NANOMECHANICS, INC.

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Sample

A cross-section of tire from a tire manufacturer was embedded in an epoxy mount and polished for testing. Nanoindentation was used to map out the viscoelastic properties of the cross-section and understand the mechanical properties of the multiple polymer layers. Figure 1 shows the tire cross-section mounted in epoxy and ready for testing.

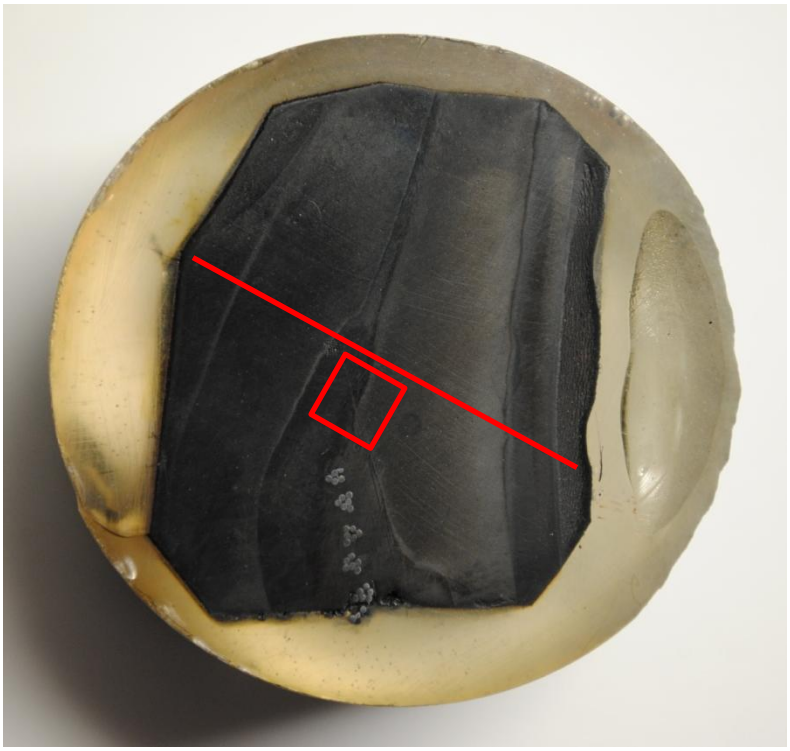

Figure 1: Cross-section of the tire sample mounted and ready for testing. The multiple polymer layers are apparent in the cross-section. A set of tests were performed along the red line across the sample; then, the area inside the red box was mapped.

Test Protocol

First, the Nano Indenter G200 in the Nanomechanics Analytical Services Laboratory was used to perform a cross-sectional array of indentations across the sample to construct a single line profile examining the viscoelastic properties of all layers. Then, a 3 mm X 3 mm area consisting of the highest number of polymer interfaces was chosen for mapping the viscoelastic properties. In each case, a flat punch tip with a 100 µm diameter was used to conduct the tests and each test was separated by 150 µm (center-

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to-center distance). The test method used to conduct the tests is provided as standard with the Nano Indenter G200 from Agilent Technologies and is labeled "XP CSM Flat Punch Complex Modulus." More information on the test methodology is described elsewhere [1]. The inputs used in these tests are shown in Table 1.

Table 1: Inputs for all of the tests conducted on the tire cross-section

Frequency	40 Hz
Oscillation amplitude	50 nm
Poisson's ratio	0.4
Pre-test compression (5% of the punch diameter)	5 µm
Punch Diameter	99.81 µm

Results

The results for the tests performed on the cross-section (red line in Figure 1) of the tire sample are shown in figures 2 and 3. Each layer shows clearly different results for the storage modulus in Figure 2 and, for the most part; minor differences in the loss factor across the sample are shown in Figure 3. The repeatability for the results in each layer is exceptional and the interfaces between layers are very clear. None of the indentations were performed in the epoxy mount; the tests were started and stopped in the outer layers of the tire specimen.

Figures 4 through 7 show the viscoelastic properties maps of the storage and loss modulus for the area inside the red box in Figure 1. The 3-D plots for storage and loss modulus maps in figures 4 and 6, respectively, show dramatic transitions from one polymer layer to the other. Contour maps in figures 5 and 7 provide the viscoelastic properties as a function of position and clearly show the boundaries of the individual layers.

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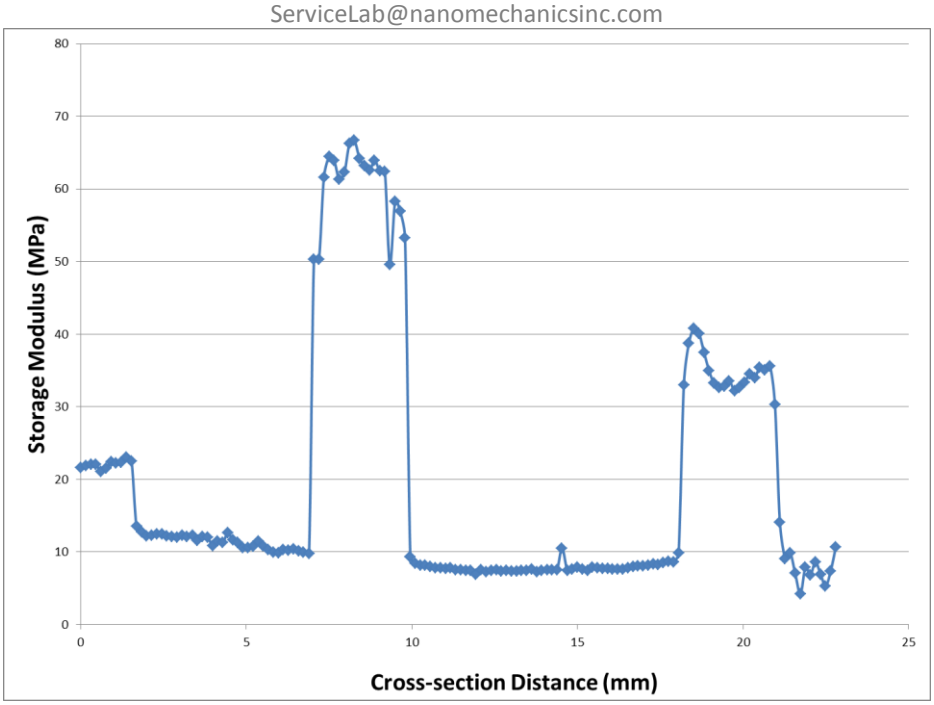

Figure 2: Storage modulus as a function of position along the cross-section indicated by the red line on Figure 1.

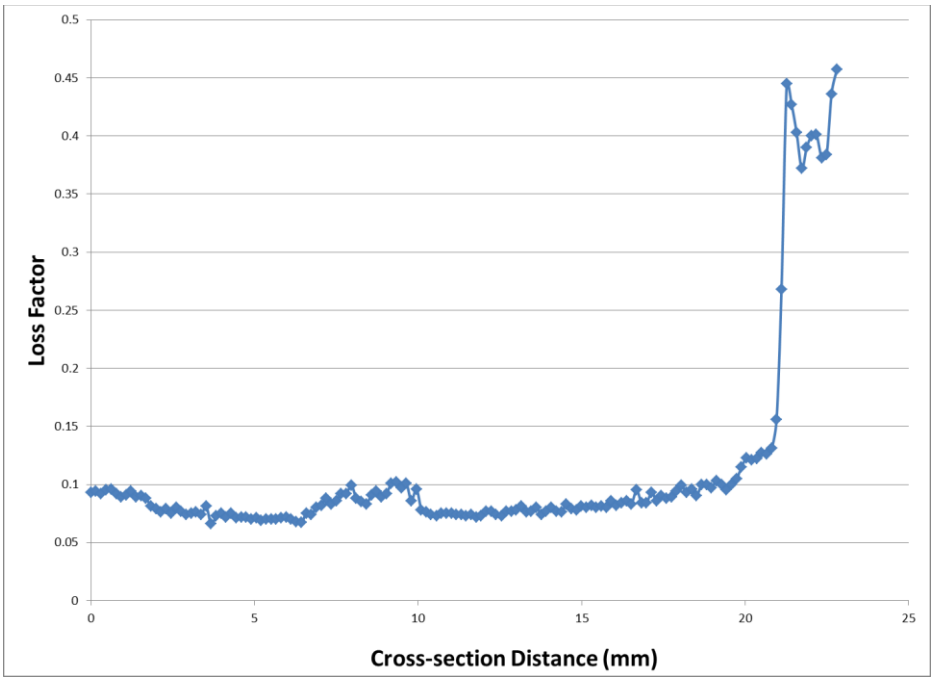

Figure 3: Loss factor as a function of position along the cross-section indicated by the red line on Figure 1.

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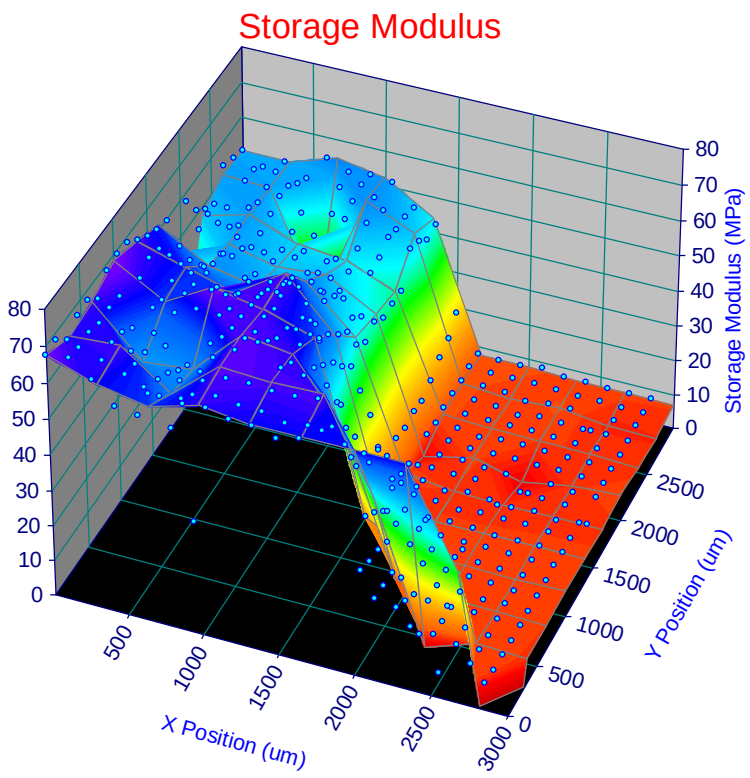

Figure 4: Storage modulus map over the square area indicated in Figure 1. Test locations were separated by 150 µm in both the X- and Y-directions.

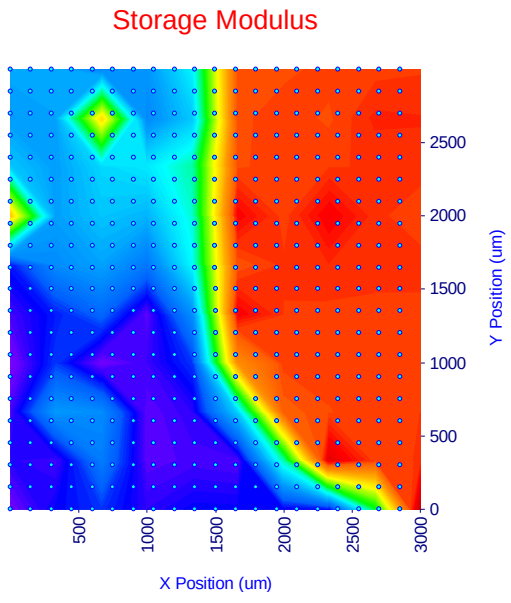

Figure 5: Contour plot of the storage modulus of the square area indicated in Figure 1.

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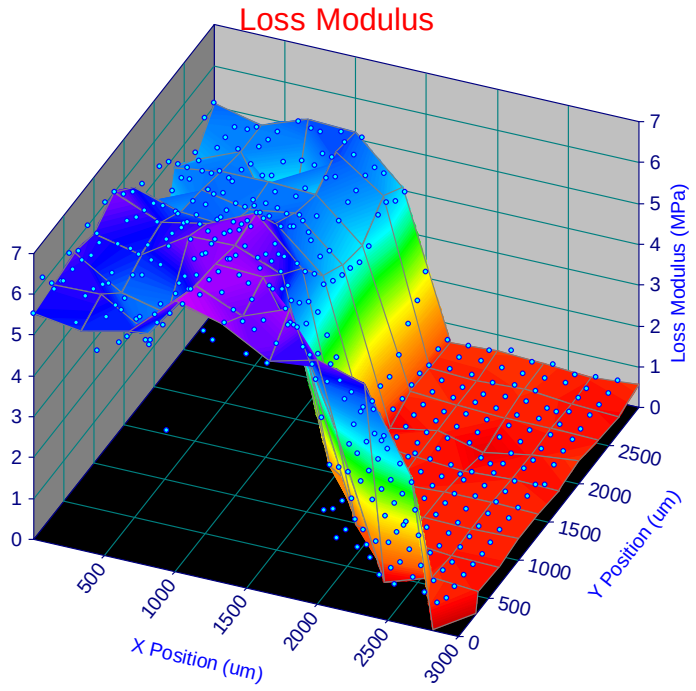

Figure 6: Loss modulus map over the square area indicated in Figure 1. Test locations were separated by 150 µm in both the X- and Y-directions.

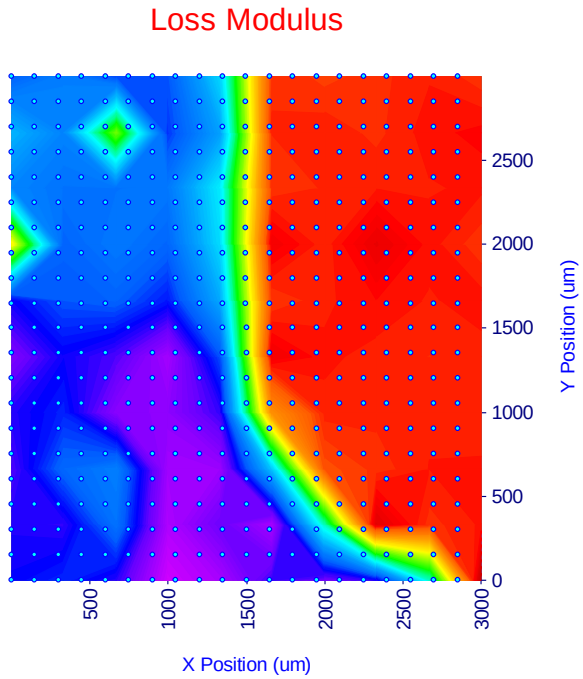

Figure 7: Contour plot of the storage modulus of the square area indicated in Figure 1.

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References

[1] 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)