Interfaces in copper-rubber based stretchable electronics

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Stretchable electronics are nowadays finding applications in electronically textiles and biomedical diagnostic devices. These are typical engineering systems that seek for compromises between mechanical strength and electrical conductivity. This has led to various patterning solutions in which a stiff copper material is integrated on top of or within a compliant rubber substrate. The weak spot of this design is the copper-rubber interface, where delimitation is the precursor to failure of the device. The mechanisms that govern the macroscopic toughness of this interface are therefore important, but unfortunately not really understood. At the micro-scale, the typical order of magnitude for the adhesion energy is 1 J/m^2, whereas at the macroscopic scale it can amount to 1000 J/m^2 and higher. This difference of three orders of magnitude is an open multi-scale question, in particular since the rubber used is known as a hyperelastic material with an intrinsic fracture toughness that is even much higher.

This contribution aims to unravel the huge gap that exists between the microscopic adhesion energy of a copper-rubber system and its macroscopic work-of-separation. The different contributions to the macroscopic energy are identified in a progressive manner, using homogenisation methods and numerical tools to identify the role of discrete fibrils in the copper-rubber interface. The systematic analyses carried out, which rely on a combination of micro mechanics, small-scale experiments and multi-scale simulation methods, have provided a sound physical basis for the energy gap across the scales in copper-rubber interfaces. The results also reveal intrinsic shortcomings of continuum based methods, like cohesive zone models, where all dissipative phenomena have to be lumped in the interface, which cannot resolve the underlying phenomena in a physical manner.