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Compressive properties of epoxidized soybean oil/clay nanocomposites

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Abstract

High- and low strain-rate compression experiments were conducted on epoxidized soybean oil (ESO)/clay nanocomposites with nanoclay weights of 0%, 5%, and 8%. A pulse-shaped split Hopkinson pressure bar (SHPB) was employed to conduct high strain-rate experiments. The pulse shaping technique ensures nearly constant-strain-rate deformation under dynamically equilibrated stresses in specimens such that accurate stress–strain curves at various high rates were obtained. A MTS 810 hydraulically driven materials testing system was used to obtain low strain-rate stress–strain curves. Strain-rate and nanoclay weight effects on the compressive properties of the nanocomposites were experimentally determined. A phenomenological strain-rate-dependent material model was presented to describe the stress–strain response. The model agrees well with the experimental data at both large and small strains as well as high and low strain rates.

Keywords: Compressive properties; Nanocomposite; Split Hopkinson pressure bar (SHPB); Strain-rate; Material model

1. Introduction

During the recent years, increasing attention has been paid to polymers obtained from renewable resources. This interest is justified by the environmental advantage of these

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materials, which are neutral in carbon dioxide cycle and often biodegradable. These polymers may also constitute a new outlet for vegetable products. Among products from agricultural resources, natural oils may constitute raw materials useful in polymer synthesis. For example, United States agriculture produces over 12 billion pounds of soybean oil annually, and frequently carry-over exceeds one billion pounds. Thus, developing new materials from soybean oil for industrial application has become highly desirable. These new materials can open new market for this important crop.

Soybean oil is a double bond containing triglyceride. These double bonds may also be converted into the more reactive oxirane moiety by reaction with peracids or peroxides. In the past, epoxidized soybean oil (ESO) is mainly used as platicizer for polyvinyl chloride, chlorinated rubber and polyvinyl emulsions to improve stability and flexibility. The preparation of structurally strong soy-based composites is attractive from both commercial and environmental perspectives. Soy composites can be reinforced with glass, carbon or natural fibers. Proper combination of natural clay and soybean oil can form nanocomposites that have unique properties and applications.

Since the Toyota group developed the nylon 6-clay hybrid (Okada et al., 1989; Kojima et al., 1993a,b,c,d, 1994, 1995; Usuki et al., 1995), the interest in nanocomposites has been inspired by the fact that nanoscale materials often exhibited dramatically different properties, such as gas permeability (Kojima et al., 1993e), water absorption (Kojima et al., 1994c; Drozdov et al., 2003; Kim et al., 2003), chemical (Okada and Usuki, 1995), thermal (Hao et al., 2002; Kim et al., 2003; Lee et al., 2003), and mechanical properties (Okada et al., 1989; Kojima et al., 1993b; Lan and Pinnavaia, 1994; Usuki et al., 1995; LeBaron et al., 1999; Tyan et al., 2000; Nam et al., 2001; Sur et al., 2001; Tien and Wei, 2001; Zerda and Lesser, 2001; Zhou et al., 2001; Abdalla et al., 2002; Ha and Thomas, 2002; Hao et al., 2002; Svoboda et al., 2002; Young and Mauritz, 2002; Chen et al., 2003; Drozdov et al., 2003; Kim et al., 2003; Lee et al., 2003; Liu et al., 2003; Uribe-Arocha et al., 2003; Zhang et al., 2003) from their bulk counterparts, which is earning them wide applications in automobile and transportation industries, construction and fire-safety engineering, and even military armors. One of the most promising composite systems would be organic polymers (i.e., nylon 6) and inorganic clay minerals consisting of silicate layers. As an inexpensive natural mineral, clay has been used as filler for rubbers and plastics for many years. However, its poor reinforcing ability limits its usage only for conventional microcomposites. In order to improve the reinforcing ability of clay, chemical modifications with various chemistries have been recently developed to make the clay complexes compatible with organic monomers and polymers.

While more and more nanocomposites are developed, the synthesis, morphology and structure of nanocomposites have been well reviewed by Okada and Usuki (1995), Giannelis (1996), LeBaron et al. (1999), Sur et al. (2001), and Hamley (2003) in recent years. These nanocomposites are recognized to reduce shrinkage and residual stress, to alter electrical, electronic and optical properties, to improve thermal endurance, flame resistance, abrasion resistance, and barrier properties, as well as to efficiently reinforce mechanical properties (Hamley, 2003). In addition, many potential benefits such as fire resistance, electrostatic dissipation (ESD), and electromagnetic interference (EMI) are being developed (Hamley, 2003). Among these properties, the research on mechanical properties of nanocomposites is attracting more and more researchers' attention.

One of the motivations for optimizing nanocomposites is to improve their mechanical properties. Besides low strain-rate compression and fracture toughness tests by LeBaron