

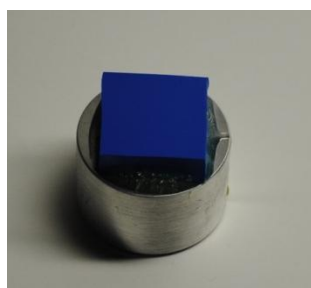


Analytical Services Laboratory  
105 Meco Lane  
Suite 100  
Oak Ridge, TN 37830  
(865) 978-6490 Ext. 300

ServiceLab@nanomechanicsinc.com

## Sample

The bulk polymer sample was a high-damping thermoplastic manufactured by E-A-R Aearo Technologies - a 3M® company. The polymer was cut to a size of 1" square and the surface was polished to remove any surface layer. Then the sample was mounted to a sample puck for testing and is shown in Figure 1. The primary advantage of using a nanoindenter for performing polymer characterization is spatial resolution; the Nanomechanics Analytical Service Laboratory can provide high resolution mapping of storage and loss modulus around interfaces and features of interest. This material was also tested by Herbert *et al.* providing a basis for conducting dynamic mechanical analysis using an MTS Nano Indenter XP system with a 100  $\mu\text{m}$  flat punch [1]. This material is tested in the Nanomechanics Analytical Services Laboratory as a reference polymer.



**Figure 1: High-damping thermoplastic mounted and ready for testing.**

## Test Protocol

The bulk polymer sample was tested using an Agilent Nano Indenter G200 in the Nanomechanics Analytical Services Laboratory equipped with an XP force transducer and the Continuous Stiffness Measurements option. Each test was performed using the test method titled "XP Flat Punch Complex Modulus." The Nano Indenter system is capable of performing dynamic mechanical analysis over a frequency range from 1 to 150Hz. More information on the modeling of the instrument and operation of the test method is available elsewhere [2]. A 50  $\mu\text{m}$  flat punch tip was used to conduct the indentation tests and evaluate the viscoelastic properties. The test parameters are shown in Table 1.

**Table 1: Test parameters for measuring the storage and loss modulus of the high-damping thermoplastic.**

<b>Maximum frequency</b>	45 Hz
<b>Minimum frequency</b>	1 Hz
<b>Number of frequencies (scaled logarithmically)</b>	8
<b>Oscillation amplitude</b>	50 nm
<b>Poisson's ratio</b>	0.4
<b>Pre-test compression (5% of the punch diameter)</b>	5 $\mu\text{m}$
<b>Punch Diameter</b>	49.78 $\mu\text{m}$

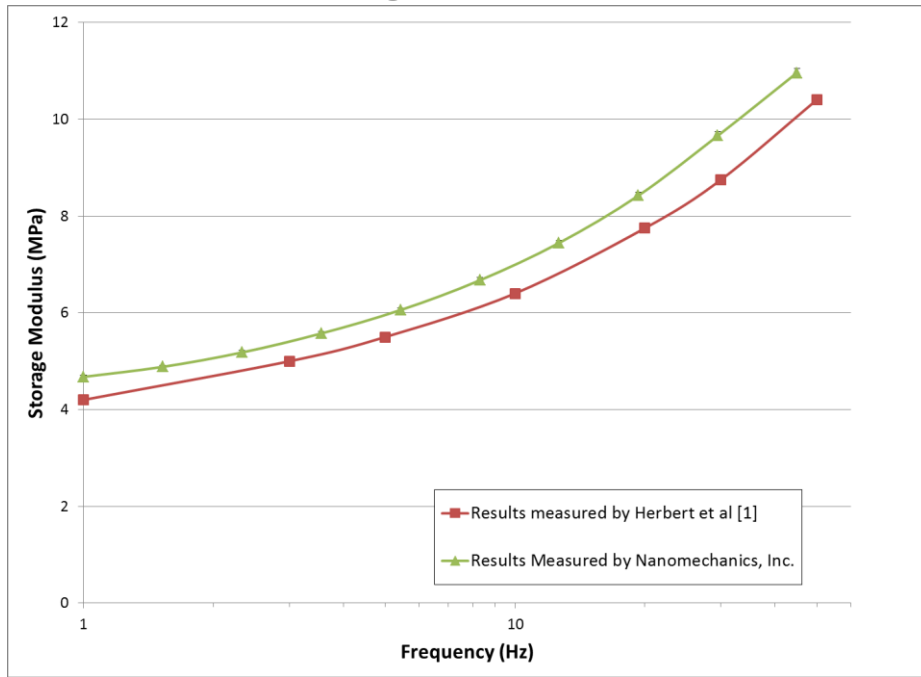
## Results

Fifteen tests were performed on the polymer sample and during each test all 10 frequencies were scanned. The average measured results for the storage and loss modulus are provided as a function of frequency in Table 2. These results are plotted against the results published by Herbert *et al* in figures 2 and 3. The results for the storage and loss modulus of the polymer sample have good agreement to the reported values. While there was not a statistical difference in the measured loss modulus of the material, there was a small discrepancy in the measured storage modulus that could have been caused by several influences such as minor temperature differences, sample variation, or aging of the sample.

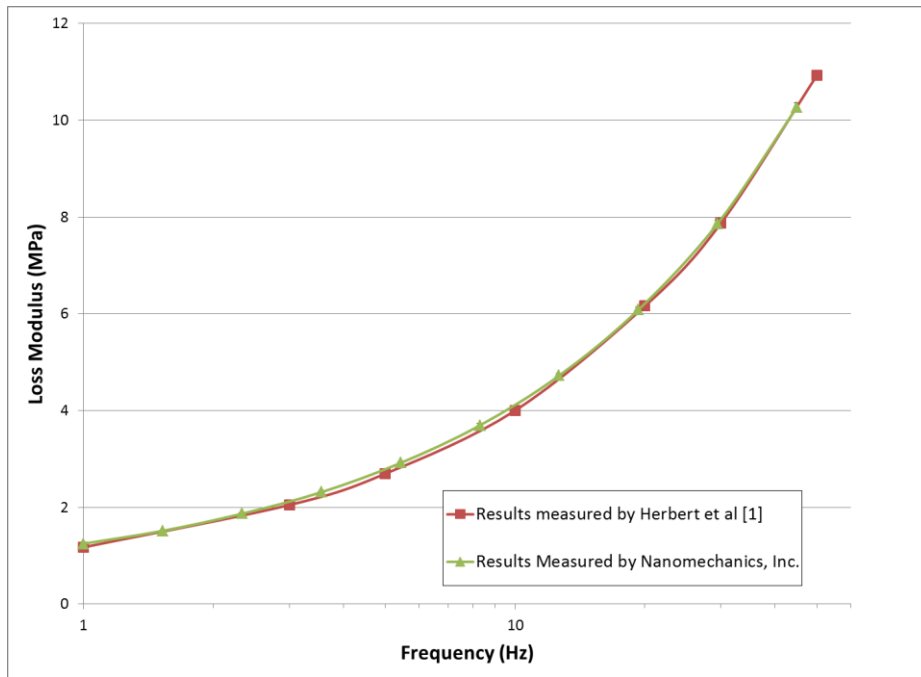
**Table 2: Averaged results for the viscoelastic properties of the polymer sample over the range of frequencies.**

<b>Frequency</b>	<b>Storage Modulus</b>	<b>Standard Deviation of Storage Modulus</b>	<b>Loss Modulus</b>	<b>Standard Deviation of Loss Modulus</b>
<b>Hertz</b>	<b>MPa</b>	<b>MPa</b>	<b>MPa</b>	<b>MPa</b>
<b>45.0</b>	10.96	0.08	10.27	0.09
<b>29.5</b>	9.66	0.08	7.86	0.07
<b>19.3</b>	8.42	0.07	6.08	0.06
<b>12.7</b>	7.44	0.06	4.72	0.04
<b>8.3</b>	6.67	0.05	3.69	0.03
<b>5.4</b>	6.06	0.05	2.92	0.03
<b>3.6</b>	5.57	0.04	2.31	0.02
<b>2.3</b>	5.18	0.04	1.87	0.02
<b>1.5</b>	4.88	0.03	1.52	0.01
<b>1.0</b>	4.68	0.03	1.25	0.01

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**Figure 2: Measured storage modulus versus frequency as compared to the published results measured by Herbert *et al.***



**Figure 2: Measured loss modulus versus frequency as compared to the published results measured by Herbert *et al.***



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## References

[1] E.G. Herbert, W.C. Oliver, and G.M. Pharr, "Nanoindentation and the dynamic characterization of viscoelastic solids," *J. Phys. D:Appl. Phys.*, Vol. 41, pp. 1-9, 2008.

[2] J.L. Hay, Instrumented Indentation to measure the complex modulus of highly plasticized polyvinyl chloride. *Agilent Technologies Application Note*, 2010. (web address: <http://cp.literature.agilent.com/litweb/pdf/5990-6330EN.pdf>)