

Stress-strain behaviour of fibrous biological material measured using an AFM/SEM hybrid

Bone is a complex composite material with a structural hierarchy from the millimeter down to the nanometer scale. On the latter, collagen fibrils - the building blocks of bone - form the predominant structural feature, significantly contributing to the overall performance of the bone. In order to understand the relationship between deformation at this fibrillar level and larger length scales, an investigation of the mechanical properties of the collagen fibrils becomes important.

In this application note, attocube's cantilever-based attoAFM I was used inside a FEI Quanta 3D Scanning Electron Microscope (SEM) to perform nanometer-scale tensile measurements of individual collagen fibrils¹. The fibrils were extracted from the fractured surface of antler and were attached to the cantilever with the aid of a high vacuum compatible glue. The actual process of coating the silicon cantilever with glue is depicted in Fig. 1a. After the collagen fibril was attached and the glue had hardened, the cantilever was slowly retracted while the force imposed on the collagen fibril was recorded. The latter measurement was achieved by interferometrically tracking the deflection of the cantilever (for the setup see Fig. 1b). With a typical cantilever spring constant of only 0.2 N/m, a force resolution better than 100 pN was readily achieved in a 1 kHz measurement bandwidth.

Fig. 2 shows the actual result of the stress-strain measurement conducted on a single collagen fibril. Up to a strain of 4 per cent, the collagen fibril deforms elastically whereas higher strain values lead to strain hardening. It is interesting to note that the collagen fibril has a failure strain of 6 % and an ultimate strength of 0.18 GPa. This makes the fibril half as strong as structural steel (ultimate strength typically 0.4 GPa) and indicates that the fibril has some degree of mineralization improving its overall performance.

Apart from the above measurements, Barber *et al.* have also addressed the question as to whether or not the vacuum conditions inside the SEM chamber alter the mechanical properties of the fibril. In this context, it was shown that vacuum exposure of less than an hour does not provide any degradation of the mechanical properties of the fibril. However, the ultimate tensile strength is reduced to 25% of its initial strength when exposed to vacuum for about 400 minutes. This decrease in strength is attributed to dehydration of the fibril.

In summary, attocube's attoAFM I was used inside an SEM chamber to measure the stress-strain behaviour of collagen fibrils, the building blocks of bone. With a force resolution of better than 100 pN, the cantilever-based attoAFM I allowed precise measurements of the mechanical behaviour of the fibrils, providing insight to their contribution to the overall mechanical performance of bone.

¹A. Barber et al., Mater. Res. Soc. Proc. 1197 (2009)

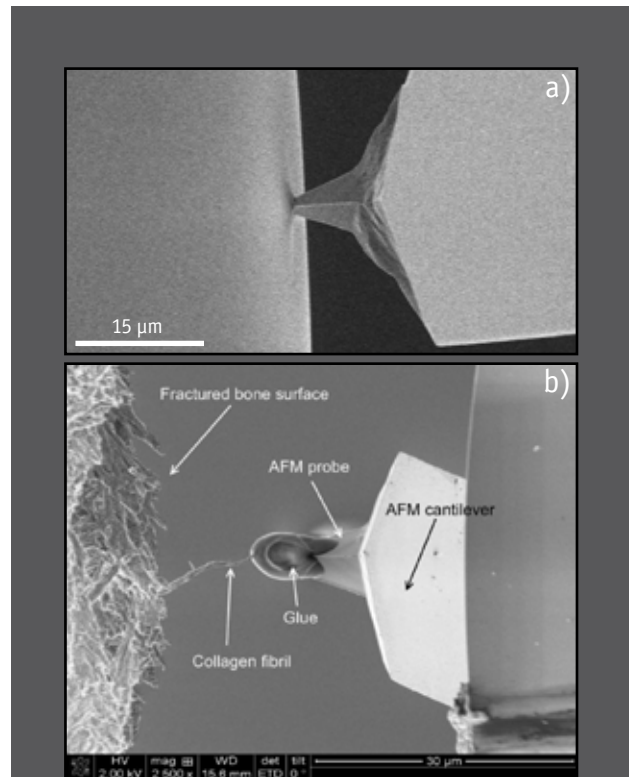


Fig. 1: (a) SEM image showing the AFM cantilever in touch with the vacuum compatible glue which is later on used to attach individual collagen fibrils to the cantilever (b) after the glue is cured, the tensile measurement is initiated. The circular object to the right hand side is the optical fiber which is used to interferometrically measure the deflection of the cantilever during any experiment.

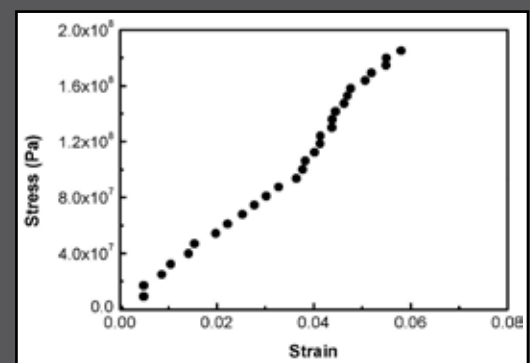


Fig. 2: Actual stress-strain measurement of a single collagen fibril. With an ultimate strength of 0.18 GPa, the tensile fibril is nearly half as strong as structural steel (0.4 GPa).

RELATED PRODUCTS

attoAFM I / SEM	cantilever-based atomic force microscopes for in-situ SEM operation
ASC500	fully digital, FPGA based SPM controller