Engineering Notes

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Strain Damage Effects on Chemical Aging

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Introduction

MECHANICAL properties of solid propellants change with time, often adversely affecting missile motor capability. Gel fraction studies[1] have shown that these chemical property changes are paralleled by chemical changes in the binder. Correlations have been developed[1,2] that relate mechanical property and chemical at elevated temperatures where the propellant chemistry is accelerated. Thus, a predictive scheme has emerged that can use the results of short-term elevated temperature tests to predict long-term changes in propellant mechanical properties.

More recently, observations of accelerated aged propellant samples held under strain have shown a lower relaxation modulus (2 min modulus) than propellant aged in the unstrained state.[2] The same work has also shown that strain during aging did not detectably influence the chemical rate of reaction leading to gel formation. If mechanical properties are influenced by age-strain related mechanisms other than viscoelasticity and/or cumulative damage, the use of recent chemical aging models is questionable.

To evaluate this phenomena, an experimental program was initiated to examine the propellant strain aging phenomena in greater detail. Previous work[2] showed that measuring only the short-term relaxation modulus and the strain history provided no correlation to relate the modulus decrease of the strain-aged propellant with that of unstrained material. A logical extension of the previous work is to monitor the complete stress and strain history rather than one selected time point. Conducting experiments to measure accurate mechanical and chemical changes required consideration of the sample geometry and test equipment. The sample factors are listed below.

1) Relatively low strain levels during aging: a) Low strain levels require a minimum of sample handling damage. b) Low stress and strain levels over long periods of time require adequate instrumentation stability to acquire meaningful data.

2) Low surface to volume ratio is necessary to minimize surface aging effects.

A large propellant specimen test was used that meets the above requirements. Previous evaluation has shown the effectiveness of this sample geometry for long-term, small-strain work.

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Experimental Procedure

Samples approximately 2½ × 2½ in. square and 4 in. long were prepared from a single batch of TP H1011 propellant aged 29 months at 105°F. The well-aged propellant was used to minimize the chemical aging contribution and therefore emphasize the strain aging effects. Figure 1 illustrates the sample hardware and instrumentation for measuring stress and strain as a function of time. Accurate sample displacement measurements were obtained with dual-dial gages (accurate to 0.0001 in. providing strains within ±0.13%). The force data were obtained with a stable force transducer (Transducer, Inc. accurate to ±0.4 psi and repeatable to ±0.12 psi) and were recorded with digital recorders (Monitor Lab accurate to ±0.003 mV, repeatable to ±0.001 mV) during and immediately after strain incrementing. Long-term data were acquired using a portable digital meter (Fluke accurate to ±0.002 mV, repeatable to ±0.001 mV). Time was recorded in seconds at the beginning of each increment and in minutes after two hours. Both excitation and output readings were recorded at all test times. The strain was induced by manually turning a turnbuckle connecting the sample holder to the test rack and thereby generating strain rates of approximately 0.2 in./in./min. Sample strain histories comprised two groupings: 1) samples were aged under gravity loadings for various times and then displacement incremented to 2% or greater tensile strain; 2) samples were tested and stored 2% tensile strain for various periods of time and were then displacement incremented to higher strain levels.

Results and Discussions

A reference 70°F test was conducted on a large sample strained to ~1% and then incremented in ~1% strain levels to ~8% strain. The relaxation modulus for each strain increment is presented in Fig. 2.

The viscoelastic modulus was essentially the same for each strain increment where all strains and stresses are referenced to the initial zero stress and strain. The viscoelastic modulus relaxed approximately 50% during each time increment of about 500 min.

Figure 3 illustrates the relaxation modulus of a typical strain aged specimen history at 70°F. It was strained to 2.3% and monitored for 33 days. At this time the sample was incremented to 3.6% and then monitored another 36 days. The

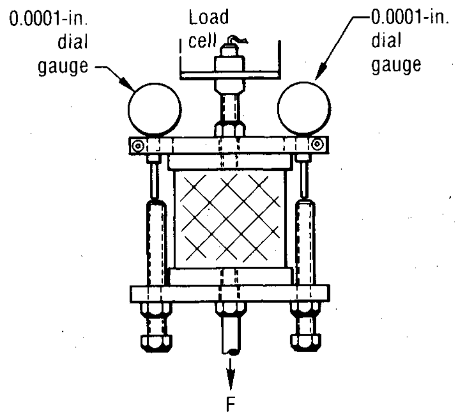

Fig. 1 Load and displacement fixtures for large sample tests.

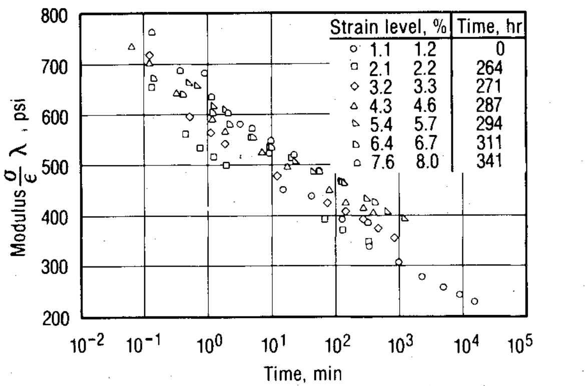

Fig. 2 Relaxation modulus of TP H1011 propellant at seven strain levels (70°F).

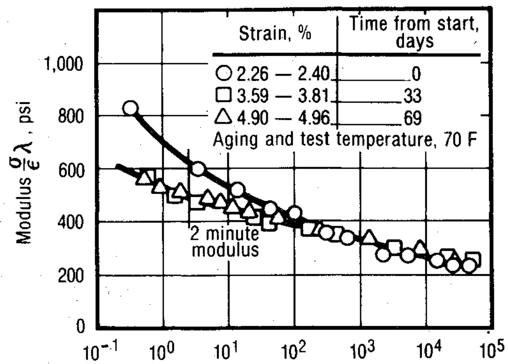

Fig. 3 Relaxation modulus vs log time of TP H1011 propellant aged at various strain increments (70°F).

sample was then incremented to 4.9% and allowed to stress relax. The beginning of each strain increment was used as the new zero time. Total stress and strain were used to compute the modulus.

The short time relaxation modulus is higher for the first strain increment than for the next two steps. The modulus difference for approximately 50 psi (at 2 min) is well within the range of values (0-135 psi) obtained by previous workers.[2] At relaxation times over 100 min all strain aged sample modulus values are the same as the undamaged specimens.

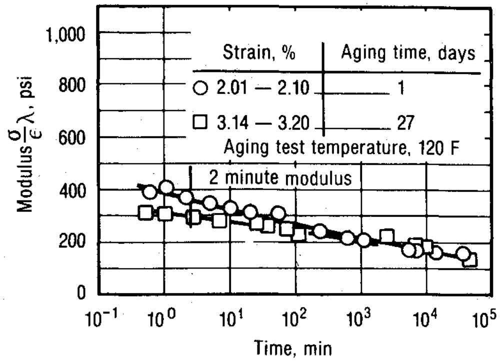

Fig. 4 Relaxation modulus vs log time of TP H1011 propellant aged at various strain increments (120°F).

The slopes of successive relaxation curves at longer times also remain unchanged which shows no dramatic changes have been induced by strain aging. Figure 4 illustrates a similar effect for propellant strain aged at 120°F. The modulus difference of the successive strain steps at 120°F is less than at 70°F because the samples are closer to viscoelastic equilibrium at the elevated temperature.

Conclusion

The short time viscoelastic modulus (2-min modulus) of strain aged propellant showed a decrease when compared to zero strain aged material. However, the viscoelastic moduli data observed for strain aged and unstrained propellant converged at longer times. The results for greater than an hour indicate that strain aging has no significant effect on the relaxation modulus of a well-aged solid propellant.

Achnowledgments

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References

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[2] Layton, L. H., Bennett, S. J., and Breitling, S. M., "Advanced Surveillance Technology for Service Life Analysis," Special Rept. AFRPL-TR-77-51, Contract F04611-75-C-0031, June 1977.