International Journal of Plasticity 27 (2011) 1093–1102

Contents lists available at ScienceDirect

International Journal of Plasticity

journal homepage: www.elsevier.com/locate/ijplas

Transient and steady-state nanoindentation creep of polymeric materials

Chien-Chao Huang [a], Mao-Kuo Wei [b], Sanboh Lee [a,*]

[a] Department of Materials Science and Engineering, National Tsing Hua University, Hsinchu, Taiwan
[b] Department of Materials Science and Engineering, National Dong Hwa University, Hualien, Taiwan

ARTICLE INFO

Article history:
Received 20 December 2009
Received in final revised form 4 November 2010
Available online 4 December 2010

Keywords:
Nanoindentation creep
Viscoelasticity
Power-law creep
Polymer

ABSTRACT

The transient and steady-state nanoindentation creep of polymeric materials was investigated. The creep model is used to explain the experimental data of transient and steady-state creep dominated by viscoelastic deformation and power-law creep deformation, respectively. The Burgers viscoelastic model was used to interpret the transient creep in polymers under nano-indentation. Explicit expression for the displacement of transient creep was derived using the correspondence principle of linear viscoelasticity theory. The power law of strain rate-stress relation was used to explain the creep displacement during the steady state. Three polymers of poly(methyl methacrylate), hydroxyethyl methacrylate copolymer, and the fast-cure acrylic resin were used to measure the nanoindentation creep. The transient creep data are in good agreement with the predictions from the Burgers viscoelastic model. The creep displacement is mainly attributed to the viscous flow of the Kelvin element, and the computed values of viscosities ($\eta_{1,c}$,$\eta_{2,c}$) increase with decreasing preloading rate. By comparing the steady-state creep data with the power law of strain rate-stress relation, the stress exponents for the above polymeric materials were quantitatively determined.

1. Introduction

Mechanical properties are of important concern in microelectromechanical systems (MEMS) and the MOS device design, fabrication and application, especially on the micrometer and nanometer scales. The depth-sensing indentation (DSI) technique becomes a standard tool for measurements of the elastic modulus and the hardness of the small sample. Oliver and Pharr (1992) proposed the indentation method to measure the Young's modulus based on the assumption that the material is purely elastic. However, in many cases, the behavior of the contact area between indenter tip and sample is viscoelastic (exhibiting both viscous flow and elastic deformation) not just elastic (LaFontaine et al., 1990; Syed and Pethica, 1997; Feng and Ngan, 2001a; Li and Ngan, 2004; Tang et al., 2006; Jager et al., 2007; Oyen, 2007; Choi et al., 2008). The extreme case that the load–displacement curve exhibiting a ‘‘nose" occurs when the shear viscosity dominates during unloading. When the nose appears, the stiffness at the onset of unloading curve becomes negative, and the Young's modulus calculated by the Oliver and Pharr method becomes negative. In order to obtain an accurate Young's modulus from the nano-indentation test, Briscoe et al. (1998) suggested maintaining a sufficient time at the peak load for stress relaxation before unloading. However, such an experiment requires a long time for completion. Based on the linear viscoelasticity, Feng and Ngan (2002) proposed a simple formula to correct the contact stiffness of Berkovich nanoindentation measurement within a short dwell time. In the following year, Tang and Ngan (2003) refined the approach of Feng and Ngan by modifying both the contact stiffness and contact area measurements. They provided a formula to eliminate the effect of creep on modulus measurement for both

* Corresponding author. Tel.: +886 3 5719677.
E-mail address: sblee@mx.nthu.edu.tw (S. Lee).

0749-6419/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijplas.2010.11.005