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MULTI-SCALE MODELLING OF DELAMINATION THROUGH FIBRILLATION

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Stretchable electronic devices improve the design freedom, comfort and portability of electronic products. These devices typically consist of small rigid semiconductors which are interconnected with thin metal conductor lines. These interconnects are located on top of, or encapsulated in, a highly compliant substrate (typically a rubber material). It has been shown that the maximum stretchability that can be achieved for a given interconnect design is determined by stretching-induced interface failure [1].

In earlier work it was observed that the main interface failure mechanism was fibrillation [2]. This involved the formation, elongation and rupture or delamination of rubber fibrils. Because of the fibrillation process, several problems arise when using with traditional macroscopic modelling approaches. The first concern is the lack of a clear quantitative relation between the obtained cohesive zone parameters and the observed fibrillation micromechanics. It was observed by [3] that the fibril length was about 6 times smaller than the obtained cohesive zone critical opening length. Furthermore the fibrillation micromechanics, and thus the associated dissipation, depend on the loading conditions [2]. As a result, the obtained macro-scale interface properties are system properties instead of interface properties. This issue can only be resolved by accounting for the fibrillation micromechanics in the macro-scale interface description, which requires a multi-scale approach.

In the multi-scale method the macro-scale interface is still described by a cohesive zone formulation. However, the traction-separation law (TSL) is no longer defined *a priori*, but obtained from a micro-model through a numerical homogenization approach. Hence, this method allows the explicit modelling of the fibrillation micromechanics and simultaneous exploitation of the obtained response at the macro-scale. The multi-scale scheme is outlined in Fig. 1.

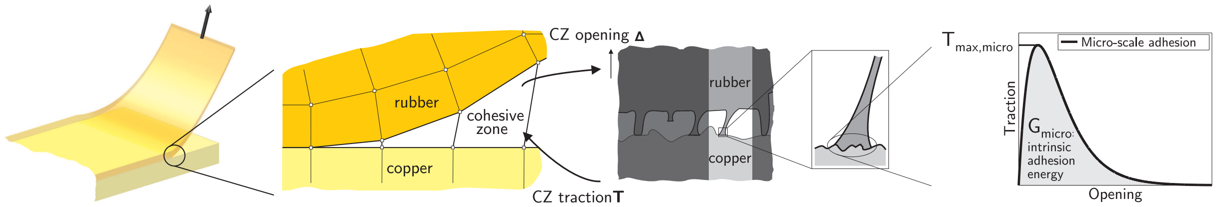

Figure 1: Multi-scale procedure. Macro (left) and micro (right).

In the micro-model physical small scale phenomena such as fibril deformation and debonding are taken into account. The fibril-substrate interface is characterized by the intrinsic adhesion energy and the interface strength. The micro-model results show the growth of a fibril, including the drawing of material from the bulk into the fibril, which is accompanied by large strains that are well beyond typical bulk strain values, see Fig. 2. Finally, the interface traction locally exceeds the interface strength and the fibril debonds instantaneously. The interface strength is shown to have a significant influence on the fibrillation process, whereas the value of the micro-scale intrinsic adhesion energy is found to be less important. The influence of the discrete nature of the fibrillation on the resulting macroscopic interface law is also studied.

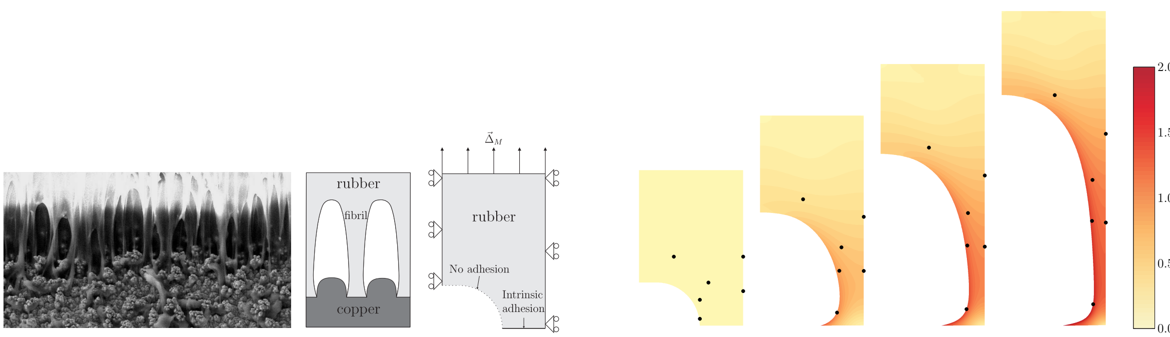

Figure 2: (Left) Fibrils connected to substrate in roughness valleys, the idealized representation and the single fibril model. (Right) Several stages of the fibrillation process. Colors indicate maximum principal true strain. The large displacement of material points is tracked by the dots.

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