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MECHANICAL BEHAVIOR OF ELASTOMER UNDER COMPRESSION AND ITS MICROSTRUCTURE

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1. Introduction

Elastomers are used in many engineering structures such as bearings in bridges, shock absorber, etc. Their use for base isolation is also increasing rapidly. This increasing trend of elastomers leads the engineers to develop a rational constitutive model for such materials for design optimization and performance evaluation.

In general, the mechanical behavior of elastomers shows both material and geometric non-linearity. The effects of loading rate, strain history and temperature further complicate the behavior.

This paper presents the experimental observations for mechanical behavior of elastomer and its microstructure as well. An attempt was made first to observe Mullein's effect in virgin specimens during persuading. Then the preloaded specimens were subjected to uniaxial compression with varied strain rate to observe their rate-dependency. Cyclic relaxation tests and Scanning Electron Microscope (SEM) observation on virgin and loaded materials have also been carried out.

2. Experimental Setup

Figure 1 illustrates the experimental setup for mechanical testing. Cubic specimens (50mm x 50mm x 50mm) of elastomer were used for all tests.

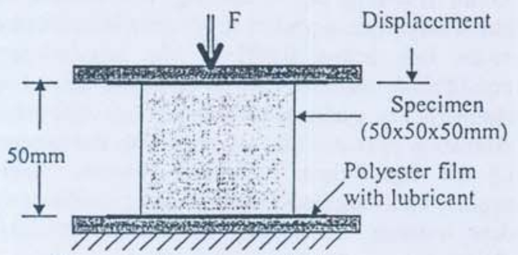
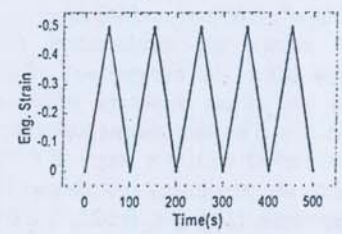


Figure 1. Experimental setup

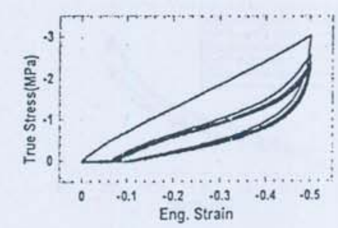
A computer-controlled servohydraulic-testing machine was used for the experiment. In order to cut friction between the sample and the loading plates, polyester film with lubricant on top and bottom of the sample was used. The axial force and the displacement were recorded for each test using a personal computer. Engineering strain and true stress were calculated under the assumptions of homogenous deformation and incompressibility of the specimens, respectively.

3. Preloading and Mullin's Effect

All specimens were subjected to specified preloading. Cyclic uniaxial loading with the same strain amplitude was applied. For each specimen, 50% compressive strain was applied for 5 cycles with a strain rate of 0.01 s^{-1}. Figure 2a presents the strain history applied on the virgin material as preloading. Figure 2b presents the corresponding stress-strain relation of the material, where substantial softening behavior in the first loading cycle, known as Mullin's effect [1], is evident. The softening is attributed to the modification and reformation of virgin elastomer network structures involving microstructural damage, single-chain/multi-chain damage, and micro-void formation. After passing 2-3 loading cycles, the specimen shows the repeatable stress-strain behavior.



(a)



(b)

Figure 2. Preloading of virgin material (a) applied strain history, (b) stress-strain response.

4. SEM Observation

With a view to developing a micromechanics-based

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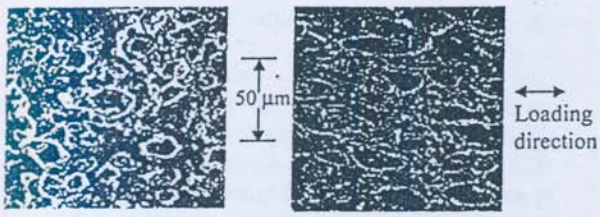
constitutive model, SEM observation of the rubber was conducted. For SEM observation, samples of a dimension of 1.5 x 3.0 x 4.0 mm were used. The magnification factor for all observations was 250 times.

Figure 3 shows the presence of voids in the specimen. In the virgin material the void shapes are approximately circular, while upon the application of in-situ tension force, voids take elliptical shapes. The cross-sectional shape of the voids was found to depend on the amount of load and the time interval between loading and observation.



(a) (b)

Figure 3. SEM photograph of (a) virgin and (b) loaded specimen at 40% tensile strain.

5. Uniaxial Compression Test

After 20 minutes from the preloading, uniaxial compression tests were carried out at different loading rates to obtain the equilibrium response. The experiments were done at strain rates of 0.001 s^{-1}, 0.005 s^{-1}, 0.025 s^{-1}, 0.075 s^{-1} and 0.225 s^{-1}.

Figure 4 shows the stress-strain relation at different strain rates. The comparison of the curves displays that the stress increases with increasing applied strain rate. The rate-independent equilibrium response is observed at strain rates of 0.001s^{-1} and 0.005s^{-1}, where the responses are almost the same. But for higher strain rates (i.e. 0.025s^{-1}, 0.075s^{-1} and 0.225s^{-1}) the stress increases.

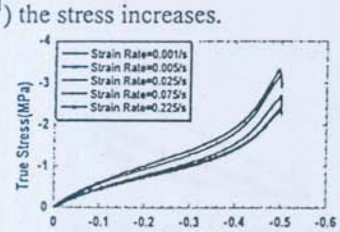
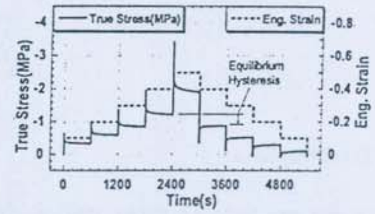


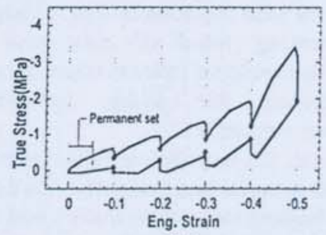
Figure 4. Stress-strain responses for different strain rates.

6. Cyclic Relaxation Test

Cyclic relaxation tests were carried out to study the relaxation along with the equilibrium hysteresis behavior of elastomers. The relaxation period for each strain level was 10 minutes. Figure 5a illustrates the appearance of the equilibrium stress response during each relaxation period. For a particular strain level the equilibrium stress level differed from the loading to unloading path due to hysteresis effects. This is the so-called equilibrium hysteresis [2].



(a)



(b)

Figure 5 Responses of Cyclic Relaxation test (a) Stress response, (b) Stress-strain behavior

Again, due to the cyclic process, some amount permanent set occurs in the specimen. This is shown in figure 5b. It is found that around 5% permanent set occurs at the end of the test.

7. Conclusion

The uniaxial stress-strain response of elastomer shows highly nonlinear behavior. The preloading of virgin specimens causes substantial softening below the maximum strain level. The SEM observation revealed the presence of voids in the elastomer matrix. The cross sectional shape of such voids was found to change due to loading. The uniaxial stress-strain responses at varied strain rates indicate that at a strain rate below 0.005 s^{-1} the rate-independent equilibrium response can be achieved for the tested material. The cyclic relaxation test has delineated the relaxation phenomenon together with the appearance of the equilibrium hysteresis feature. Thus the experiments reported in this paper provides a viable data towards developing constitutive models for elastomers.

References

1. Mullins, L. (1969). Softening of Rubber by Deformations. *Rubber Chem. Technol.* Vol. 42, pp. 339-362.

2. Lion, A. (1996). A constitutive model for carbon black filled rubber: Experimental investigations and mathematical representation. *Continum Mech. Thermodyn*. Vol. 8, pp. 153-169.