Mapping the viscoelastic properties of polymers using nanoindentation

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Video Abstract

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Abstract

Many materials scientists are in the business of “feeling” things out. Using a testing method known as nanoindentation, they’re able to tell how hard or strong a material is (and, to some extent, what it’s made of) much the same way we do—by pressing down on it. Now, researchers at the National Institute of Standards and Technology have expanded the technique to include an important material behavior previously inaccessible to these robotic fingertips: viscoelasticity. This new ability could help researchers better predict how up-and-coming supermaterials such as carbon nanotube-polymer composites behave, leading to the design of stronger and safer materials. Think about the last time you shopped for a new mattress. At some point, you probably considered going with the memory foam option (swayed, perhaps, by its billing as a NASA-designed material). What makes memory foam able to contour to your body is its viscoelastic properties. It slowly absorbs your body shape, and it doesn’t quite spring back when you roll out of bed. While we can get an intuitive sense for these properties of materials, it’s much harder to do so quantitatively using nanoindentation. In fact, most models of mechanical behavior are built to capture only two deformation modes of materials: elasticity, or how a material immediately springs back to shape, and plasticity, how permanently deformed a material remains. To measure more complex and time-dependent viscoelastic properties, Andrew Gayle and Dr. Robert Cook at NIST added an extra step to conventional nanoindenter experiments: pressing down on a material for a long time. Doing so enabled them to isolate the material’s viscoelastic behavior. It also required them to revamp the mathematical model that relates properties such as strength and hardness to the deformation data picked up by a nanoindenter. The result was a model that could predict those properties for several different materials, including these polymers, given simple input. That input could be the time it takes for a tip to press down with maximum force or that maximum force itself. The team was also able to map the properties of sample materials in 2D by creating rows and columns of tiny indentations. This is important for composite materials like this one, which is composed of carbon nanotubes dispersed in a polymer. Because they’re so strong, these small tubes make the surrounding polymer more structurally sound—but only if they’re evenly spread out. Using their mapping technique, the researchers could identify areas where some nanotubes appeared to clump together, creating fatal soft spots in the polymer around it. Better predictions of material properties will require researchers to expand the library of materials they’ve tested using this improved technique. They’ll also have to find ways to speed up the rather slow process of mapping materials, divot by divot. But the researchers’ method may already help “feel out” and shore up defects in many important structural materials, pointing the way toward stronger and safer parts and devices.