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Experimental Investigation of Multi-step Shear Stress Relaxation and Recovery of Silicone Rubber

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Abstract— Single-step stress relaxation tests may not be sufficient to explain the nonlinear viscoelastic behavior of rubber. Therefore, it may be necessary to perform these tests at different strain rates or different strain levels. Applying multiple strain levels is a way to determine the nonlinear viscoelastic behavior of rubber. In this study, shear stress relaxation and stress recovery of silicone rubber were examined at the single-step and multi-step (with different strain history) strain loading. The results of this study show that while strain history affects stress relaxation significantly, it does not have a significant effect on stress recovery.

Keywords: Multi-step; Silicon Rubber; Stress Relaxation; Stress Recovery

I. INTRODUCTION

Silicone rubber, also known as polysiloxane, offers high durability, high chemical stability, high electrical, and high thermal resistance. It is widely used in the electronics, automotive, aerospace, and food processing industries. [1–6]. Besides, silicone rubber has a higher dielectric property than natural rubber or other synthetic rubber [7]. Therefore, it is the most commonly used material in electrical applications.

When rubbers are subjected to tension until the desired strain level is achieved and then released for returning to their initial position, transient effects to stress are observed. Hence, when loading is applied and then held constant, the stress response is stress relaxation. Similarly, when the load is removed and then held steady to rest, this cause is also affecting rubbers' stress behavior. The result of unloading is stress recovery and constitutes a converse procedure of stress relaxation and is relative to the shear tendency of the viscoelastic material to return to its initial position. Stress or creep relaxation tests help to understand the viscoelastic behavior of rubbers [8]. In stress relaxation, stress decreases over time at a constant strain, while in the creep, strain increases over time at constant stress [9]. Both tests contribute to simulating the linear viscoelastic behavior of rubbers analytically. Single-step stress relaxation or creep tests may not be sufficient to explain the nonlinear viscoelastic behavior. Therefore, it may be necessary to perform these tests at different strain rates or different strain levels. One way to determine the nonlinear viscoelastic behavior of rubber is to perform relaxation tests at multiple strain levels [10–13].

The aim of this paper is to investigate shear stress relaxation and its recovery for the nonlinear viscoelastic behavior of silicone rubber at single-step and multi-step strain loading.

II. MATERIAL AND METHODS

A. Material

Rogers corporation provided the silicone rubber that was used in the experiments. Test samples were cut into 150 mm x 100mm x 1.5875 mm for the planar relaxation tests.

B. Relaxation and recovery tests

Relaxation and recovery tests were carried out using MTS universal testing machine at a constant crosshead speed of 5 mm/s at room temperature. The strain was measured by a laser extensometer during the tests. For the current research, three different strain histories were applied to silicone rubber. At the first strain history, named a single step, a constant strain level was applied to each silicone rubber, and then samples were held constant for 15 minutes. Then they were unloaded to a lower 25% strain level and were held for another 15 minutes. The applied strain levels in a single step are shown in Fig.1. At the second strain history, multi-step loading-unloading, the strain gradually increased and then gradually decreased. The sample was held for 15 minutes at each strain level. Lastly, at the third strain loading history, multi-step unloading- loading, unlike the previous test, the strain was initially decreased and then increased. As in the previous strain histories, the sample was held for 15 minutes at each strain level. Multi-step loading-unloading strain profile and multi-step unloading-loading strain are shown in Fig. 2a and Fig. 2b.

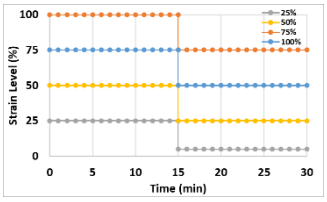
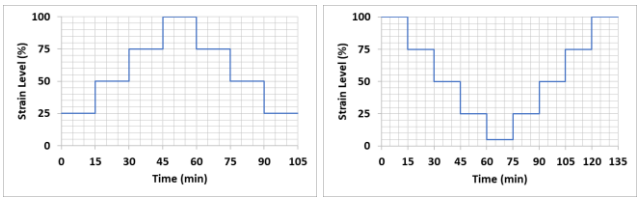


Figure 1. Strain levels in single-step relaxation



(a) multi-step loading-unloading (b) multi-step unloading-loading

Figure 2. Strain history for stress relaxation and recovery

III. RESULTS

A. *Stress relaxation and recovery*

Fig. 3 shows the single-step stress relaxation and recovery at different strain levels with respect to time. As expected, shear relaxation modulus increased with the increase in strain level.

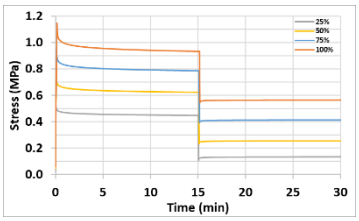
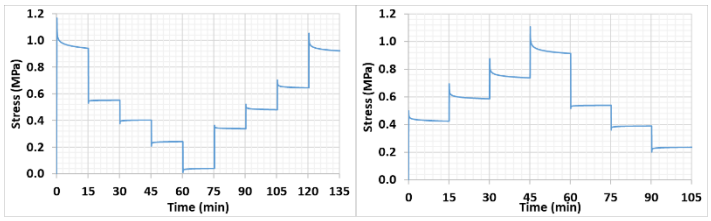


Figure 3. Single-step stress relaxation and recovery for different strain levels

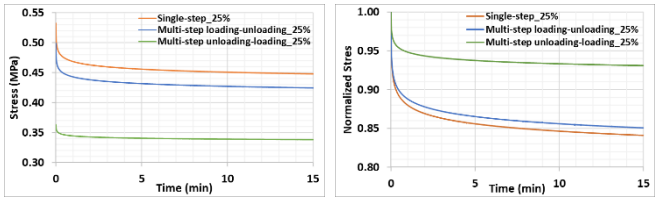
Multi-step stress relaxations at different strain histories with respect to time are shown in Fig. 4. As it is shown, stress decreased during the relaxation after loading strain and stress increased during recovery after unloading strain.



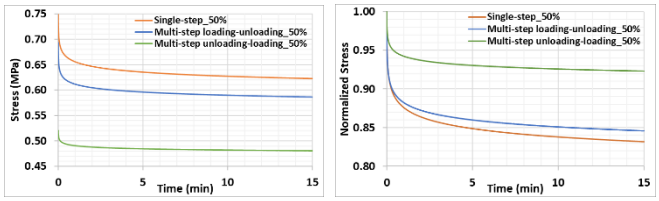
(a) Multi-step loading-unloading (b) multi-step unloading-loading

Figure 4. Stress relaxation and recovery for different strain histories

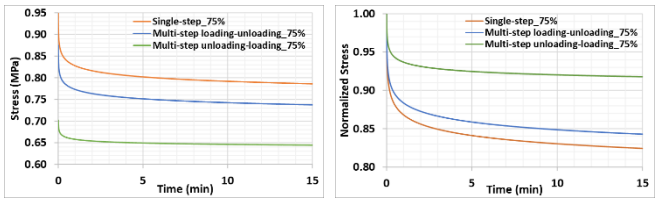
Shear relaxation modulus and normalized stress relaxation for single step, multi-step loading-unloading and multi-step unloading-loading at strain levels of 25%, 50%, 75%, and 100% are shown in Fig. 5. Stress relaxation has been normalized to better understand the nonlinear viscoelastic behavior of silicone rubber. It has been observed that the highest shear stress relaxation modulus and highest reduction in the stress relaxation were obtained from single-step strain loading test. However, the lowest shear stress relaxation modulus and reduction in stress relaxation have obtained from multi-stage unloading-loading strain history. It can be explained by the Mullins effect.



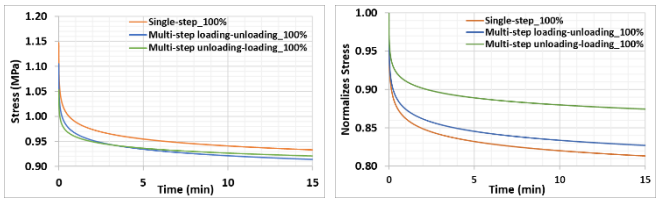
a) strain level of %25



b) strain level of %50



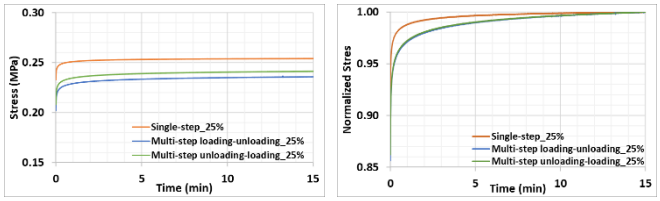
c) strain level of %75



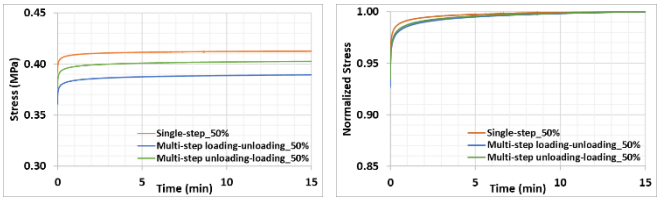
d) strain level of %100

Figure 5. Comparison of stress relaxations and recovery at the different strain histories

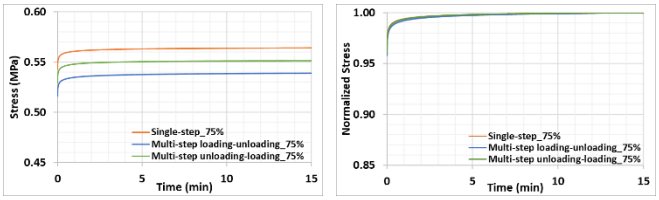
Stress recovery and normalized stress recovery of silicone rubber for multi-step loading-unloading and multi-step unloading-loading at strain levels of 25%, 50%, 75 are shown in Fig. 6. It has been observed that with the increase in the strain level, stress recovery increased, and the highest stress recovery was obtained from single-step strain loading test. Furthermore, the strain history did not affect the stress recovery time.



a) strain level of %25



b) strain level of %50



c) strain level of %75

Figure 6. Comparison of stress recovery and normalized stress recovery at the different strain histories

IV. Conclusions

In this study, shear stress relaxations and recovery of silicone rubber were examined at the single-step and multi-step (with different strain history) strain loading. This study demonstrated that:

- The stress relaxation and recovery of silicone rubber are dependent on the strain level.
- Shear relaxation modulus and reduction in stress relaxation increase with the increase in strain level.
- Although there is a significant effect of strain history on shear stress relaxation modulus and stress recovery, there is no significant effect on the recovery time.
- The minimum shear relaxation modulus stress and reduction in the stress relaxation are obtained from multi-step unloading-loading strain history.

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