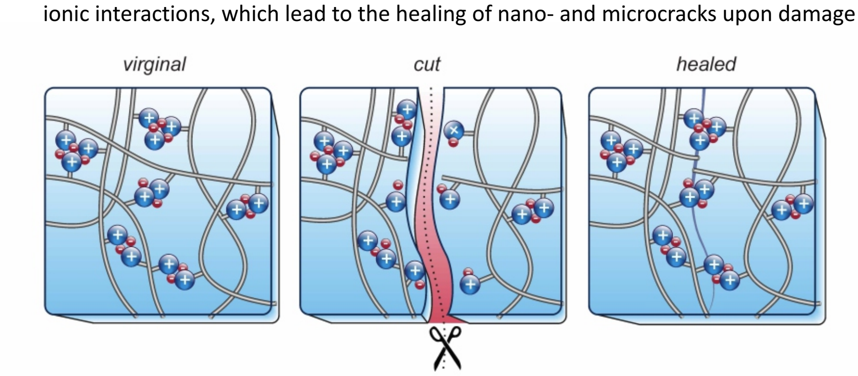
Smart Elastomeric Materials: Self-Healing, Sensors, Adaptive Systems and Energy Harvesting

Smart elastomeric materials have been developed which change one or more of their properties through external stimuli such as stress, temperature, humidity, pH value, electric or magnetic fields. By developing various intelligent elastomers, new functions for future applications are to be integrated into these new materials. Based on the studies carried out in our laboratory in recent years, we have been able to take advantage of the amorphous to crystalline phase transformation of some specific organic and inorganic fillers in a rubber matrix to control the mechanical performance of rubber products by a detailed understanding and manipulation of the phase structure. One part of our research interest is the development of electroactive elastomers, which can be used as actuators, sensors and energy harvesting materials. Another research interest of our team is the use of different chemical functionalities of polymer chains to non-covalent network structures for the development of smart rubber materials such as self-healing elastomers.

Self-Healing Rubbers

Due to frequent mechanical stress, rubbers are subject to permanent wear. In this respect, it is obvious to improve their service life by applying the principles of self-healing. Non-covalent interactions such as hydrogen bonds and ionic interactions, which lead to the healing of nano- and microcracks upon damage are utilized.

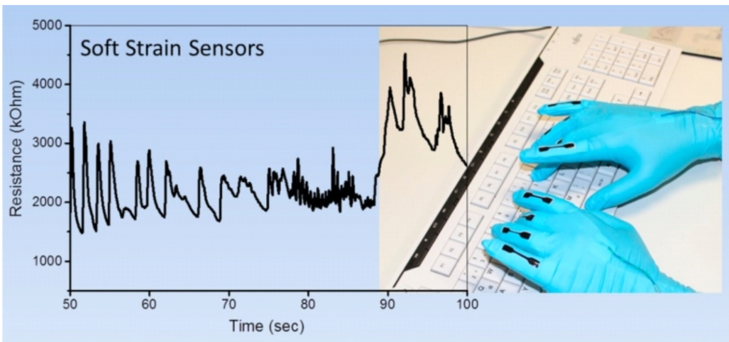


Schematic sketch of the self-healing of an ionically cross-linked elastomer: broken cross-links can heal by rearranging the ion clusters.

Compounding with surface-modified silica has significantly improved the material properties without sacrificing self-healing properties. Accelerated self-healing can be achieved by Joule heating of electrically conductive rubbers filled with conductive particles such as carbon nanotubes or special carbon blacks.

Static and Dynamic Strain Sensors from Conductive Elastomers

Electrically conductive elastomers filled with carbon nanotubes or special carbon blacks are promising materials for sensor applications. This type of elastic materials could be used in structural health monitoring, sensors in different dynamic elastomeric parts like tires, valves, gaskets, engine mounts, etc.

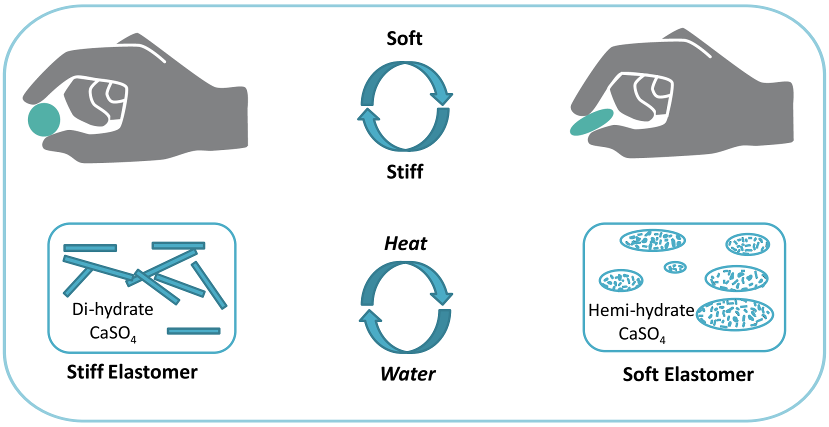


An exemplary application of elastomer sensor materials: strips of conductive rubber serve as sensors for finger movement.

Strain sensing in rubbers is based on the concept of *piezoresistivity,* where the electrical resistance of the material changes with a mechanical deformation. The piezoresistive behavior was also studied under dynamic conditions. This method offers the possibility to monitor and predict the mechanical stress relaxation from the electrical resistance data, which could be directly realized for these sensor materials serving under static as well as dynamic conditions.

Intrinsic Mechano-Adaptive Rubbers

Mechanically adaptable elastomer composites are a class of stimuli responsive polymer composites which can reversibly change their mechanical properties when it comes in contact with stimuli like electric field, light, water, solvents, ions and others.



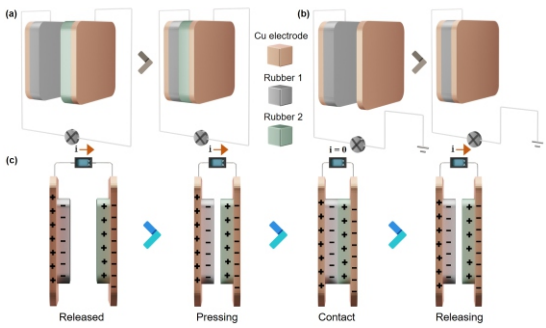
Polymorphic, transition-induced mechanical adaptability: A hydrophilic elastomer filled with calcium sulfate can be reversibly switched from the hard to the soft state by the stimuli "water" and "heat".

Two approaches for mechano-adaptive material have been studied intensively:

- Filler morphology transformation: Polymorphic transition of filler material (i. e. calcium sulfate) induced mechano-adaptability
- Phase transition of fillers: Solid-liquid transition of an additive (i.e. water) induced mechano-adaptability

Energy Harvesting Rubbers

Triboelectric nanogenerator (TENG) has now been considered as one of the emerging breakthrough technologies that can transform ambient environmental energies into electricity by coupling of triboelectric effect and electric induction. Not only energy harvesting but also different types of TENG are now being developed that can be utilized in motion, chemical sensing as well as wearable device. Our group is trying to integrate different types of flexible elastomers to TENG fabrication for environmental energy harvesting.



Working principle of contact–separate TENG.
a) Configuration of TENG under double-electrode mode.
b) Configuration of TENG under single-electrode mode.
c) Working principle of TENG.

Contact

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