JPK StretchingStage for AFM – Investigation of sample property changes under mechanical load

Introduction

Tensile testing has been an important part of material characterization since the latter part of the 15th century when Leonardo da Vinci designed a simple apparatus for testing the tensile limit of different lengths of wire. Whether the material is a metal, a thermoplastic or a biocompatible implant material, knowledge of its yield strength can be essential. Sophisticated tensile testing equipment has been commonplace for decades, but the ability to combine with AFM is less well established. AFM can now offer complete new possibilities in monitoring the sample property changes at nanometer resolution while putting the sample under controlled tensile forces. Changes in topography, adhesion and stiffness are among several parameters that can be investigated in a combination of the JPK NanoWizard® AFM and their newly developed StretchingStage. JPK's StretchingStage is a powerful addition to the material scientist's toolbox as it applies sample stress and deformation in the sample plane which can then be investigated in detail by the AFM.

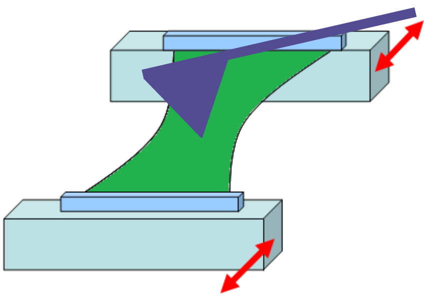

Fig. 1: Basic principle of a combination of JPK NanoWizard® AFM and JPK StretchingStage

The basic principle of tensile testing is to apply a known load to a sample and to measure the resulting strain as the sample elongates. This elongation can be either reversible or permanent and it is the stress required to effect such a permanent change that is of such importance in engineering. Accurately measuring nanometer changes in material properties can now be made directly as tensile testing is performed simultaneously with AFM measurements. In a typical experiment, the load is gradually increased and the resulting strain recorded enabling the generation of a stress-strain plot. It is common for materials to begin deforming linearly with the applied load and to reach a yield point after which the deformation increases dramatically. To get a deeper view into this process, a combination with AFM can reveal much information. The ability to study the changing morphology of the sample surface with a JPK NanoWizard® AFM can lead to interesting insights into the mechanisms involved in the yield process.

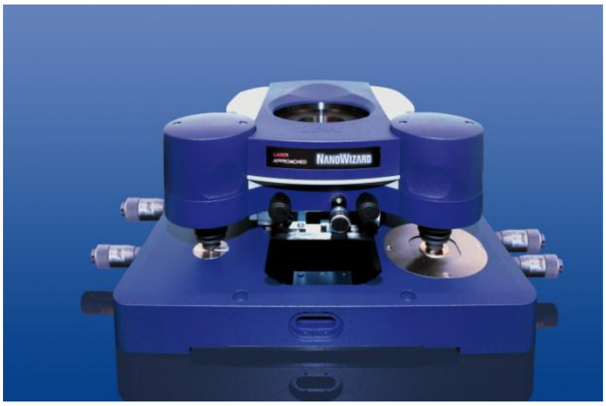

Fig. 2: The JPK StretchingStage offers motorized control of sample deformation and force readout from a choice of load cells.

New combination, new possibilities

The StretchingStage (Fig. 2) is a stand-alone stage for NanoWizard® AFM systems with integrated sample stretching and compression capabilities. The position of the head can be adjusted precisely so that the AFM cantilever is over the region of interest.

The StretchingStage is equipped with two options. While the total travel range is the same, the minimum and maximum gap of the two options is different. 10-20 mm or 25-35 mm are offered to accommodate different sample sizes. This enables the freedom to measure different sets of samples and to stretch or compress the sample horizontally while the AFM measures topographic and nanomechanical changes.

The stage houses an interchangeable load cell offering flexibility in the force range and resolution that can be accessed. The standard load cell has a maximum force of 200 N with an accuracy of ± 1 %. This means that with careful sample preparation, the uniaxial stress range that can be reliably applied runs from a few tens of kPa to a few GPa. Therefore, samples with completely different properties like plastic films, biomaterials or metals can be investigated with JPK NanoWizard® AFM while they are stressed or compressed. Experiments can be performed with fixed strain, strain rate or applied stress. The resulting force and extension data can be plotted in real-time in parallel with the AFM measurements.

Applications

The flexible and powerful design of the JPK Stretching-Stage provides the ability to study a broad range of different samples to test the influence of compressing and stretching on the nanometre scale. Possible applications include:

- Mechanical properties and structural surface changes in material science
- Deformation associated with mechanical fatigue
- Phase separation studies on block-copolymer or homo-polymer mixtures
- Study of cell behaviour on stretched biomaterials
- Interface adhesion/delamination of composites as a function of tensile stress

Example

The potential of the combination of AFM and the StretchingStage is demonstrated with a study of an elastic film. QI™ topography images of a paraffin film (Parafilm, Bemis NA, Neenah, USA) are given in Fig. 3. It shows the unstretched film (left) and then stretched to 318 % of its original length (right). What is noticeable is how much rougher the sample becomes. Note that the z-ranges are different: the stretched film is more than twice as rough.

Fig. 4 shows the stiffness (slope) images taken with QI™ Advanced mode. The images were taken simultaneously with the topography data shown in Fig. 3. It is clear that the stiffness is much more uniform before stretching.

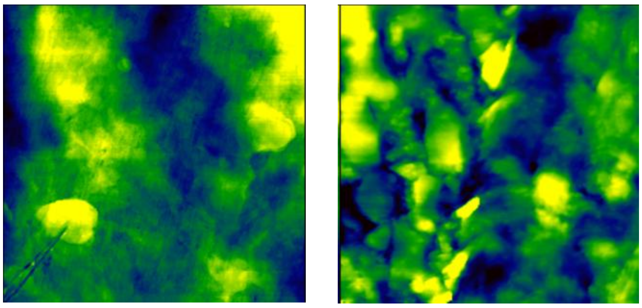

Fig. 3: Topography images of paraffin film taken in QI™ mode. Left: 8 µm x 8 µm image taken before stretching; (z-range: 100 nm). Right: after stretching to over 3 x the original length (z-range: 200 nm).

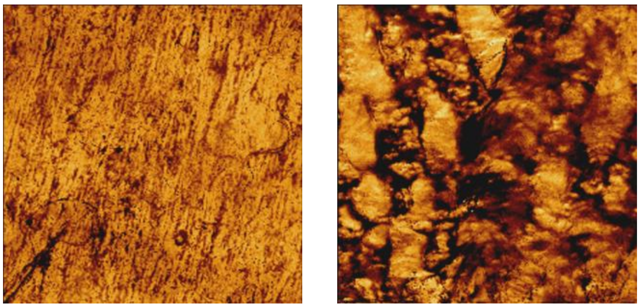

Fig. 4: Stiffness images of paraffin film taken in QI™ Advanced mode, z-range (0.2-0.45 N/m). Left: 8 µm x 8 µm image taken before stretching. Right: after stretching to more than three times the original length.

In addition, it is interesting to note that the areas that are topographically higher in the stretched image in Fig. 3 are also stiffer than the low-lying areas. Furthermore, examining the value of the stiffness in these higher islands reveals that the stiffness there is unchanged compared to the original structure. The low-lying regions are clearly softer which suggests that the original structure has a stiff layer over the top of a softer layer. This is revealed by this stretching experiment.

Conclusion

The combination of JPK's NanoWizard® and StretchingStage offers a powerful means of following changes in sample topography and mechanical properties while simultaneously straining the sample. The horizontal tensile force and displacement of the stretching device are measured and can be plotted while the AFM measurement offers a completely new insight into the nanomechanical surface changes.

Specifications

- Stand-alone stage with integrated sample stretching and compression capabilities
- Offers fine motion control for precise positioning of the AFM tip relative to the sample
- Sample size / distance between jaws 10-20 mm or 25-35 mm
- Maximum travel range: 10 mm
- Velocity: 0.1 mm/min to 1.5 mm/min
- Force range: exchangeable load cells, range 2 N and 200 N, accuracy readout +/-1 %
- Encoder: resolution 300 nm, linearity 0.1 % of full travel
- Dynamic resolution 0.1 %, static resolution 0.05 %
- Flexible design for different samples
- Real-time display of force, extension and time, live graphical display of stress/strain curve
- Other tensile testing options are available on request
- Not compatible with inverted microscopes