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Research paper

Poro-viscoelastic constitutive modeling of unconfined creep of hydrogels using finite element analysis with integrated optimization method

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ABSTRACT

Hydrogels are cross-linked polymer networks swollen with water and are being considered as potential replacements for deceased load bearing tissues such as cartilage. Hydrogels show nonlinear time dependent behavior, and are a challenge to model. A three-element poro-viscoelastic constitutive model was developed based on the structure and nature of the hydrogel. To identify the material parameters, an inverse finite element (FE) technique was used that combines experimental results with FE modeling and an optimization method. Unconfined compression creep tests were conducted on poly(vinyl alcohol) (PVA) and poly(ethylene-co-vinyl alcohol)–poly(vinyl pyrrolidone) (EVAL–PVP) hydrogels manufactured by injection molding. Results from the creep experiments showed that for PVA hydrogels, an increase in polymer concentration correlates with a decrease in the equilibrium water content (EWC) and the creep strain. In EVAL–PVP hydrogels, an increase in the hydrophobic segments (EVAL) correlates with a decrease in the EWC as well as the creep strain. An inverse FE method was used to identify the viscoelastic material parameters of the hydrogels in combination with creep testing using the poro-viscoelastic three-element constitutive model. The elastic modulus estimated from the inverse FE technique showed good agreement with the modulus estimated directly from the test data.

1. Introduction

Nearly 27 million Americans or 12.1% of the adult population of the United States are affected by Osteoarthritis (OA) (Lawrence et al., 2008). Due to their unique properties such as biocompatibility and hydrophilicity, hydrogels are being considered as promising materials as replacements for deceased load bearing tissues such as articular contact surfaces (Oka et al., 2000; Stammen et al., 2001; Kobayashi et al., 2003a,b; Kobayashi and Oka, 2004). Hydrogels are cross-linked polymer networks swollen with a liquid. Water is retained in hydrogels within a three-dimensional polymer network. However, many of these hydrogels lack the required mechanical properties to be useful as weight bearing materials (Swieszkowski et al., 2006). The mechanical strength of hydrogels is desirable for applications as replacement of load bearing tissues. There are a number of approaches to strengthen the hydrogel materials. These methods include copolymerization

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