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Materials Science

Signs Of Stress

Polymers indicate imminent failure by changing color

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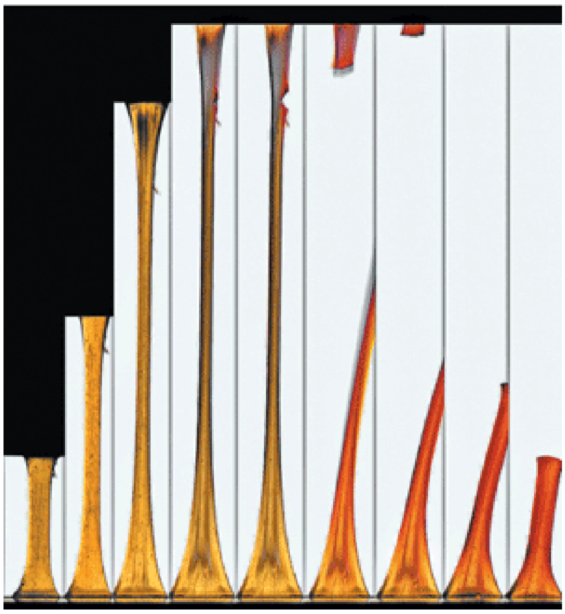
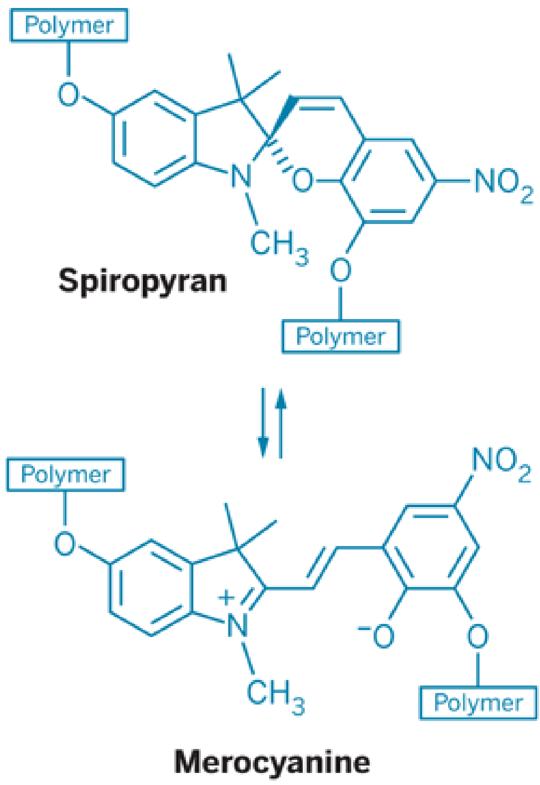
PEOPLE UNDER STRESS may exhibit certain telltale signs that indicate they're near a breaking point. Some, for example, will turn bright red just before they blow their top. Now, a new polymer does the same thing, changing color when stressed to the point of mechanical failure (*Nature* **2009**, 459, 68). Such a material could be used as a damage sensor that enables researchers to assess the effects of stress on polymeric materials before they fail.



D. Stevenson, A. Jerez, A. Hamilton & D. Davis

Embedded mechanophores turn a rubbery polymer red just before it fails.



Reckoning With Force A colorless spiropyran mechanophore undergoes electrocyclic ring opening to produce a colored merocyanine in response to mechanical force.

The new polymers can change color thanks to the addition of spiropyran molecules that undergo electrocyclic ring-opening in response to mechanical force. The resulting ring-opened merocyanine molecules are brightly colored, producing red or purple hues in the polymer, depending upon how the indicator molecule is covalently linked to the polymeric structure.

The spiropyran undergoes "a force-induced reaction inside of a solid structural polymer," explains University of Illinois, Urbana-Champaign, materials science professor Nancy R. Sottos, who spearheaded the research. "It's a selective covalent bond cleavage that occurs long before there is any backbone cleavage" of the polymer itself, she adds. Force-sensitive molecules, known as mechanophores, have been added to polymers in solution before, but this is the first time they've been incorporated in solid polymers, according to Sottos.

"The trick was precisely placing the mechanophore, which is a very small molecule, into a large polymer chain," Sottos says. She notes that her team chose a particular spiropyran as their mechanophore because it contains multiple potential attachment points. Thus they were able to incorporate the molecule in both a rubbery poly(methyl acrylate) polymer and a glassy poly(methyl methacrylate) polymer.

"These polymers are extremely interesting to materials scientists since they combine photo-, thermo-, and mechanochromic properties into a single system," comments Stephen H. Foulger, a materials science professor at Clemson University, in South Carolina. "These properties, coupled with the fact that the color change can be maintained with the cessation of stress, can be exploited by engineers in the design of polymeric components that visually indicate to the end-user their stress, strain, thermal, or ultraviolet-visible light exposure history. It's a true smart material," he says.

Sottos tells C&EN that the work demonstrates the concept that mechanical force can trigger the activation of specific covalent bonds in a polymer. She hopes to develop new mechanophores that do more than just change color. For example, molecules that cross-link or polymerize in response to mechanical stress could lead to self-toughening or self-healing materials, she says.

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