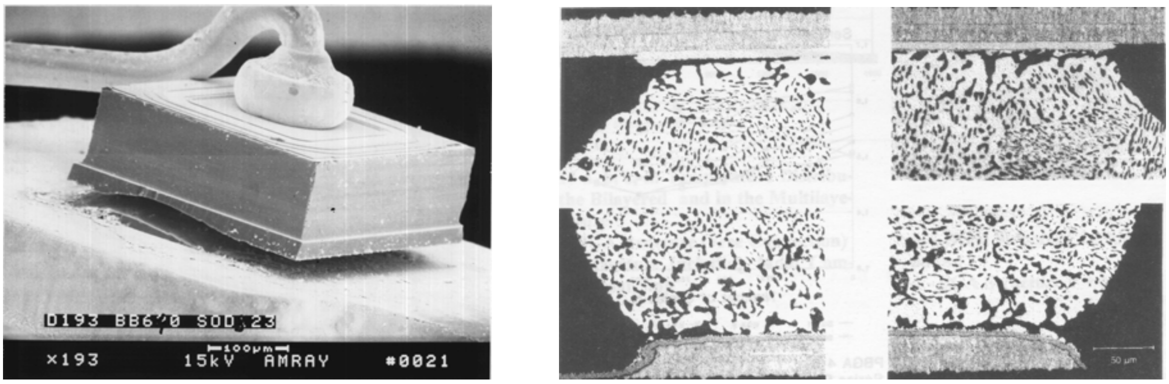
Fracture Mechanics of Heterogeneous Materials

It was the physicist Ludwig Boltzmann who said that there is nothing more practical than a good theory. Indeed, even a classical discipline of theoretical renown, such as technical mechanics, can help to improve the quality of technical products and engineering constructions. One particular example is fracture mechanics at bimaterial interfaces as they inevitably occur in structures made of more than one material. In fact, this discipline is a symbiosis of mechanics concepts and methods from materials science. Initially it was of direct advantage for large scale industrial applications, for example welding seams in pipelines (see figure) or combustion chambers (e.g. the main combustion chamber of the space shuttle), the reliability and lifetime of which became assessable in a rational quantitative manner.

Failure along the welding seam of an 8 cm diameter gas pipeline

More recently interface fracture mechanics has discovered small structures as a new field of application, for example microelectronic components. These consist of a multitude of thermally and mechanically mismatched materials, which can turn into a reliability problem during long time usage (see figures).



Fracture of a glued-on microchip (left), fracture between the solder joint and fracture at a BGA solder bump interconnect (right)

We use 3D finite element (FE) tools (ABAQUS) to study such situations and to assess crack-driving forces, for example by means of J integral techniques:

$$J_k = \lim_{\varepsilon \to 0} \oint_{\Gamma} b_{kj} \cdot n_j \cdot d\Gamma$$

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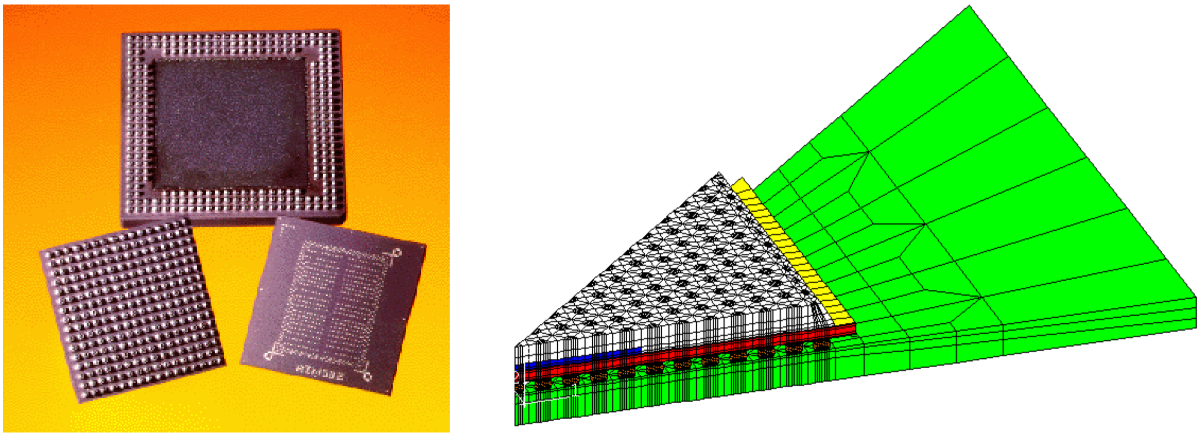
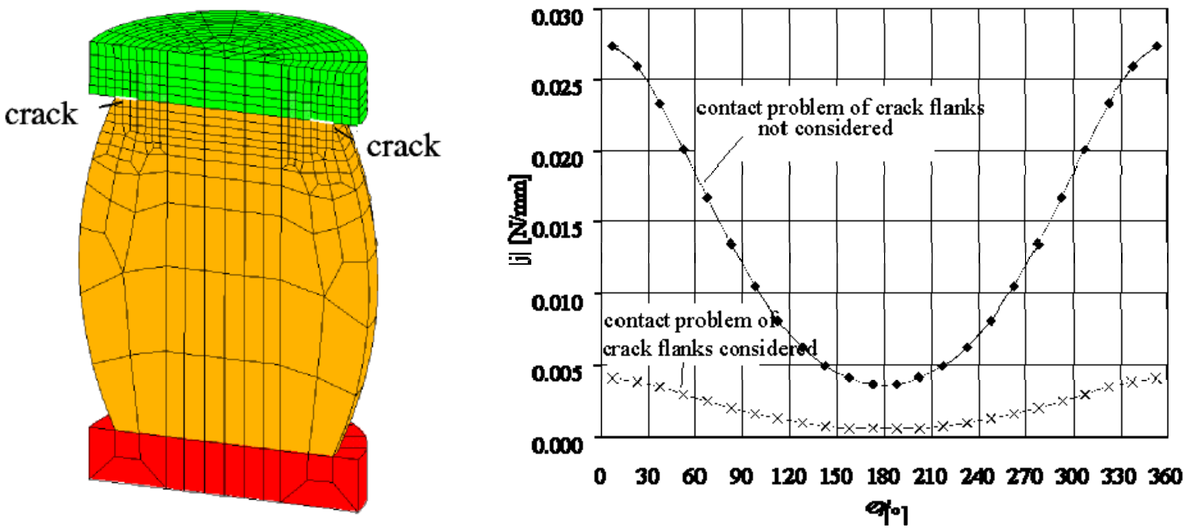
In this equation b_{kj} denotes Eshelby's energy-momentum tensor, which can be obtained from the stresses, strains and displacements around the interface crack tip, and n_j is the outward normal along a curve surrounding the crack front Γ. Equations like these are implemented in self-made postprocessors to complement an ABAQUS analysis. Use is also made of sub-modeling techniques as illustrated in the figures.



A Ball Grid Array (BGA) and its FE-representation



Submodel of a solder bump in a BGA containing a crack and the corresponding crack driving forces

Alternatively to finite elements we use discrete Fourier transforms to calculate crack driving forces. In this field of research we collaborate with Dr. Albrecht from Siemens AG in Berlin and Professor K. P. Herrmann's group at the Laboratorium für Technische Mechanik at the University of Paderborn in Paderborn/Germany.