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Measuring Viscoelastic Properties Using Compliant Systems

James W Andrews†, David Cheneler‡, James Bowen†

† School of Chemical Engineering, University of Birmingham, UK; ‡ Department of Engineering, Lancaster University, UK

1. Introduction

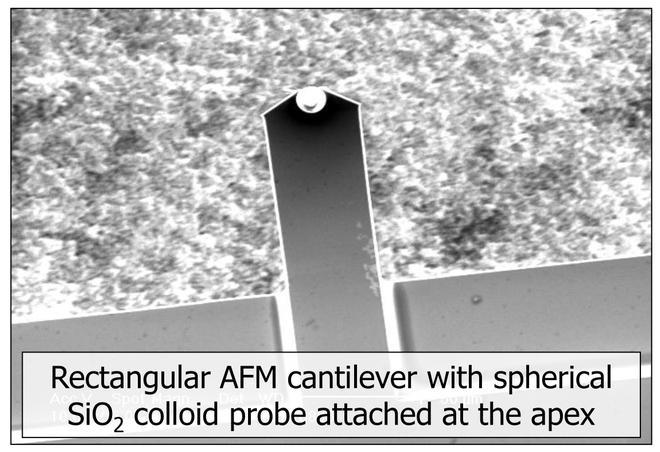
Spherical indentation is used to measure the transient mechanical properties of materials, including viscoelasticity, using stress relaxation. Example instruments include atomic force microscopes and optical tweezers.

When modelling the acquired data, common sources of error include:

(i) relaxation processes during the loading ramp are neglected;

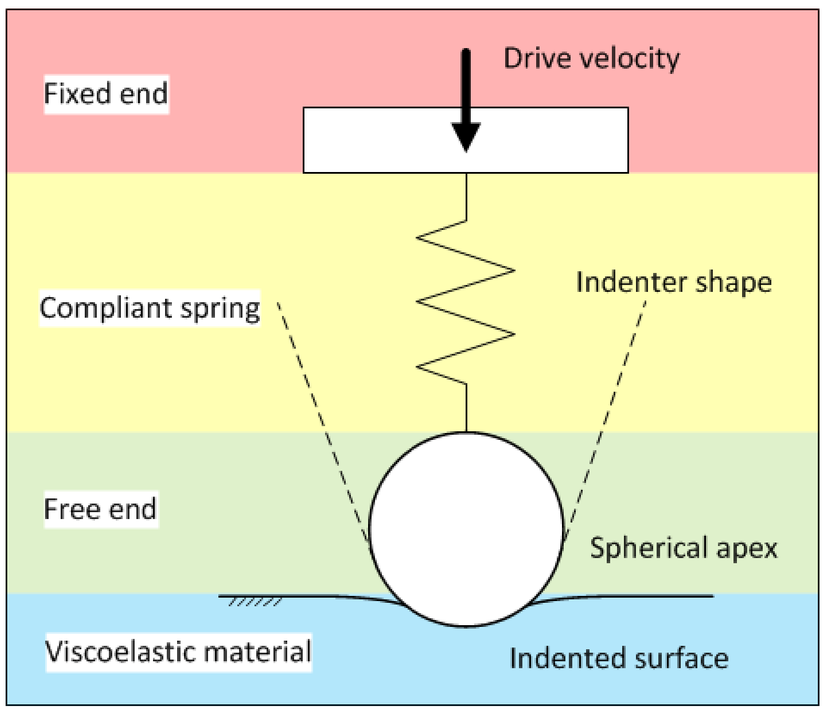
(ii) the compliance of the measuring device is not considered.

In this work, a model has been developed which incorporates both features.



Rectangular AFM cantilever with spherical SiO_2 colloid probe attached at the apex

2. Modelling and theory



Instrument designs generally contain three common elements:

(i) a fixed end, actuated piezoelectrically, mechanically or magnetically;

(ii) a compliant element or spring, which is the load measuring element;

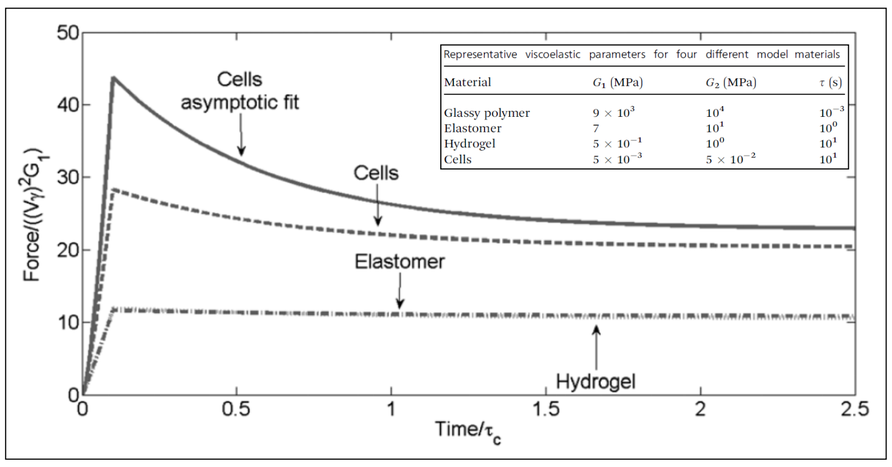
(iii) a free end, a probe of a specific geometry which contacts the sample.

Key assumptions for modelling stress relaxation in viscoelastic materials:

- Indenter is rigid compared to the material, a flat, planar half-space.
- Viscoelastic material described by a generalised Prony series model.
- Probe approaches normal to the surface.
- Contact is frictionless and there is no adhesion between the materials.

3. Results

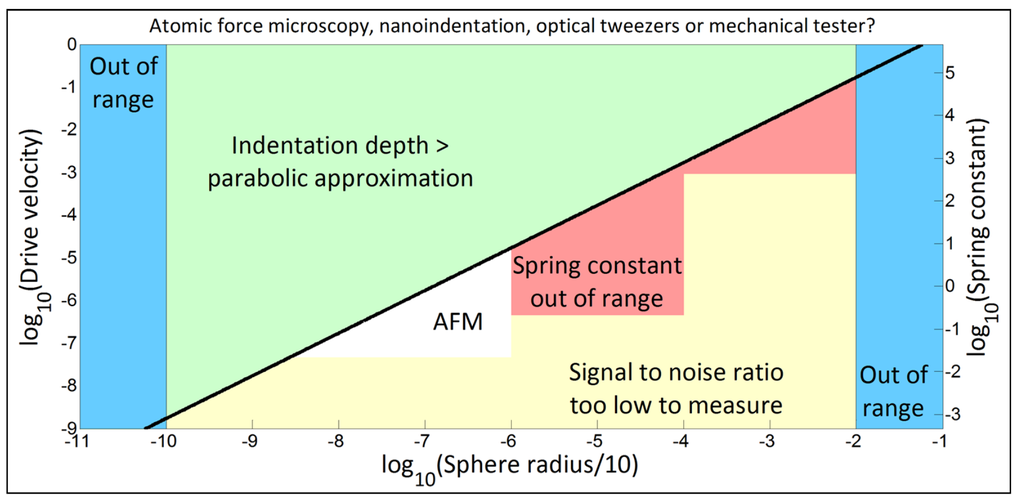
- Optimised experimental sensitivity and accuracy, ensuring relaxation spectrum is captured as completely as possible.
- Optimal indentation velocities for specified values of spring constant and indenter radius.
- Ideal ramp duration equal to one-eighth of the relaxation time.
- Materials exhibiting multiple relaxation times can be studied.
- Applicable to characterisation of poroelastic materials.



Representative viscoelastic parameters for four different model materials

Material	G_1 (MPa)	G_2 (MPa)	τ (s)
Glassy polymer	9×10^3	10^4	10^{-3}
Elastomer	7	10^1	10^0
Hydrogel	5×10^{-1}	10^0	10^1
Cells	5×10^{-3}	5×10^{-2}	10^1

4. Conclusions



- Construct maps showing permissible measurement conditions.
- Sub-optimal measurement conditions compromises the resolution of the relaxation region, giving the false impression of greater elasticity.
- Characterisation using short ramp durations and/or high spring constants is improved using this model.
- Ideal ramp durations for materials displaying multiple relaxation elements can be calculated.

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