Materials break, then remake, bonds to build strength

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Microscopic tears in a new kind of man-made material may actually help the substance bulk up like a bodybuilder at the gym.

"We've shown how normally destructive mechanical forces can be channeled to bring about stronger materials," said Duke chemist Steve Craig, who led the research. "The material responses are like Silly Putty transforming into a solid as stiff as the cap of a pen or a runny liquid transforming into soft Jell-O."

Scientists could one day use the stress-induced strength from these new materials to make better fluids such as engine oil, or soft-structure substances such as artificial heart valves. Materials like this wear out over time because of the repeated mechanical forces they experience during use. But Craig said if a material had properties to slow down its destruction, it would greatly improve quality of life.

It is the first time scientists have used force-induced chemistry within a material to make it stronger in response to stress. The results appear Monday, Aug. 5, 2013, in *Nature Chemistry*.

In past experiments, Craig's team has gripped and tugged on individual molecules of a material to see how it reacted at the atomic level. Now, the scientists have scaled up the material to contort it macroscopically and see how it responds.

Craig said the response is similar to what happens when a person lifts weights. Those individual stresses trigger biological processes in the muscles that ultimately increase the person's strength.

"It's the same idea chemists would like to use for synthetic materials," he said. "Everyday materials can wear out with repeated stress. Think of your favorite t-shirt or even the oil in your car engine. Wear after wear, fire after fire, these materials break down."

The new man-made materials Craig's team is making have characteristics already in place so that when a stress triggers a bond to break, it breaks in a way that triggers a subsequent reaction forcing the busted atomic bonds to reform new ones.

"It's like snapping a string. But before the string snaps, sites along it form so that when it breaks it can become tied to another string," Craig said.

The scientists first stressed one of the test materials by pulsing high-intensity sound waves through them. The sound waves create bubbles, which typically collapse and break the bonds of the molecules in the material. The forces breaking atoms in the new materials, however, triggered the formation of new bonds, which strengthened the liquid by transforming it into a soft Jell-O consistency.

To test the strength-building ability of a Silly-Putty-like material, the team used a twin-screw extruder, which is as damaging as it sounds. The machine bores two screws into a material and pulls the material through it, destroying some of the material's molecular bonds. Here too, the synthetic material formed more new bonds than those destroyed, becoming much more solid in structure and stronger.

Craig said one drawback to the new materials is that forces deform the material's initial structure. It is stronger at the end, but is not the same shape. The team now plans to create synthetic materials that can repair themselves after stress and retain their original shape, he said.

The team would also like to engineer the material to respond faster. "At this point it takes minutes for the strengthening reactions to start changing the material," Craig said. "We could see it happening as quickly as milliseconds."

More information: "Mechanochemical Strengthening of a Synthetic Polymer in Response to Typically Destructive Shear Forces," Black Ramirez, A. et. al. *Nature Chemistry*, August 2013. DOI: 10.1038/nchem.1720

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