Determination of Storage and Loss Moduli of Multi-Component Elastomers on the Universal Nano+Micro Materials Tester UNMT

I. Test model

The storage and loss moduli were derived experimentally from the dynamic penetration experiments. Complex modulus can be determined from the force single degree of freedom oscillator model via contact mechanics expression:

$$m\ddot{x} \quad kx \quad c\dot{x} \quad F_0 \sin(\quad t) \qquad (1)$$

where *m, k, c* and F_0 are oscillator mass, stiffness, damping, and amplitude of sinusoidal force, respectively. Solution of the Eq. 1 for the displacement amplitude X_0 can be expressed as:

$$X_0 \quad \frac{F_0}{\sqrt{(k \quad m \quad)^2 \quad (c \quad ^2)^2}} \qquad (2)$$

Here, is a cyclic frequency (rad/s). Interacting contact stiffness k_{cont} and damping c_{cont} can be derived in the following way:

$$k_{cont} \quad \frac{F_0}{X_0}\cos(\quad) \quad m \quad ^2 \quad k_{inst} \qquad (3)$$

$$c_{cont} \quad \frac{F_0}{X_0}\sin(\quad) \qquad (4)$$

where, is a phase shift angle between force and displacement, and k_{inst} is a force sensor stiffness. Utilizing contact mechanics equations:

$$k_{cont} \quad 2E\sqrt{A_{cont}} \qquad (5)$$

Adding relationship between elastic penetration depth h_{cont}, indenter radius R_i and elastic contact area A_{cont} storage modulus could be expressed in the following way:

$$E' \quad \frac{k_{cont}}{2\sqrt{2h_{cont}R_i \quad h_{cont}^2}} \qquad (6)$$

Storage modulus *E'*, loss modulus *E''*, and complex modulus *E* have the following relationships:

$$\tan(\quad) \quad \frac{E}{E} \qquad (7)$$

$$E \quad \sqrt{E^2 \quad E^2} \qquad (8)$$

II. Test procedure and equipment

A multi-component tire sample mounted in a metallurgical sample holder was tested. The test was performed on the Universal Nano+Micro Tester model UNMT-1 (Fig.1), with the tire sample attached to a force sensor, and a 1 mm diameter stainless steel ball attached to a linear reciprocating drive with a LVDT displacement sensor and oscillating with a 200- m amplitude (Fig.2). Force and displacement signals were recorded for 4 seconds at frequencies of 5, 10, 15, 20, 25, and 30Hz at several locations across the sample with 1 mm increments. Values of storage, loss, and complex moduli were derived according to the equations 6, 7, and 8.

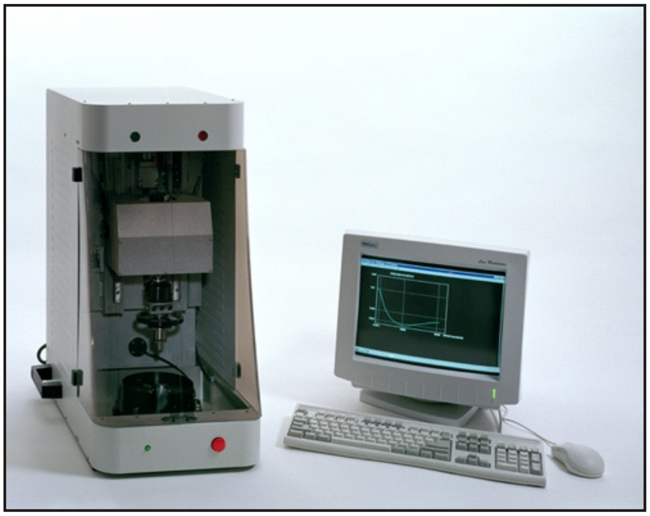


Figure 1. Nano + Micro Tester UNMT-1

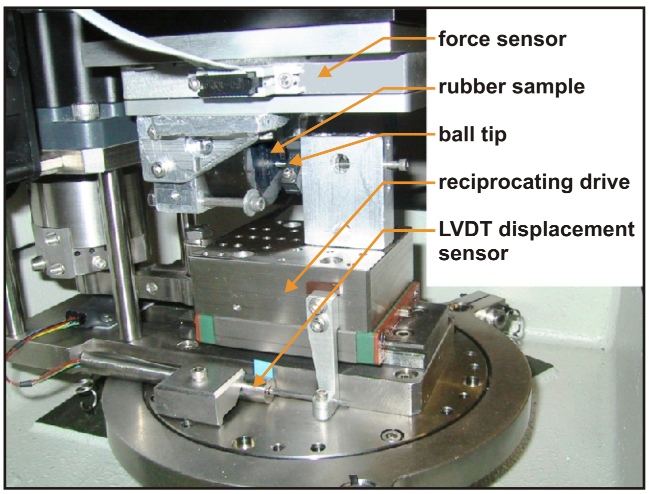
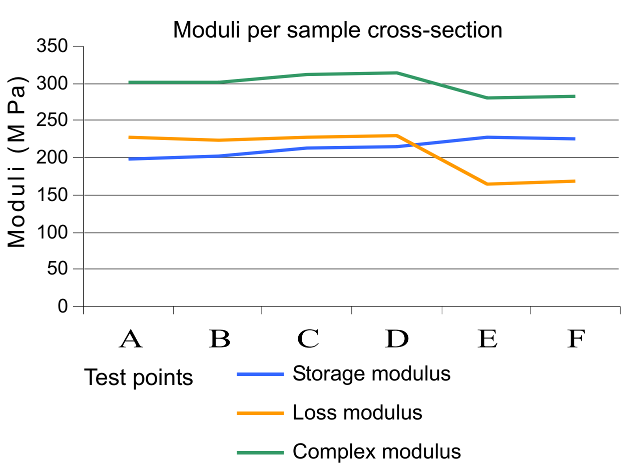


Figure 2. Test setup

III. Test results



The following differences in moduli across the sample were observed:

- three regions of different elastic moduli were distinguished, the softest in the vicinity of “A” and “B”, middle-range in vicinity of locations “C” and “D” (the closest to the metal cords), the hardest (stiffest) in the locations “E” and “F”;
- storage modulus was found to be the lowest of 198MPa ±0.5MPa at the location “A” and the highest of 227MPa ±0.5MP at the locations “E” and “F”; positions “C” and “D” had 213 and 215MPa, respectively;
- in contrast, the loss modulus was the highest at the middle locations “C” and “D” (228 and 230 +- 0.5MPa, respectively), lowest at “E” and “F” (165MPa and 170MPa ±0.5MPa, respectively);
- the complex modulus changes from 301MPa and 302MPa at the locations “A” and “B” to the highest 312 and 315 ±0.5MPa at the middle locations “C” and “D”, then drops to 281MPa and 282 ±0.5MPa at the locations “E” and “F”.

IV. Conclusions

The Universal Nano+Micro Materials Tester UNMT-1 has excellent performance in determining the storage and loss moduli across multi-layered elastomers at different local test points.

The UNMT can perform local dynamic tests on various sample sizes and shapes (servo-control of displacement allows for precision multi-positioning on non-flat rough surfaces), with automatic mapping (both the indenter and test sample can be moved and positioned in any direction with 1 m increments; easy-attachable Optical Microscope module helps in positioning on target surface areas), in either X or Y or Z directions (Linear Reciprocating Drives are easily-exchangeable modules) on both micro and nano scales (the Micro-Head and Nano-Head are easily-exchangeable modules, with various dynamic indenters). UNMT is an ideal tool for quantitative mechanical characterization of complex materials.

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