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Multi-scale modelling of fibrillation in copper-rubber interface delamination

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Introduction

Copper-rubber interfaces play a major role in a variety of products, such as stretchable electronics, figure 1.

Figure 1: Stretchable electronics examples. Left: heart ablation catheter. Right: Electronic skin for wearable mobile phone.

Interface delamination causes failure of the product. An important delamination mechanism is fibrillation, see figure 2. During peeling, the dissipation mechanisms depend on the loading conditions, rendering the experimentally determined interface properties intrinsically case-specific. This hinders the development of generally applicable predictive models.

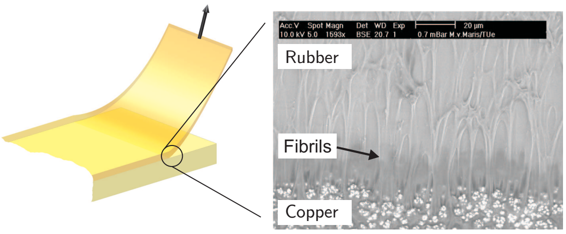

Figure 2: Fibrillation in peel test [1].

Objective: Develop a multi-scale method to take into account the micro-scale dissipation mechanisms explicitly in the macroscopic interface description.

Methods

The multi-scale approach is outlined in figure 3. Cohesive zones (CZs) are used to describe the interface behavior on the macroscale. The CZ traction-opening relation is obtained from the underlying micro-mechanical model. The current micro-model consists of a single fibril. The roughness of the substrate is taken into account in a simplified way.

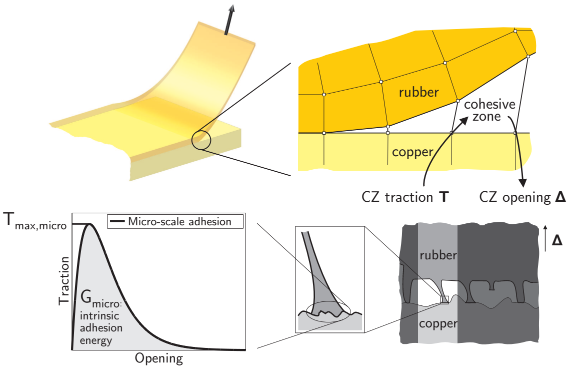

Figure 3: Multi-scale procedure. Macro (top) and micro (bottom).

Results

Micro-model results are shown in figure 4. The graph shows the homogenized traction-separation response obtained from the single fibril model. The insets show several stages of the fibrillation process. The last inset shows the fibril right before it suddenly debonds from the copper. This causes the loss of the energy stored in the fibril, leading to macroscopically observed dissipated energy G_{macro}.

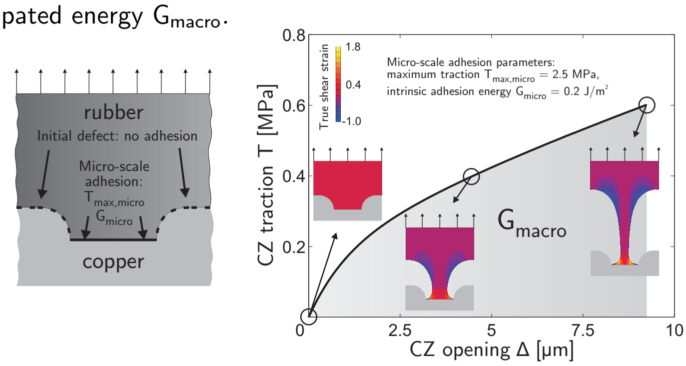

Figure 4: Left: Initial single fibril geometry with simplified roughness profile. Right: Homogenized traction-separation response.

The influence of the micro-scale adhesion parameters (maximum traction $T_{\mathrm{max,micro}}$ and intrinsic adhesion energy G_{micro}) on the macroscopic dissipation G_{macro} is shown in figure 5. The insets show the final deformed shape; for low $T_{\mathrm{max,micro}}$ no fibrillation occurs and micro-scale delamination prevails, $G_{\mathrm{macro}} = G_{\mathrm{micro}}$.

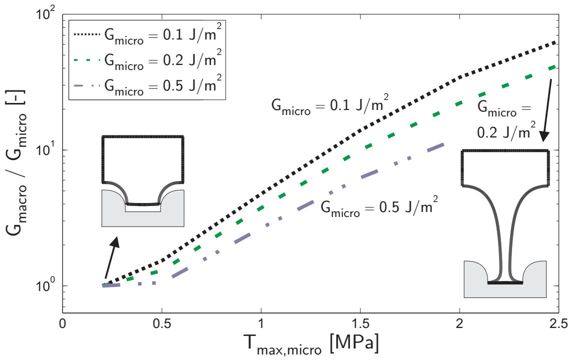

Figure 5: $T_{\mathrm{max,micro}}$ controls the fibrillation process.

Conclusions

- A micro-model describing fibrillation was developed.
- Fibrillation was taken into account in the macroscopic interface description.
- The micro-scale parameter $T_{\mathrm{max,micro}}$ mainly controls the fibrillation process.
- The macro-scale dissipated energy G_{macro} can be orders of magnitude larger than the intrinsic adhesion energy G_{micro}.

References:

[1] vd Sluis, O. *et al.*: J. Phys. D: Appl. Phys., 44:034008, 2011