Squeezing polymers produces chemical energy but raises doubts about implant safety

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A polymer is a mesh of chains, which slowly break over time due to the pressure from ordinary wear and tear. When a polymer is squeezed, the pressure breaks chemical bonds and produces free radicals: ions with unpaired electrons, full of untapped energy. These molecules are responsible for aging, DNA damage and cancer in the human body.

In a new study, Northwestern University scientists turned to squeezed polymers and free radicals in a search for new energy sources. They found incredible promise but also some real problems. Their report is published by the journal Angewandte Chemie.

The researchers demonstrated that radicals from compressed polymers generate significant amounts of energy that can be used to power chemical reactions in water. This energy has typically been unused but now can be harnessed when polymers are under stress in ordinary circumstances -- as in shoe soles, car tires or when compacting plastic bags.

They also discovered during the study that a silicone polymer commonly used in implants for cosmetic procedures releases a large quantity of harmful free radicals when the polymer is under only a moderate amount of pressure. These findings suggest the safety of certain polymer-based medical implants should be looked at more closely.

"We have established that polymers under stress create free radicals with overall efficiencies of up to 30 percent and shoot the radicals out into the surrounding medium where they can drive chemical reactions," said Bartosz A. Grzybowski, an author of the paper and the Kenneth Burgess Professor of Physical Chemistry and Chemical Systems Engineering. "These radicals can be useful or they can be harmful, depending on the situation."

Grzybowski and his team are the first to use this energy to drive chemical reactions by simply surrounding the compressed polymer with water containing desired reagents.

The radicals created in the polymer migrate toward the polymer/water interface where they produce hydrogen peroxide, which then can drive chemical processes.

"You can get a surprisingly large amount of chemical energy from a polymer under compression," Grzybowski said. "This energy is, in a sense, free for the taking. Under normal circumstances, the energy is virtually never retrieved from deformed polymers, which then age unproductively. But you could recharge a battery from the energy produced by walking or driving a car. And you could capture even more energy when compacting millions of plastic bags."

Grzybowski is also director of Northwestern's Non-Equilibrium Energy Research Center, which is funded by the U.S. Department of Energy.

"We are interested in new sources of chemical energy, and this energy from the simple breaking of polymers' bonds is not being used," he said. "By surrounding the polymer with a medium, such as water, we can produce environmentally friendly chemical energy. One direction we are pursuing is to use this energy to sanitize water in developing countries. This is possible because hydrogen peroxide produced by squeezed polymers kills bacteria."

The researchers confirmed that mechanical deformation -- moderate squeezing -- created free radicals in the polymers. They also determined the number of radicals produced in a polymer under pressure is approximately 1016 (10 to the 16th) radicals per cubic centimeter of polymer -- a substantial amount.

They next filled polymer tubes with water, squeezed the tubes and measured the total number of radicals that migrated into the surrounding solution. They found that nearly 80 percent of the radicals made the trip.

Grzybowski and his team demonstrated they can squeeze a polymer, such as what might be found in a shoe, tire or plastic bag, and get a mechanical-to-chemical energy conversion of up to 30 percent -- approaching the energy efficiency of a car engine.

The hydrogen peroxide produced when a polymer surrounded by water is squeezed can power a variety of chemical reactions, including fluorescence, nanoparticle synthesis and dye bleaching, the researchers showed.

To illustrate the process, they converted a Nike Air LeBron shoe into a "lightning shoe," where the air pockets in the polymeric sole are filled with a solution of a compound that lights up in the presence of radicals. After a person walked in the shoe for 30 minutes or more, enough radicals were created to generate a blue glow visible to the naked eye.

The researchers studied seven different polymers, including a number of particular public interest. Poly(dimethylsiloxane), a silicon-based material commonly used in medical implants, was one of them. In the lab experiments, the medium surrounding the polymer and the amount of pressure exerted on the material were similar to what would be found in the human body, Grzybowski pointed out.

"Our findings are somewhat worrisome since every polymeric implant in the human body experiences mechanical stresses and, as we now know, can produce harmful free radicals and liberate them into surrounding tissues, which may contribute to diseases such as cancer, stroke, myocardial infarction, diabetes and other major disorders," Grzybowski said. "With this knowledge, I am quite happy to have a metal implant in my knee, rather than a polymer implant.

"From a scientific perspective, our work proves yet again that a phenomenon can be useful or harmful depending on how we implement it," he said. "The same polymer can be a useful source of energy when outside of a human body, yet a potential risk hazard when implanted into it."

More information: The title of the paper is "Mechanoradicals Created in 'Polymeric Sponges' Drive Reactions in Aqueous Media." In addition to Grzybowski, other authors of the paper are H. Tarik Baytekin and Bilge Baytekin (who contributed equally).

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