Resiliency of Silicone O-Rings

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ABSTRACT: The recovery of silicone o-rings after 23% compression at room temperature (22°C) was determined. Two sets of experiments were performed. To determine the effect of temperature on resiliency, the recovery of o-rings that had been compressed for 24 h at room temperature was measured at both 22°C and −7°C. To determine the effect of storage under compression on resiliency, the recovery at 22°C of o-rings compressed at room temperature for 6 months or 1 year was compared with those compressed for 24 h. In addition, the effect of a silicone lubricant on the recovery of the o-rings was determined. The initial room temperature recovery of silicone o-rings after being compressed for 6 months is somewhat slower than those compressed for 24 h. There is very little change in the recovery of the o-rings compressed for 1 year compared with those compressed for 6 months. Recovery after 24 h of compression is slower at −7°C than at 22°C. Silicone oil lubricant appears to aid recovery after 24 h of compression but has little effect after 6 months or 1 year of compression. © 2009 Wiley Periodicals, Inc. J Appl Polym Sci 114: 843–846, 2009

Key words: aging; elastomers; o-rings; resiliency; silicones

INTRODUCTION

O-rings are one of the simplest and most ubiquitous of mechanical sealing methodologies. The o-ring itself is an elastomeric polymer that is placed in a carefully machined gland that compresses it to a predetermined amount. This compression produces contact stresses that prevent leakage. The gland must be of a very precise size and geometry to assure optimum sealing.[1–3] One of the known limiting factors in o-ring utility is that in some situations the size and /or geometry of the gland may be suddenly changed to a suboptimum condition by impact, pressure spike, vibration, or other sudden event. When one or more of these events occur, in some cases long after the o-ring is installed, the necessary contact stresses can only be maintained by the o-ring's resiliency or speed of recovery.[4–7] This resiliency is a function of the o-ring material, the amount of time the o-ring has been compressed, and the temperature of the o-ring at the time of recovery.

Silicone o-rings are used in a wide variety of applications because of their superior resiliency, especially at temperature extremes.[8,9] To better understand the rates at which silicone o-rings can respond to sudden changes in gland configuration,[10,11] this paper examines the resiliency of silicone o-rings that have been compressed at room temperature. Two sets of experiments were performed. To determine the effect of temperature on resiliency,[12,13] the recovery of o-rings that had been compressed for 24 h at room temperature was measured at both 22°C and −7°C. To determine the effect of storage under compression on resiliency, the recovery at 22°C of o-rings compressed at room temperature for 6 months or 1 year was compared with those compressed for 24 h.

EXPERIMENTAL

Silicone o-rings were purchased from Parker Seals (Lexington, KY; part no. S1224-2-395, compound S1224-70). The o-rings are orange-rust colored, and x-ray diffraction studies in our laboratory found that the silicone polymer is filled with quartz (SiO_2) and hematite (Fe_2O_3) particles. The o-ring diameters were 63.5 cm with a cross-sectional diameter of 5.33 mm. The manufacturer certifies a Shore A hardness of 67, a specific gravity of 1.41, a tensile strength of 7 MPa (1023 psi), and a modulus of 3.2 MPa (466 psi). Polydimethylsiloxane silicone oil (500 cs) from QPL Corporation (Thibodaux, LA) was used as a lubricant on some of the test specimens.

One-inch lengths of o-ring were compressed 23% (1.23 mm) for 24 h, 6 months, or 1 year at room temperature (22°C). A diagram of the compression fixture used is shown in Figure 1. The top of the compression fixture was held down with four screws that were removed when the compression fixtures were

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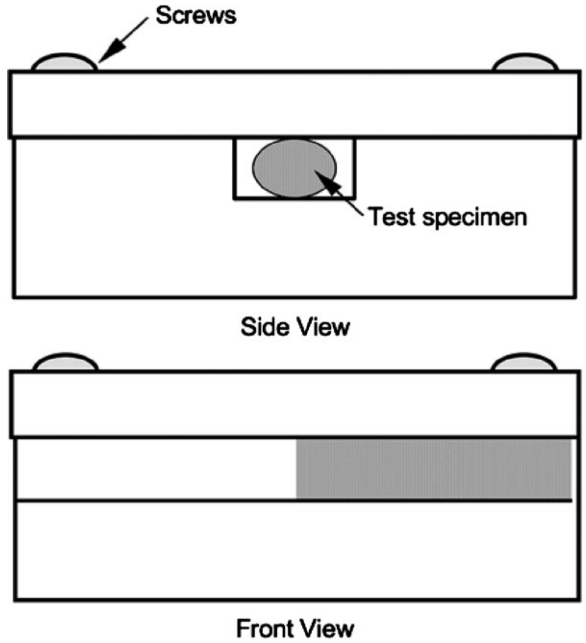

Figure 1 Compression fixture.

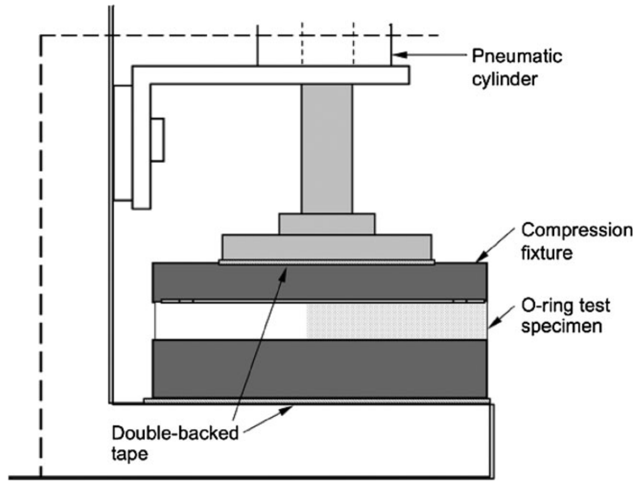

Figure 3 Test stand configuration (front view).

placed in the test stand as described below. The o-rings were either not lubricated or lubricated with a thin coating of silicone oil. The sides and ends of the o-ring samples were not constrained.

Recovery data were acquired at −7°C and 22°C after 24-h compression and at 22°C after 6-month or 1-year compression. Figures 2 and 3 show the test stand configuration. A pneumatic cylinder (Norgren model RLD01A-DAP-NA00; Norgren, Littleton, CO) operating at 8 atm was used to hold the compression fixture closed during the removal of the four screws. A solenoid valve (ASCO model UB4018101; ASCO® Valve, Florham Park, NJ) was then triggered that lifted the top plate of the compression fixture, thus allowing the o-ring samples to expand. The top plate lifted away from the o-ring samples within 8 ms. A high-speed camera manufactured by Photron (San Diego, CA; model no. 1024-Fastcam-PCI) operated at 500 frames/s was triggered at the same time as the top plate lifted and used to record recovery of the o-ring specimen. Data were collected for 2 s (1000 frames). Individual image frames from the high-speed camera were then analyzed to determine recovery as a function of time. For the −7°C tests, the compression fixture (mounted in the test stand) was packed with dry ice and a type "K" thermocouple was mounted in the compression fixture just below the o-ring specimen. When the temperature of the compression fixture stabilized at the target temperature, the pneumatic cylinder and camera were triggered.

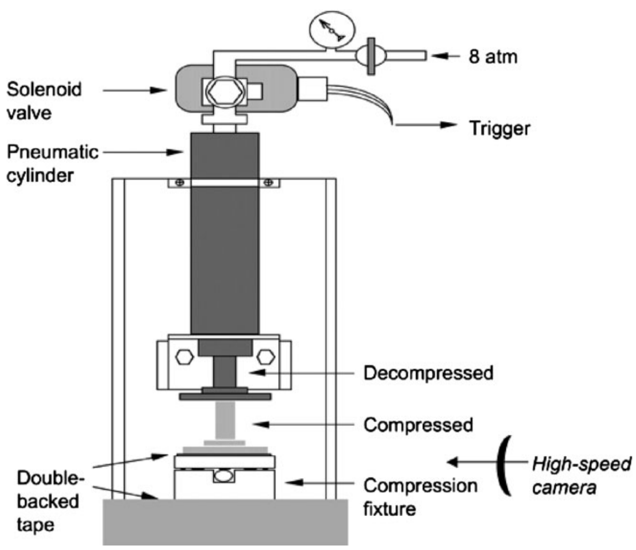

Figure 2 Test stand configuration (side view).

Figure 4 shows a typical image frame from the high-speed camera. This frame, taken after compression release, shows the orange recovering o-ring inside the compression fixture as well as the scale used for calibration. Because recovery can vary along the length of the sample, recovery values of at least four axial locations were measured for each frame and then averaged. The recovery data presented in Figures 5 through 10 are the averages of 7 to 10 individual experiments. Data uncertainty is estimated to

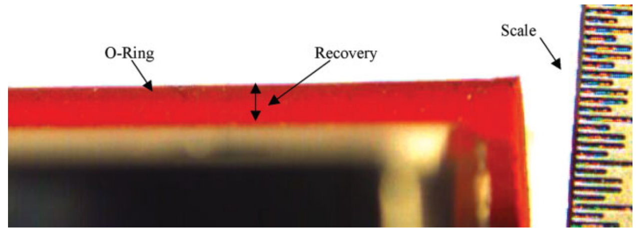

Figure 4 Typical frame from high-speed camera used to measure o-ring recovery. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

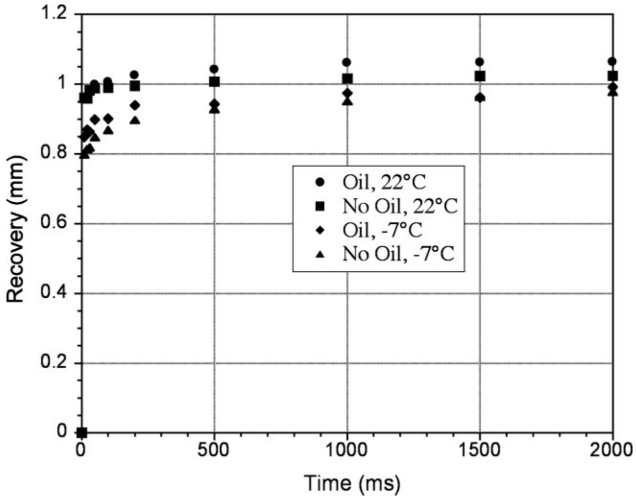

Figure 5 Recovery of silicone o-ring after 24 h of compression.

be ±0.03 mm. The errors accrue primarily from the resolution of the high-speed photographs.

The glass transition temperatures (T_gs) of as-received o-rings as well as o-rings compressed for 2 years at room temperature (with and without silicone oil lubricant) were measured by dynamic mechanical analysis (DMA) (TA Instruments, New Castle, DE; model 2980), using the single cantilever vibration mode (1 Hz, 0.02 mm displacement, 5°C/min heating rate). The loss moduli of the three specimens were compared.

RESULTS AND DISCUSSION

Figure 5 shows the recovery of the o-ring specimens after being compressed 23% (1.23 mm) for 24 h. Recovery is very fast, illustrating the good resiliency of silicone o-rings. After 1 s, the o-rings recover to about 80% of their initial cross-sectional diameter. There is a noticeable difference in initial recovery between 22°C and 7°C. As expected, the cold specimens initially responded measurably slower than those tested at room temperature. However, after about 1 s, the recovery values at the two temperatures are similar. Figure 6 focuses on the first 200 ms of the tests and adds error bars to the data points. The figure illustrates that most of the recovery occurs within the first 50 ms. There is some difference at both temperatures between the specimens that have been lubricated with silicone oil and those that have not. The lubricated specimens appear to recover slightly faster.

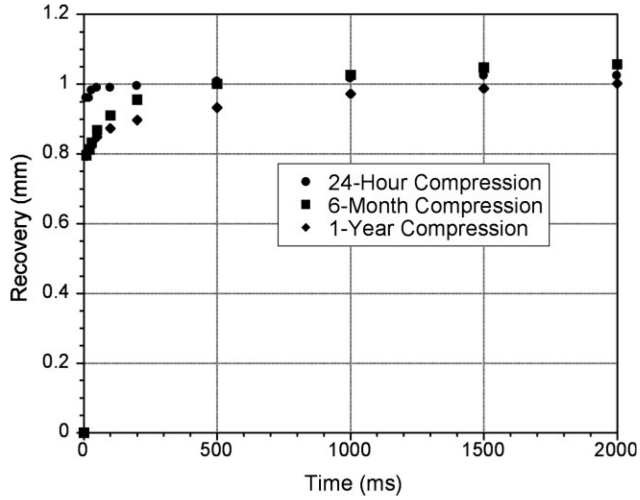

Figure 7 Recovery of silicone o-rings at 22°C; no oil.

Figures 7 through 10 add data points from the 6-month and 1-year tests to the room temperature 24-h compression data seen in Figures 5 and 6. The interesting observation here is that 6 months of compression results in slower initial recovery times than

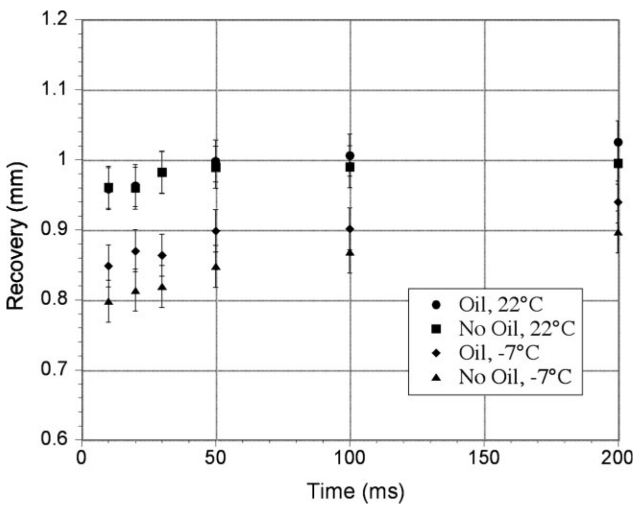

Figure 6 Initial recovery of silicone o-rings after 24 h of compression; expanded ordinate, error bars.

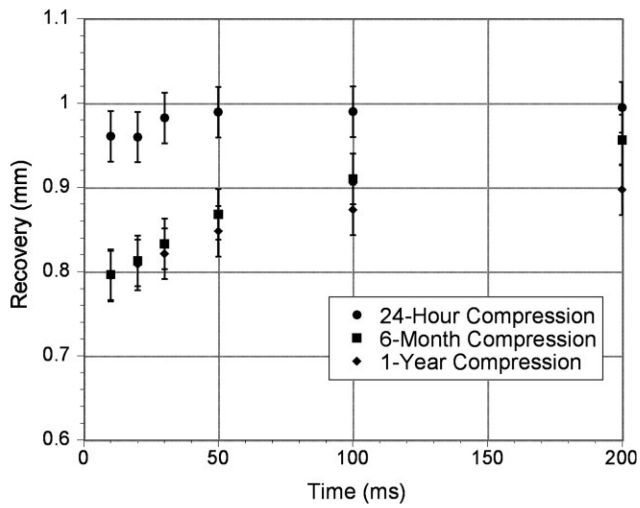

Figure 8 Initial recovery of silicone o-rings at 22°C; no oil; expanded ordinate, error bars.

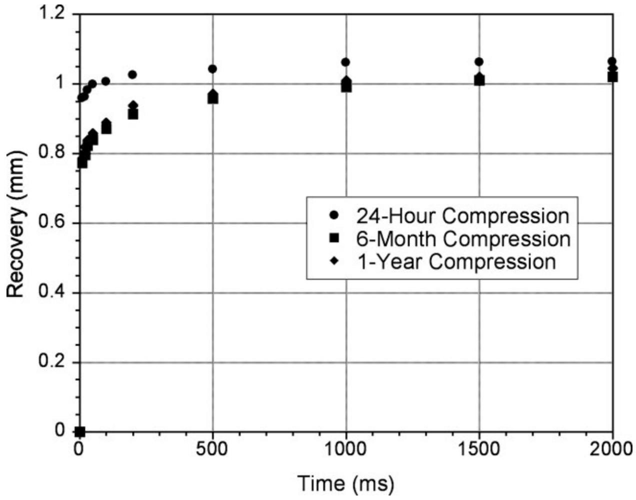

Figure 9 Recovery of silicone o-rings with oil at 22°C.

24 h of compression, but initial recovery after 1 year of compression is quite similar to that seen in the 6-month specimens. Recovery after about 1 s is similar for 24 h, 6 months, or 1 year of compression. This indicates that compression times of more than 1 year will probably not result in greatly reduced recovery times compared with 6 months. Comparing Figures 7–9 and 8–10 shows that the presence of oil on the longer-term specimens does not have the same level of influence as it does on the 24-h specimens. This may be due to the oil migrating out of the compression fixture during storage. The ends of the grooves in the compression fixtures were not sealed, and no special efforts were made to contain the oil. Alternatively, the oil could have diffused into the o-rings, thereby making it unavailable to act as a lubricant.

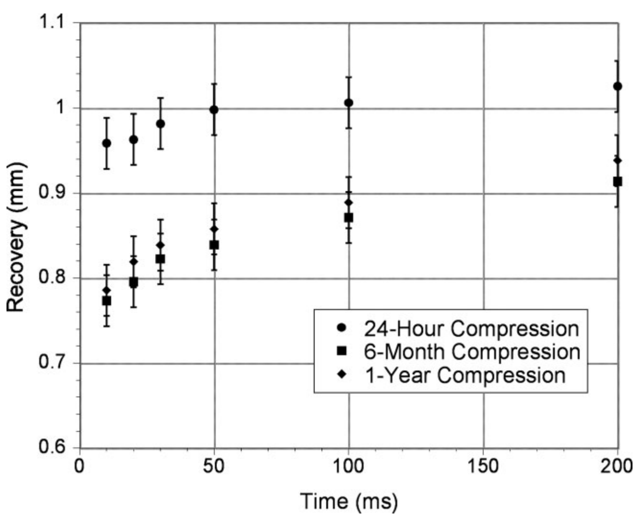

Figure 10 Initial recovery of silicone o-rings with oil at 22°C; expanded ordinate, error bars.

The glass transition temperatures (T_gs) of as-received o-rings as well as o-rings compressed for 2 years at room temperature (with and without silicone oil lubricant) were determined by DMA. The T_gs of all three specimens were identical (−116°C). This leads us to believe that the change in initial recovery in samples compressed either 6 months or 1 year is not due to any permanent change in the silicone polymer. Since the fillers are also not expected to change, we postulate that the difference in initial recovery is due to possible loss of bonding and change of load transfer between the fillers and the silicone polymer.

CONCLUSIONS

The initial room temperature recovery of silicone o-rings after being compressed for 6 months or 1 year is slower than those compressed for 24 h. Initial recovery after 1 year of compression is similar to recovery after 6 months of compression. Recovery after about 1 s is similar for 24 h, 6 months, or 1 year of compression. Not surprisingly, the recovery of silicone o-rings after being compressed for 24 h is slower at −7°C than at room temperature. A thin coating of silicone oil appears to aid recovery after 24 h of compression but has little effect after 6 months or 1 year of compression. We postulate that the difference in initial recovery is due to possible loss of bonding and change of load transfer between the fillers and the silicone polymer.

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