Application Note

Continuous Dynamic Analysis and Quasi-Static Measurement of Spider Silks

Introduction

Nanoscale characterization of biological materials continues to be a challenge in the fields of mechanics and material testing. One example of this type of research is the characterization of the mechanical properties of spider silks. Such silks have an astounding strength-to-weight ratio that has attracted interest across multiple industries ranging from medical to military. Complexities associated with spider silk research include the small and hard-tomeasure diameter of the silks, difficulties harvesting and gripping the samples, and the ability to obtain meaningful quasi-static results over large strain ranges as well as to measure various dynamic characteristics.

Sample Preparation

Among the greatest challenges of measuring such small fibers are harvesting the specimens and determining a suitable method for mounting them. The samples can be harvested in several ways: silks can be collected from native sources such as webs, egg sacs, draglines, and the swathing silks used to wrap prey. As shown in Figure 1, silks can also be harvested via forcible silking, a process that entails pulling fibers directly from the spinnerets of anesthetized spiders.

Figure 1. Forcible silking of *Argiope argentata*.

KLA Instruments™ scientists used a template technique to prepare spider silk samples of similar size. A circular or rectangular window was cut into the template and a specimen was glued across the window. The template was then clamped at both ends in a T150 universal testing machine (UTM). Next, the template was cut on either end of the window so the material could be tested.

Displacement Sensing

Three spider silk samples were tested using the T150 UTM. The three spider silks presented in this application note are from the species *Uloborus diversus*, *Argiope argentata* (silver garden spider), and *Latrodectus hesperus* (western black widow). Figures 2 and 3 show the SEM image and quasi-static results for Uloborus diversus. This sample is of particular interest, as it is only 500nm in diameter. These fibers can only be seen with the naked eye by the reflection of strong light. Note that the load portion of the curve in Figure 3 is in μN.

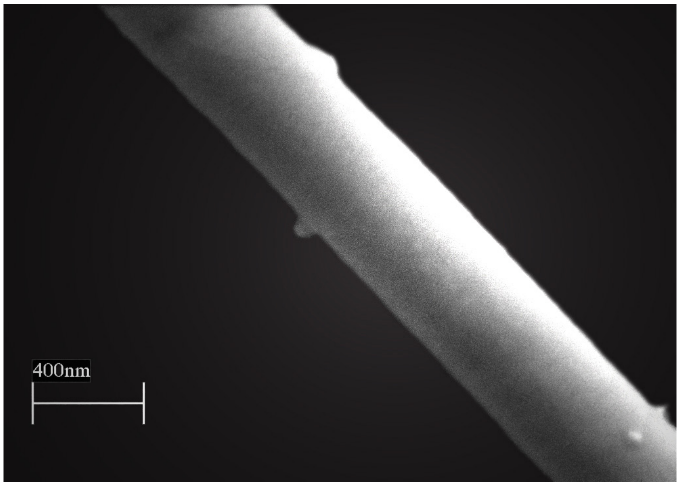

Figure 2. SEM image of 500nm *Uloborus diversus* spider silk.

Uloborus diversus has some notable material characteristics, including an ultimate tensile strength of 1.150GPa and a modulus as high as 13.861GPa. Furthermore, a sample with a stiffness as low as that shown in Figure 3 (~0.124N/m) presents significant challenges and exemplifies the capabilities of the T150 UTM.

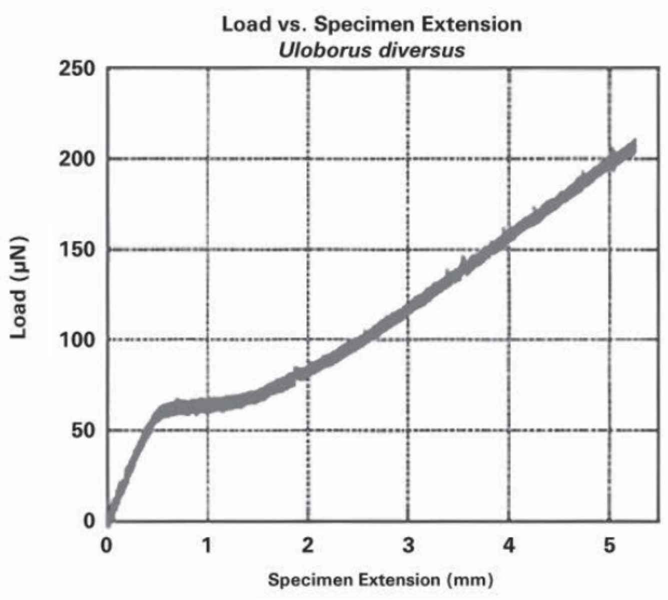

Figure 3. Loading curve for *Uloborus diversus*.

In Figure 4, the engineering stress/strain curve can be seen for silk harvested from the species *Argiope argentata*. This silk is often referred to as a "sticky silk" and is not as dry as the other two silks previously mentioned. An interesting characteristic of this silk that differs from the other two is the extreme strain that it can withstand. The stress/strain curve is very shallow out to nearly 300% strain before it starts to rise. In fact, it was pulled to nearly 430% strain before it broke. This remarkable behavior is what allows this material to perform its function so well.

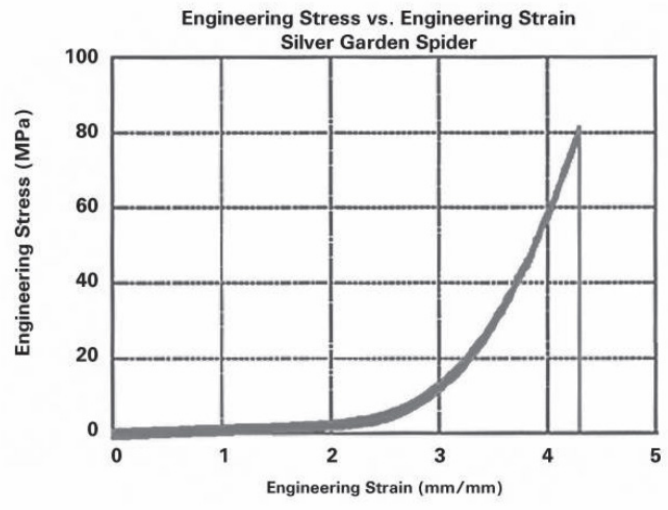

Figure 4. Loading curve for *Argiope argentata*. The sample was pulled to nearly 430% strain prior to failure.

Other material properties of interest include the dynamic characteristics (storage and loss modulus) and how these properties evolve as the static strain in the sample is increased. This analysis is done by continuously superimposing an oscillatory force on the loading of the specimen. From this oscillating force and the resulting displacement oscillation, meaningful dynamic data can be obtained. The ability to make such measurements as the static strain progresses to very large values is a unique capability of the T150 UTM.

Figures 5 and 6 show the storage modulus, loss modulus, and tangent delta respectively for the spider species Latrodectus hesperus. Tangent delta is the ratio of loss modulus to storage modulus. The dynamic data is impressively quiet for a

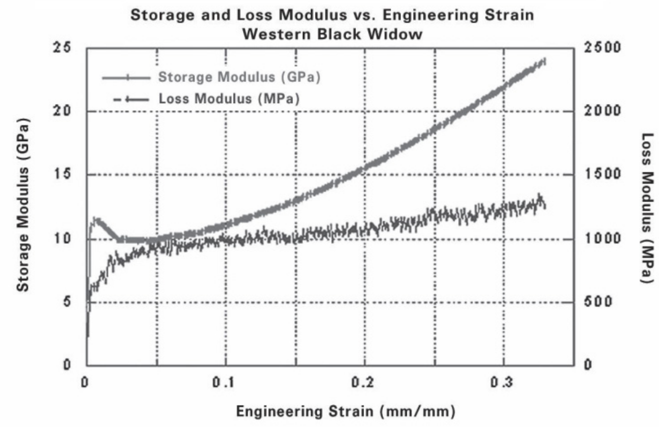

Figure 5. Storage and loss moduli for *Latrodectus Hesperus* (western black widow).

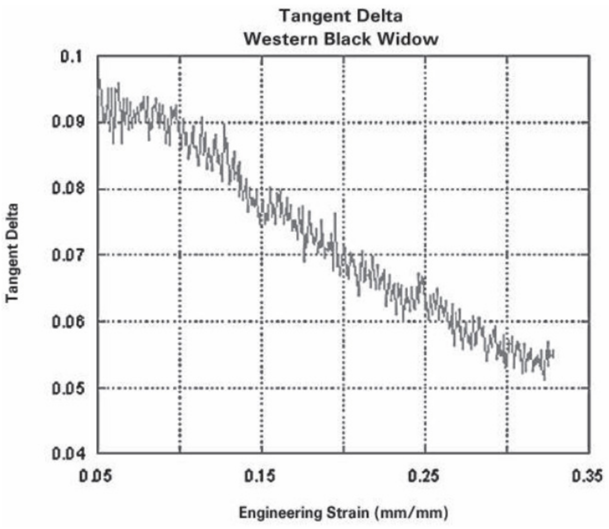

Figure 6. Tangent delta for *Latrodectus Hesperus*.

viscoelastic spider silk with a diameter of 5.574µm. Accurate measurement of such properties offers valuable support for emerging research on spider silks.

Technology and Applications

The T150 UTM is a tensile testing machine that is capable of measuring force and extension on the nanoscale with exceptional noise control. Its extension axis, driven by a screw drivetrain, operates with better than 35nm resolution using a rotary encoder; a nanomechanical actuating transducer head measures the force on the specimen with 50nN resolution.

To enable mechanical properties to be determined continuously as the specimen is strained, the KLA Instruments Continuous Dynamic Analysis (CDA) option allows the direct, accurate measurement of the specimen's stiffness at each point in the experiment. CDA makes it possible to determine storage and loss modulus, as well as to measure complex moduli over a range of frequencies.

Applications of the T150 UTM include yield of compliant fibers and biomaterials, dynamic studies of fibers and biomaterials, and tensile and compression studies of polymers.

Acknowledgments

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KLA SUPPORT

Maintaining system productivity is an integral part of KLA's yield optimization solution. Efforts in this area include system maintenance, global supply chain management, cost reduction and obsolescence mitigation, system relocation, performance and productivity enhancements, and certified tool resale.

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