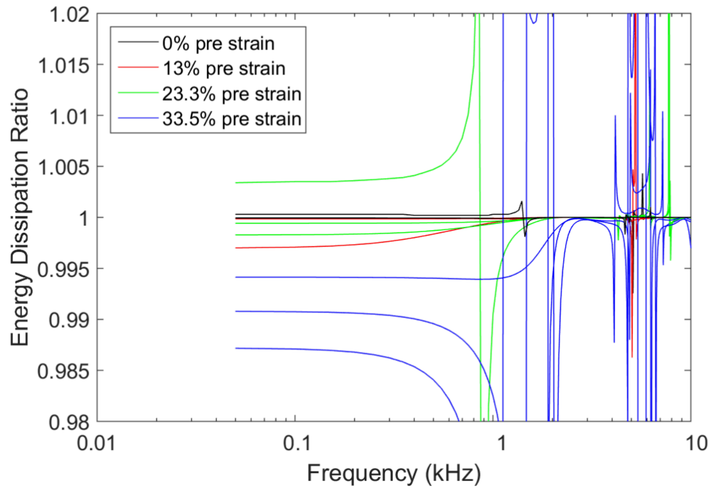

Fig. 2. Energy dissipation behavior as a function of pre-strain and frequency for silicone foam

Conclusion

Silicone foam was found to be an excellent material for dissipating impact energy across a range of input frequencies up to about 10 kHz. The laterally confined and pre-strained specimens gave an accurate representation of a real application where silicone foam is used to mitigate impact energy to components. The methods presented here can be used to investigate specific applications for different levels of pre-strain and impact speeds.

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