NANOMECHANICS, INC.

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Sample

Seven O-ring samples were provided by a manufacturer of sprinkler systems. The samples were nominally the same material but were either from an alternate supplier or exposed to different chemicals and working conditions. The seven conditions are described below; the numbers correspond to the sample numbers in the results. Figure 1 shows a picture of the O-ring samples and the samples mounted to a sample puck ready for testing.

1. Untreated and unexposed O-ring
2. Treated O-ring but unused
3. Treated O-ring and returned from the field
4. Treated O-ring but exposed to chlorine
5. Treated O-ring but exposed to trihalomethane
6. Older batch of treated O-rings but left unused
7. Alternate source of treated but unused O-ring

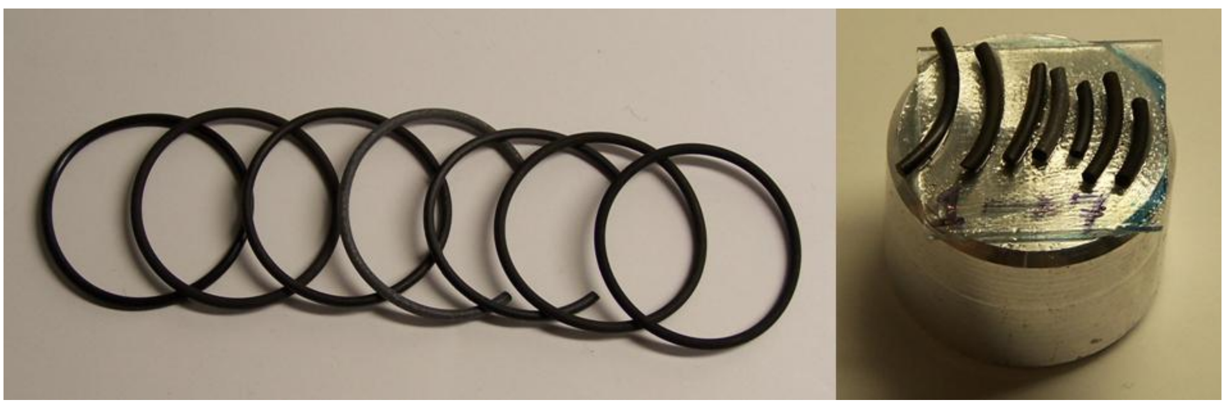

Figure 1: Unmounted and mounted O-ring samples.

Test Protocol

Samples were tested using the MTS Nano Indenter XP located in the Analytical Services Laboratory at Nanomechanics, Inc. with the test method labeled "G-Series XP CSM Flat Punch Complex Modulus" which is a standard test method with the Agilent NanoSuite software. This test method provides the viscoelastic properties of materials over a range of frequencies; the frequency range for these samples was 1 to 45 Hertz. More detail on the systematic operation of the test method and modeling assumptions are available elsewhere [1]. Table 1 lists the inputs used for the test method.

Table 1: Input test parameters for the O-ring samples.

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Maximum Frequency	45 Hz
Minimum Frequency	1 Hz
Number of Frequencies	5
Oscillation Amplitude	50 nm
Poisson's Ratio	0.4
Pre-Test Compression	10 µm
Punch Diameter	99.81 µm

Results

Tabulated results for the storage and loss moduli of the seven O-ring samples are provided in Table 2. The test frequencies were automatically selected by the test method so that they would appear equally spaced on a logarithmic plot. Figures 2 and 3 graphically display the results for the storage and loss moduli, respectively. The O-ring treatment substantially increased both the storage and loss moduli as seen in the results from samples 1 and 2. O-ring 3, the field failure, showed a dramatic increase in the storage modulus over the other samples. Exposure to chlorine and trihalomethane produced a softening of the rubber and caused a decrease in the storage and loss moduli of O-rings 4 and 5. The treated and unused O-ring provided by an alternate source, O-ring 7, had a storage modulus closest to that of the original treated and unused sample, O-ring 2, but the damping capacity of O-ring 7 was closer to that of aged O-ring, O-ring 6.

Table 2: Results of storage and loss modulus for the O-ring samples; the individual frequencies are automatically selected by the test method to be equally spaced on a log plot.

		Frequency (Hz)				
		1.00	2.59	6.71	17.37	45.00
Sample						
O-ring 1	Storage Modulus	13.80	15.08	16.66	18.47	20.53
	Loss Modulus	2.44	2.68	3.09	3.88	5.50
O-ring 2	Storage Modulus	23.76	25.81	28.38	31.37	34.91
	Loss Modulus	4.02	4.38	5.03	6.24	8.56
O-ring 3	Storage Modulus	34.55	36.41	39.14	42.35	46.32
	Loss Modulus	4.04	4.55	5.40	6.85	9.66
O-ring 4	Storage Modulus	8.12	8.61	9.31	10.12	10.86
	Loss Modulus	1.02	1.15	1.32	1.60	2.19
O-ring 5	Storage Modulus	8.45	9.01	9.79	10.67	11.62
	Loss Modulus	1.18	1.33	1.57	2.04	3.04
O-ring 6	Storage Modulus	20.67	22.08	24.03	26.36	29.11
	Loss Modulus	2.88	3.27	3.89	4.96	7.01
O-ring 7	Storage Modulus	27.10	28.44	30.41	32.79	35.60
	Loss Modulus	2.86	3.31	3.95	5.04	7.20

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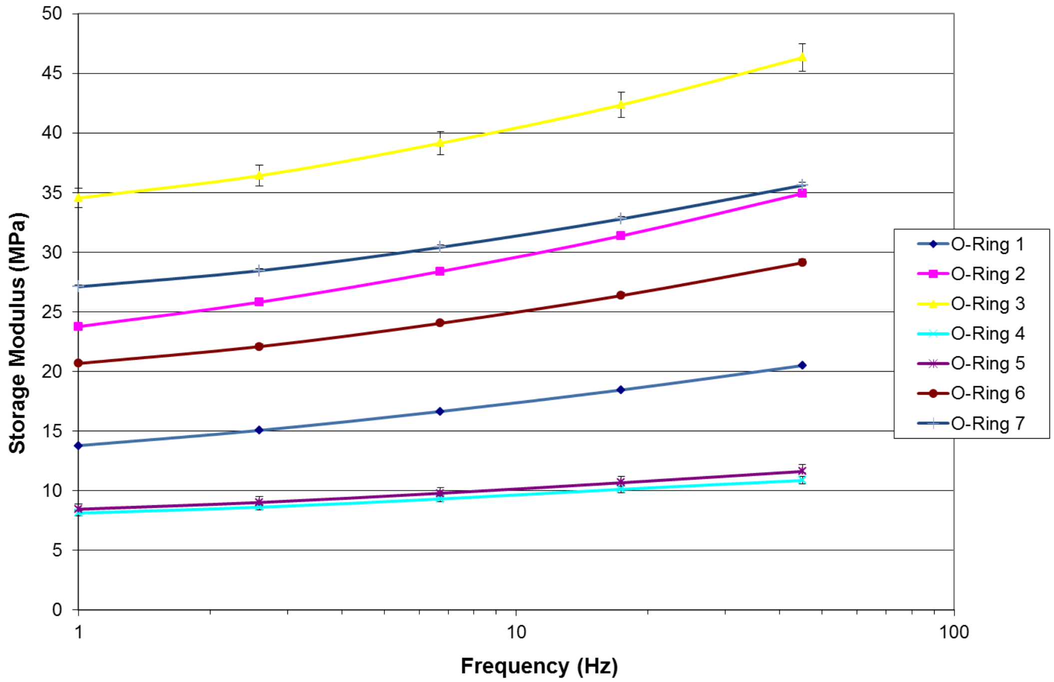

Figure 2: Storage Modulus of the O-ring samples from 1 to 45 Hz.

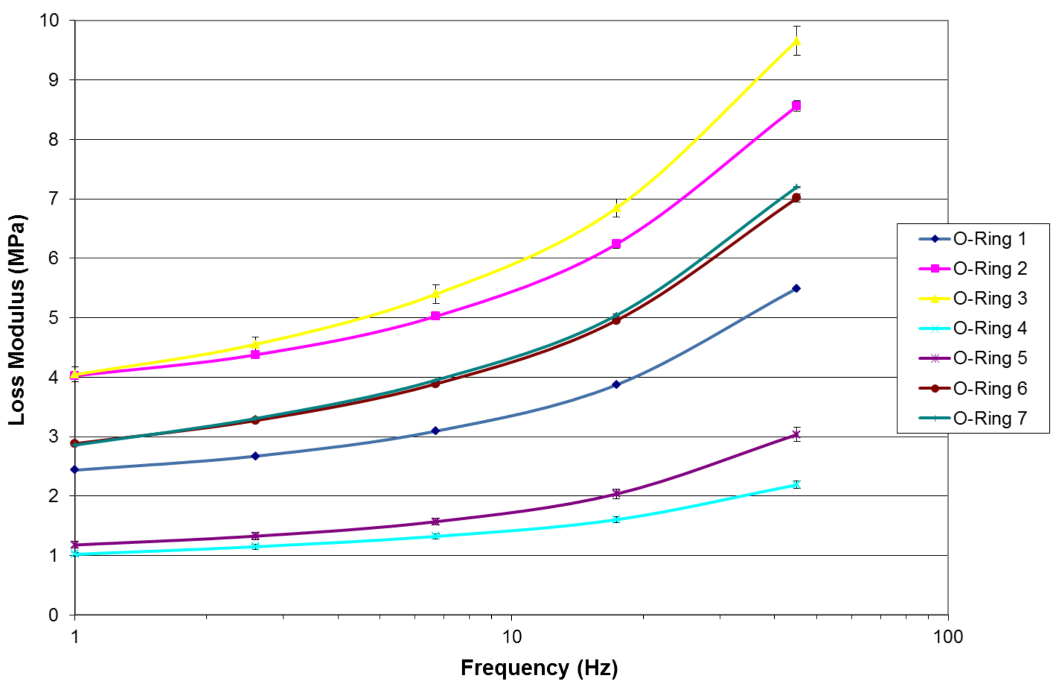

Figure 3: Loss Modulus of the O-ring samples from 1 to 45 Hz.

References

[1] J.L. Hay. "Using instrumented indentation to measure the complex modulus of highly plasticized polyvinyl chloride." *Agilent Technologies Application Note*, 2010. http://cp.literature.agilent.com/litweb/pdf/5990-6330EN.pdf