available at www.sciencedirect.com

ScienceDirect

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

Research paper

Poroviscoelastic characterization of particle-reinforced gelatin gels using indentation and homogenization

Matteo Galli[a,b,*], *Elvis Fornasiere*[a,b], *Joël Cugnoni*[b], *Michelle L. Oyen*[a]

[a] *Engineering Department, University of Cambridge, Trumpington St., Cambridge, CB2 1PZ, UK*
[b] *Laboratoire de Mécanique Appliqée et d'analyse de Fiabilité, École Polytechnique Fédérale Lausanne, Lausanne, 1015, Switzerland*

ARTICLE INFO

Article history:
Received 23 July 2010
Received in revised form
26 January 2011
Accepted 27 January 2011
Published online 4 February 2011

Keywords:
Gelatin
Particle
Indentation
Homogenization
Poroviscoelastic

ABSTRACT

Hydrogels are promising materials for bioengineering applications, and are good model materials for the study of hydrated biological tissues. As these materials often have a structural function, the measurement of their mechanical properties is of fundamental importance. In the present study gelatin gels reinforced with ceramic microspheres are produced and their poroviscoelastic response in spherical indentation is studied. The constitutive responses of unreinforced gels are determined using inverse finite element modeling in combination with analytical estimates of material parameters. The behavior of composite gels is assessed by both analytical and numerical homogenization. The results of the identification of the constitutive parameters of unreinforced gels show that it is possible to obtain representative poroviscoelastic parameters by spherical indentation without the need for additional mechanical tests. The agreement between experimental results on composite gelatin and the predictions from homogenization modeling show that the adopted modeling tools are capable of providing estimates of the poroviscoelastic response of particle-reinforced hydrogels.

1. Introduction

Hydrogels, including gelatin, are water-swollen polymer networks. These materials have found common use in industrial products, including food and cosmetics (Schrieber and Gareis, 2007), in healthcare applications, such as contact lenses and wound dressings (Peppas et al., 2006; Kopecek and Yang, 2007), and in bioengineering research, as substrates for cell cultivation and stem cell differentiation (Drury and Mooney, 2003; Discher et al., 2005; Lutolf, 2009). Owing to their biocompatibility and resorbability, gelatin gels are among the most promising candidate materials for tissue engineering applications (Broderick et al., 2005). For these applications, hydrogels have a structural function and the knowledge of their mechanical behavior is of primary interest. Moreover many new possible applications could be envisioned with the development of 'stronger' hydrogels (Calvert, 2009). Because of their relatively poor mechanical properties, many studies have also considered reinforcing gels with a stiff second phase (Ross Murphy and Todd, 1983; Wan et al., 2000), for example for mineralized tissue engineering (Lu et al., 2008).

Gelatin gels and hydrogels in general exhibit time-dependent mechanical behavior. The simplest approach to characterize such a response is to consider the hydrogel a homogeneous, isotropic, viscoelastic material. This approach

* *Corresponding author at:* EPFL-STI-IGM-LMAF, Station 9, 1015 Lausanne, Switzerland. Tel.: +44 21 6932931; fax: +44 21 6937340.
E-mail address: matteo.galli@epfl.ch (M. Galli).

1751-6161/$ - see front matter
doi:10.1016/j.jmbbm.2011.01.009