3P4-1

Stress dependence of the ultrasonic wave propagation characteristics in silicone rubber subjected to repeated tensile loading

繰返し引張負荷を受けたシリコーンゴムにおける超音波伝搬特性の応力依存性

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1. Introduction

Ultrasonic measurements offer an effective means to evaluate the mechanical properties of polymeric materials. For some types of polymers such as elastomers which show large strains, it is expected that the ultrasonic wave propagation characteristics are strongly influenced by their deformation and stress states. The stress dependence of ultrasonic wave velocities is known as the acoustoelastic effects(1), which are attributed to the nonlinear stress-strain relation of the solid. While these effect have been studied extensively for memetallic materials, the corresponding studies for elastomers are relatively limited.(2) Understanding of these effects in elastomers under large strains is beneficial for nondestructive characterization of the material properties, and may lead to the control of ultrasonic waves by applied stresses. In this study, the ultrasonic wave propagation characteristics in silicone rubber subjected to uniaxial tensile loading/unloading cycles are experimentally studied. In particular, it is examined how the stress dependence of the ultrasonic wave velocity varies with the repeated tensile loading cycles.

2. Experimental procedure

A schematic view of the experimental setup is shown in **Figure 1**. A strip specimen of as-received silicone rubber (hardness A70, Tigers Polymer Corp., dimensions 240 mm × 24.8 mm × 4.89 mm) was attached to a tensile testing machine, and the tensile loading was applied between 0 N and 200 N in 13 cycles. Each cycle consisted of loading/unloading of the specimen at the crosshead speed of 10 mm/min with the holding time of 60 seconds at 0 N and 200 N. In the first, 11th, 12th and 13th cycles (referred to as Cycles 1, 11, 12 and 13), the tensile load was held constant for 60 seconds at every incremental load of 10 N during the loading or unloading to perform the ultrasonic measurements. The process of loading/unloading cycles is shown in **Figure 2**, where the load is converted to the nominal stress using the cross-sectional area of the strip measured before the experiment. The holding times were increased to 80 minutes and 20 hours for the intervals between Cycles 11 and 12 and between Cycles 12 and 13, respectively, in order to examine the variation of the ultrasonic properties with the elapsed time after the preceding loading cycle.

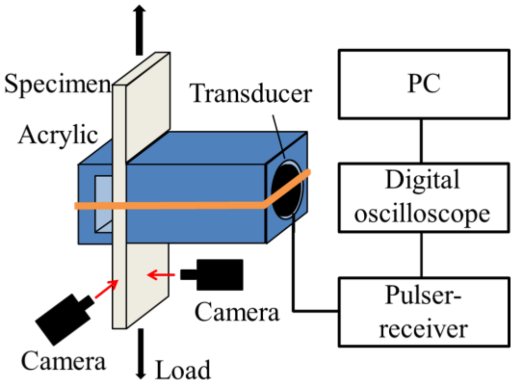

Fig. 1 Schematic of experimental setup.

During the holding time at each load for the ultrasonic measurements, digital photographs of the specimen were taken using two CMOS cameras. The dimensions of the specimen in the axial and the

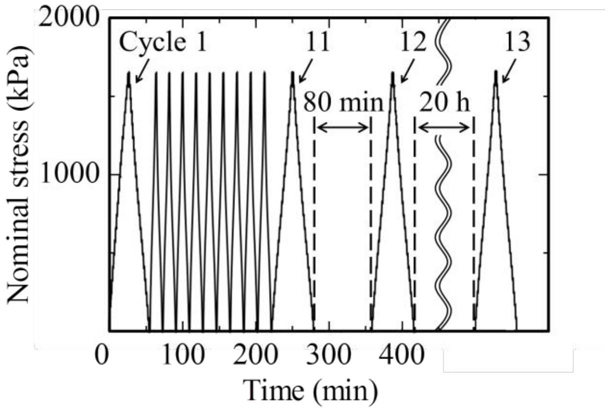

Fig. 2 The process of loading/unloading cycles.

other two perpendicular directions were then obtained from the number of pixels, and the stretch ratios were determined with correction for the effect of variation of the distance between the cameras and the specimen by the deformation.

In the ultrasonic measurements, a Panametrics pulser-receiver 5072PR was used to excite a piezoelectric transducer (nominal center frequency 2.25 MHz) to emit an ultrasonic wave pulse to the specimen in the direction perpendicular to the loading direction, via an acrylic block which acted as a delay medium. The reflected wave was recorded with the same transducer and stored in a PC as a digital waveform. The recorded waveform contains two echoes which are reflected at the front and back surfaces of the specimen. The wave velocity was calculated from the time difference of two echoes and the thickness of the deformed specimen determined from the digital images.

3. Results and discussion

The recorded waveforms are shown in **Figure 3** at two different nominal stresses in Cycles 1 and 13. It is seen in Figure 3 that the attenuation of the ultrasonic wave increased with the loading cycles, and with the stress in each loading cycle. The ultrasonic wave velocity in the specimen is shown in **Figure 4** as a function of the applied nominal stress in different loading cycles. For some ranges of stress in each cycle, the velocity data is not shown since the wave attenuation was too high to quantify the wave velocity.

Figure 4 clearly shows the effect of loading cycles on the wave velocity. Namely, while in Cycle 1 the wave velocity is almost constant in a low-stress range and starts to decrease remarkably above 1000 kPa, such threshold behavior is not so evident in Cycles 11, 12 and 13, where the wave velocity starts to decrease at lower stresses. Furthermore, the results also indicate the effect of elapsed time after the preceding loading on the wave propagation characteristics. Namely, as compared to the decrease of wave velocity with the stress in Cycle 11, the velocity changes in Cycles 12 and 13 are relatively small due to the elapsed times of 80minutes and 20 hours, respectively.

The stretch ratios of the specimen in Cycles 1 and 13 are shown in **Figure 5**. It is seen that the static stress-stretch relation of silicone rubber also changed by the loading cycles. This could be correlated to the change in the ultrasonic properties. It is the subject of our future study to examine the static stress-stretch relation as well as the wave propagation characteristics of elastomers based on the theory of compressible hyperelastic solids.

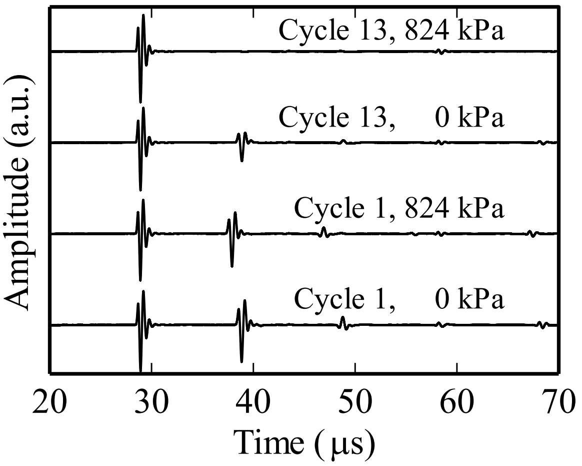

Fig. 3 Measured reflection waveforms in Cycles 1 and 13.

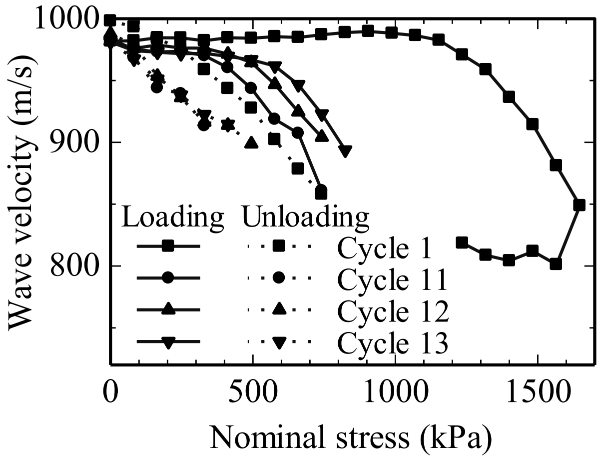

Fig. 4 Variation of the wave velocity with the nominal uniaxial stress.

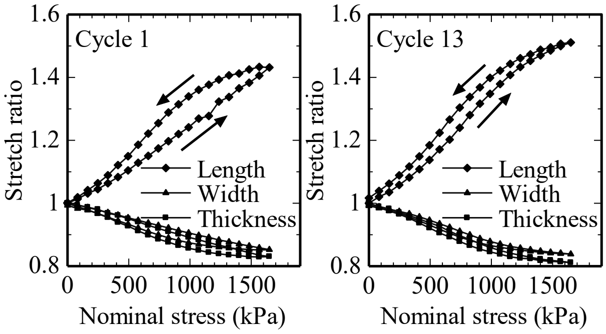

Fig. 5 Variation of the stretch ratios with the nominal uniaxial stress in Cycles 1 and 13.

References

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2. H. Kobayashi and R. Vanderby, J. Appl. Mech., 72 (2005), 843-851.