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Probing Linear viscoelasticity with micro-indentation

C.G.N. Pelletier, L.E. Govaert, J.M.J. den Toonder, H.E.H. Meijer
Eindhoven University of Technology, Department of Mechanical Engineering

Introduction

This study gives a quantitative comparison of the creep compliance and relaxation modulus obtained by indentation with those obtained by conventional tests. For that, DMTA tests were performed, and creep compliance and relaxation modulus were predicted from the master curves obtained using a generalized Maxwell approach. The samples investigated, were two acrylate films with a glass transition temperature of 50°C and 80°C respectively.

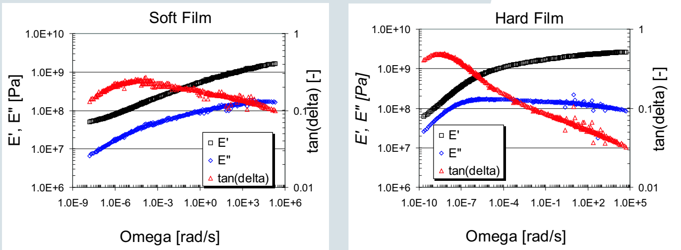


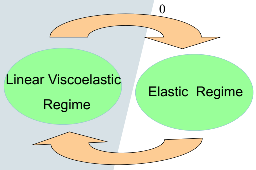
Figure 1a and b: *DMTA master curves at 25° C for both films.*

Theoretical Background

Creep compliance and relaxation modulus were calculated from the experimental data using the correspondence principle [1]:

Laplace Transform:

$L[f(t)] \quad F(s) \quad f(t)e^{st}dt$ 0

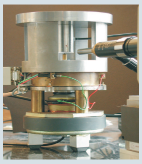


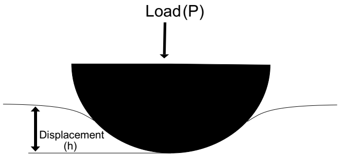
Inverse Laplace Transform:

$L^{1}[F(s)] \quad f(t) \quad \frac{1}{2 \quad j} \quad F(s)e^{ts}ds$ j j

Experiments

Indentation tests were performed on the micro-indenter designed by Philips, with a 300μm diameter spherical tip.





Indentation creep

A stepwise load is applied on the indenter and indentation depth is monitored in function of time. From the experimental data we can calculate the creep compliance for ν =const [2]:

$$D(t) = \frac{\frac{8}{3}\sqrt{R}h_0^{\frac{3}{2}}(t)}{2P_0(1-\nu^2)} \quad (1)$$

where h(t) is the monitored displacement, R the tip radius, P_0 is the maximum applied load.

Indentation relaxation

A stepwise indentation depth is applied and the load is monitored in function of time. From the experimental data we can calculate the relaxation modulus for ν =const [2]:

$$E(t) = \frac{2P(t)(1-\nu^2)}{\frac{8}{3}\sqrt{R}h_0^{\frac{3}{2}}} \quad (2)$$

where P (t) is the load, h_0 is the maximum applied displacement, R the tip radius.

Results

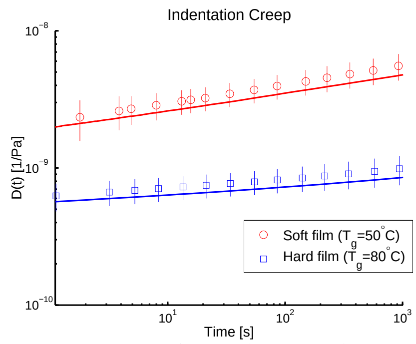


Figure 2: *Creep compliance obtained from indentation (open symbols) compared with the prediction of creep compliance obtained from modelling the DMTA master curve (solid line).*

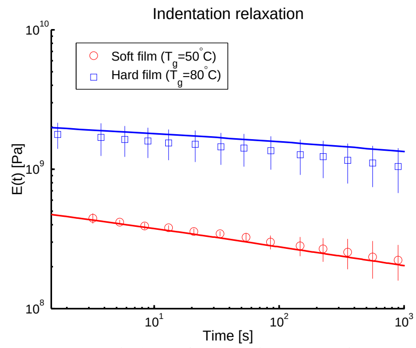


Figure 3: *Relaxation modulus obtained from indentation (open symbols) compared with the prediction of relaxation modulus obtained from modelling the DMTA master curve (solid line).*

Conclusions

For both creep and stress relaxation, the experimental data obtained by micro-indentation compare well to the prediction based on the (macroscopic) DMTA master curves.

References:

[1] N.W. Tschoegl, The phenomenological theory of linear viscoelastic behavior an introduction: *Springer, Berlin, 1989*

[2] J.M.J. den Toonder, Y. Ramone, A.R. van Dijken, J.G.J Beijer, G.Q. Zhang.: *proc. ESIME 2002, IEEE,2002,pp270-280*

PO Box 513, 5600 MB Eindhoven, the Netherlands