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Issue 41

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Biomimetic Muscles: New Possibilities From Spider Silk

Scientists and engineers have studied and measured the amazing mechanical properties of spider silk for decades. Spider silks are stronger than steel and more elastic than rubber. They're tough; they can absorb a large amount of energy without breaking, such as when a bee collides with the web. They're sticky; some silks are spun with glue droplets along their lengths to keep that bee secure. These studies have led to developments in textiles, notably Kevlar® from the DuPont Company, with properties that mimic some of those of spider silk.

One would think that given all the research that has taken place on the mechanical properties of spider silk that there was little more to discover. But scientists at the University of Akron have recently uncovered a fascinating new fact about this material that offers intriguing possibilities for the future.

Spider silk is a fiber comprising complex protein molecules. Spiders manufacture silk from their spinnerets; organs located on the spider's abdomen. Depending on the species, spiders can have anything from two to eight spinnerets, usually in pairs.

A single spider can produce several different kinds of silk from different pairs of spinnerets, each with varying properties for specific functions. For example, dragline silk, used for a spider web's outer frame and spokes, is strong and very tough, but not sticky. Capture silk, used to trap and hold the prey, is sticky and elastic.

Silk is not exuded under pressure from the spinneret. The spider touches the spinneret to a surface, adhering the silk, and then its own motion away from that surface draws out the silk. This offers the spider even further control over the properties of the silk as the stiffness varies with the rate, and thus the force, of silk withdrawal[1].

Recently Dr. Ali Dhinojwala, the H.A. Morton Professor in the Department of Polymer Science at the University of Akron became interested in an observation made by a colleague, Dr. Todd Blackledge who commented on the fact that spider silk contracted and relaxed under varying humidity conditions.

Drs. Dhinojwala and Blackledge began to research this new behavior by hanging weights on lengths of spider silk and exposing the silk to varying humidity conditions[2]. They found that the silk contracted as humidity decreased and subsequently relaxed as the humidity increased. The contraction was sufficient to lift the weight. Moreover, the contraction of the silk was directly proportional to the humidity and was repeatable and fast – within three seconds of the humidity change. They calculate that the work generated is up to 50 times greater than that of the equivalent mass of human muscle fiber. However, the overall contraction of the silk is very small at around 2.5 per cent of the overall length.

A further limitation is the difficulty of mass production of the silk. Spiders don't tend to live too peacefully together; they have a habit of eating one other. Thankfully, the same, albeit somewhat weaker, property of contraction is found in silkworm silk where mass production is more feasible.

Artificial, or biomimetic muscle, in the form of electroactive polymers, has existed for some time. Electroactive polymers undergo changes in size or shape when activated by electricity.

Using humidity control and biological material as a source of power offers a range of fascinating possibilities in industry and the life sciences. Actuators and valves operating environmental control systems, ligaments and tendons in prostheses, all operated by exposure to wet or dry air.

The more we look, the more we learn about the incredible properties of spider silk and that master materials scientist – the humble spider.

[1] **J. Pérez-Rigueiro, M. Elices, G. Plaza, J. I. Real and G. V. Guinea** (2005). The effect of spinning forces on spider silk properties. J. Exp. Biol. 208, 2633-2639

[2] **Ingi Agnarsson, Ali Dhinojwala, Vasav Sahni and Todd A. Blackledge** (2009). Spider silk as a novel high performance biomimetic muscle driven by humidity. J. Exp. Biol. **212**, 1990-1994

Rockwell Hardness Testing of Thin Materials

Material thickness is of primary importance when choosing a Rockwell hardness scale. Too great a test load can cause material flow to occur throughout the full material thickness and to therefore react against the tester anvil. This reaction results in erroneous readings and significant misinterpretation of the actual material hardness.

As a rule of thumb, make sure the material thickness is at least 10 times the indentation depth when using a diamond indenter and at least 15 times the indentation depth for a ball type indenter. Examine the underside of the material to ensure that no deformation of the material is evident.

A far better solution is to refer to your ASTM standards which offer detailed minimum thickness requirements and appropriate conversion values. With very thin specimens, it can become necessary to reduce the applied force to eliminate breakthrough of the indenter. You can choose a Rockwell scale that uses lower test forces and has the appropriate conversion values. ASTM provides detailed tables and graphs that you should use to select the scale that offers the best results.

As an example, suppose you wish to perform a hardness test on a sheet steel specimen that is 0.51 mm. (0.20 in.) thick with an approximate hardness value of 58 HRC. ASTM E18 states that material with this hardness value must be at least 0.76 mm (0.030 in) thick to obtain valid results. So you cannot perform a standard HRC scale test on this specimen.

Reviewing ASTM E-140 conversion tables shows that 58 HRC approximately converts to 15N 89.3, 30N 79.7, or 45N 64.3. Referring to the ASTM minimum thickness table (partially reproduced below) you can see that for material 0.51 mm thick there are two scales to choose from, HR30N and HR45N. According to the table, at .51 mm the material should be at least HRN45 63 or HRN30 57 indicating that either converted scale is suitable (remember, the converted value is HR45N 64.3 and HR30N 79.7). When more than one choice is available, we recommend that you choose the higher test force scale, in this case HR45N.

Q. Do I have any options to increase productivity in Brinell Testing?

A. Conventional Brinell hardness testing is a labor-intensive manual process requiring constant human intervention. But there are options that you can use to increase automation and throughput of your testing.

The Production Brinell testing system uses the Rockwell test principle of measuring the depth of penetration to determine hardness to automatically and accurately determine Brinell hardness in a production environment.

ASTM standard E103: Standard Test Method for Rapid Indentation Hardness Testing of Metallic Materials details this test type. The systems can be integrated to production automation lines or can stand-alone. They are customizable to meet many application requirements.

Other means of achieving optical Brinell measurements are available if your test must use the more common ASTM E10 standard. A compact but integrated system incorporating a tester with a rotating turret, a high-resolution digital camera, and image capture and analysis software provides adherence to ASTM E10 while enabling fast and accurate optical measurement as an alternative to the manual measuring process.

The software automatically focuses, identifies, measures, and records the indent size and calculates hardness values. This capability significantly improves the throughput of testing, analysis and reporting. With a fully integrated system the labor-intensive, subjective, and error prone process of manual measurement is replaced with a significantly more accurate and productive process.

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