Examples Computational Mechanics (4MC10) – Two-dimensional vector

Indentation is a quick and effective method to characterise the mechanical properties of solid materials. Contrary to the classical hardness measurement, modern indentation-equipment (see for instance the picture on the left in Figure 1) allows one to continuously monitor the displacement of and the force acting on the indenter tip. Micro-indentation, in which indenter tips are used with dimensions on the order of micrometres, is an appropriate method to characterise coatings. In this example we assume a flat indenter tip as depicted on the right in Figure 1.

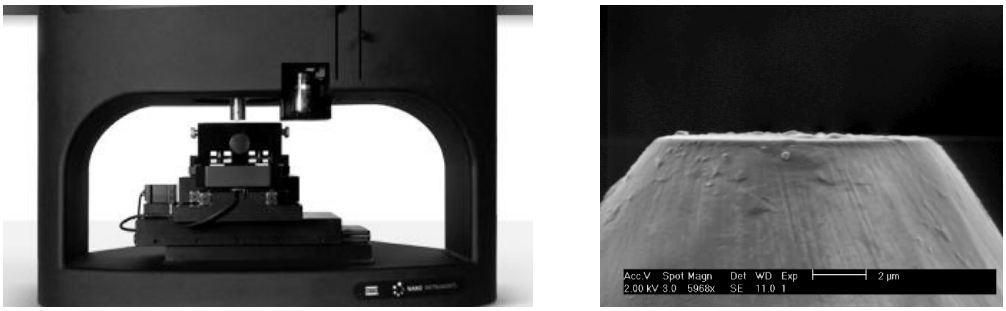

Figure 1: Indentation equipment: (left) image of a micro-indenter and (right) electron-micrograph of a flat indenter tip (depicted upside-down)

In this example we analyse the deformation and stress state induced in the coating during an indentation measurement. We assume a flat indenter tip of 10 μm width – see the sketch on the left in Figure 2. For simplicity, we limit ourselves to a two-dimensional analysis. This implies that the indenter has a trapezoidal shape. In the direction perpendicular to the plane of the sketch we assume a plane-strain state; the size of the indenter in this direction equals $T = 1.0\,\text{mm}$. We consider a segment of coating which has a length $L = 50\ \mu\text{m}$ and a thickness of $H = 20\ \mu\text{m}$. The coating is assumed to be perfectly bonded to a rigid substrate. It is furthermore assumed that the indenter tip is rigid and that no relative displacement (e.g. sliding) occurs between the tip and the coating. In the indentation test, the tip penetrates the coating surface by a distance of $d = 2.0\ \mu\text{m}$. De coating is assumed to deform elastically under the influence of the indentation. Its bulk modulus and shear modulus equal $\kappa = 30\,\text{MPa}$ and $G = 20\,\text{MPa}$, respectively.

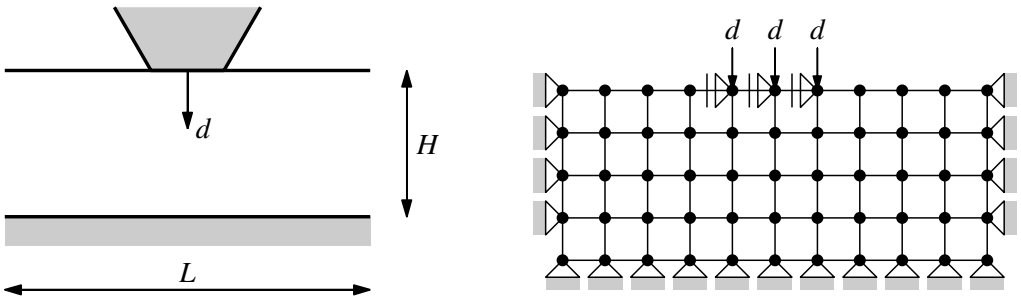

Figure 2: Sketch of (left) the problem considered and (right) the finite element discretisation and boundary conditions used in the numerical analysis

The finite element discretisation which is used to numerically compute the deformation and stress state in the coating consists of 10×4 bilinear isoparametric elements. The finite element mesh, together with the boundary conditions as described above, are shown in Figure 2.