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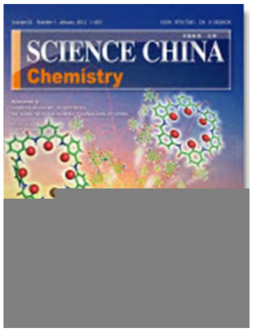

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Rubbery Neat Carbon Aerogels

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Polymeric elastomers possess unique elastic mechanical properties that set them apart from other materials, and enable wide applications in a large variety of products such as elastic films, foams and tires. The polymer chains tend to be coil-like due to thermal fluctuation but can also be straightened by external forces, leading to large reversible deformations. But essentially all elastic polymers soften and break down at high temperatures and more typically, undergo glass transition and gradually become hard and brittle and lose the elasticity at lower temperatures. As to inorganic materials, the short-range strong ionic/covalent bonds limit their elastic transformation, which only offers very small reversible elongations. Light-weight, super compressible carbon aerogels with multi-functionalities, such as high conductivity, and light driven response [1] and so on, are providing a promising platform to overcome such limits. Their compress elasticity has been achieved but the stretching elasticity is extremely poor. As a result, to achieve such a carbon-only based rubber with high stretching elasticity still remains a great challenge.

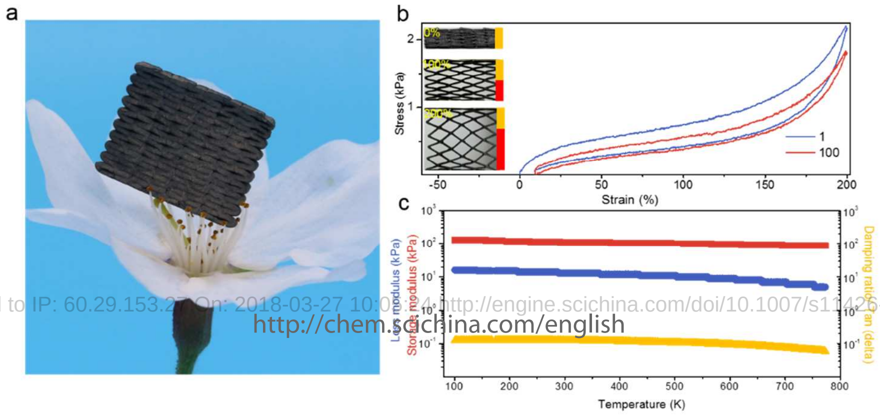
Recently, the group led by Prof. Chao Gao and Zhen Xu at Zhejiang University overcome the stretchable brittleness of neat carbon aerogels using graphene as the building block with a hierarchical structure ranging from the nanometer to centimeter scale [2]. The synergy of the hierarchical structure across multi-scales together with pre-buckled micro conformations is an important strategy to enable a macroscopic object or material flexible and stretchable to conform to complicated deformations, if the proper building block is used. This useful strategy has been found often in the Mother Nature, such as the growth of embryos to leaves in plants and wrinkles on our skins.

The authors fabricated their hierarchical graphene-carbon nanotube (CNT) aerogels by 3D printing, freeze-drying and confined reduction (Figure 1a). This procedure endowed carbon aerogels with tunable hierarchy and high elasticity. The aerogels are able to be reversibly stretched to more than triple their original length (Figure 1b) and maintained initial macroscopic shape and microstructures after more than million cycles of stretching and release. In addition, the elasticity could be well maintained from -198~500 °C (Figure 1c), surpassing the all traditional polymer elastomers which become viscous or brittle in extreme temperatures.

Guo and colleagues' work also revealed the root of synergistic effect between two types of carbon nanomaterial with mixed topologies. They used a strain-induced buckling metrology [3] to assess the enhancement effect of CNT and proved that the elasticity modulus and fatigue resistance are improved dramatically by introducing CNT.

Furthermore, profiting from the integration of ink-print technique, the deformation behavior of carbon lattices can be programmed to meet various application needs. This new ultralight carbon rubber with tunable stretchability and compressibility can be used as logically strain sensors to decipher motion modes of a "snake" robotic arm. Its good electric conductance may lead to a host of new applications of carbon aerogels as multifunctional components in actuators, sensors, soft robots and wearable devices.

The results indicate that neat carbon materials can possess rubber stretchable elasticity with other advantages such as ultra-lightness, temperature invariance and mechanically robust



performance. This might also offer some hints to design more exciting multifunctional materials using the recently emerged other 2D nanomaterials and even conventional inorganic constituents and ceramics.

Figure 1. (a) A digital photograph of ultralight rubbery carbon aerogel with density of 5.7 mg/cm^3 floating on a flower. (b) Cyclical tensile-release curves for a designed carbon aerogel with stretchable ratio of 200%. (c) Storage modulus (red), loss modulus (blue), and damping ratio (yellow) as function of temperature.

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