Available online at www.sciencedirect.com
ScienceDirect
Polymer Testing 26 (2007) 878–885
POLYMER TESTING
www.elsevier.com/locate/polytest

Test Method

A simple method to predict high strain rates mechanical behavior of low interconnected cell foams

Luigi Sorrentino*, Marco Aurilia, Salvatore Iannace

Institute for Composite and Biomedical Materials, CNR P.le E. Fermi 1, loc. Granatello, 80055 Portici (NA), Italy

Received 15 April 2007; accepted 8 June 2007

Abstract

A method to model high strain rate compressive properties of PU foams was investigated. The nonlinear mechanical response of the foam was split into three independent contributions: foam morphology, time-dependent polymer response, gas entrapped in the cells.

The foam morphology contribution was estimated by a simple uniaxial compression test at very low strain rate. The time (temperature)-dependent behavior of the polymeric foam was evaluated by stress relaxation tests. Due to the low degree of cell interconnections of the studied foam, at low strain rates the gas contribution was predicted by using a gas flow model derived from Darcy's law. Starting from $2\,s^{-1}$ compressive strain rate, the foam exhibited a transition and the gas contribution was evaluated by a scaled closed cell model.

The proposed method is able to predict the mechanical response of foams at high strain rates using data obtained by few low strain rates mechanical tests.

Keywords: Polymeric foams; Impact behavior; Mechanical properties; Stress relaxation

1. Introduction

Polymeric foams are low-density solids widely used in many fields of application, such as for energy absorption, cushioning systems and sandwich core material [1], due to their high specific mechanical, acoustical and thermal properties.

Polymeric foams used in mechanical energy absorbers can dissipate high impact energy reacting with low mechanical stress. Energy is absorbed by several mechanisms, involving walls and edges of cells: elastic and/or plastic bending, buckling or fracture (depending on the brittleness of the bulk polymer). The stress is limited by the long flat plateau of the stress–strain curve. By choosing the right polymer, density and morphology, the foam can be tailored to give the best combination of properties for a given application.

All mechanical properties of foams are affected by cell morphology, foam density, temperature (strictly related to the bulk material properties) and strain rate (related either to the viscoelastic properties of the bulk material or the viscosity of the fluid which fills the cells) [2–9].

In particular, in open cell foams the fluid flow through interconnections affects the stress response due to the gas viscosity. In fact, the fluid inside the

*Corresponding author.
E-mail address: luigi.sorrentino@imcb.cnr.it (L. Sorrentino).

0142-9418/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.polymertesting.2007.06.004

cells, generally a gas, is compressed during deformation and expelled or drawn into the solid, dissipating energy by viscous flow [4,8]. In closed cell foams the gas contribution is dependent only on strain, due to the volume reduction of the cell that increases the internal pressure. The gas contribution can be neglected when the foam stiffness is very high.

In literature, several methods have been proposed to address the compressive behavior of foams, both at low and high strain rates. As evident by a work of Gruenbaum and Miltz [3], the amount of energy absorbed in the quasi-static and shock tests is almost the same, but the force applied to the product is significantly higher in dynamic tests. Rusch [4,5] first proposed the hypothesis of two different functions to separate time (or temperature) and strain dependence in the $\sigma-\varepsilon$ constitutive relationship, trying to predict impact loading behavior of open cell foams. Schwaber and Meinecke [6,7] tested open cell foams, finding that impact behavior at high strain rates was correctly predicted by a model with a rate-independent strain factor and a rate-dependent time factor, by using data collected at low strain rates, up to 2 m/min.

Many works in the literature try to model the impact behavior using high strain rate loading, due to easier experimental setup [10–12]. In fact, constant high strain rate deformations are difficult to obtain, mainly because of inertia problems. More recently, several works proposed the use of Hopkinson bars to reach very high strain rates up to $2500\,s^{-1}$ or above, but instrumentation is not easy to use, needing complex design of experiments and testing procedures, and proper specimen-bar material coupling [1,13–15].

A different approach, based on a nonlinear viscoelastic model, was proposed by several authors who used thermomechanical creep measurements to take into account the viscoelastic properties of the bulk polymer [16–18].

The aim of this work was to assess a simple method to predict high strain rate mechanical response of a foam by using few mechanical quasi-static compressive and thermomechanical stress relaxation tests. For the first time, to the best of knowledge of the authors, the compressive behavior of a foam is predicted combining the polymer viscoelasticity and the gas entrapped in the cells contributions to the mechanical response. Moreover, this approach is useful when the bulk polymer properties are not available.

2. Experimental

The studied PU foam (CF 45 Blue) was produced by EAR Speciality Composites. It is a polyurethane foam with a density of $0.093\,g/cm^3$. The bulk material is characterized by a T_g near room temperature.

All compression tests were executed on cylindrical-shaped samples to minimize the effect of sample geometry and to assure the maximum accuracy, as proposed by Sims and Bennet [9], who studied the effect of air flow on the impact behavior of open cell polyurethane foams.

DMA tests were accomplished to establish the dynamical-mechanical T_g. The samples had a cylindrical shape with 15 mm diameter and 10 mm thickness, according to specimen requirements of TA Instruments DMA 2980 apparatus used for this measure. The samples were cooled at $-100\,^{\circ}C$ and then heated to $50\,^{\circ}C$ with a heating rate of $5\,^{\circ}C/min$. The amplitude and the frequency of oscillation were set, respectively, at $40\,\mu m$ and 1 Hz.

A Leica S440 scanning electron microscope was used for morphological analysis of the foam structure. The SEM samples were prepared by cutting a thin foam slice in liquid nitrogen and metallizing it with gold.

An Instron 4201 was used to perform quasi-static and stress relaxation tests. In the first case, five tests were executed for each selected strain rate (ranging from 1 to 500 mm/min) on 30 mm diameter and 25 mm thick cylindrical samples at $25\,^{\circ}C$. Due to the high sensitivity of the compressive properties with temperature, a special chamber (Fig. 1) was designed to control the temperature of the foam within an experimental error of $0.2\,^{\circ}C$. The chamber was conditioned with a thermal bath liquid circulation

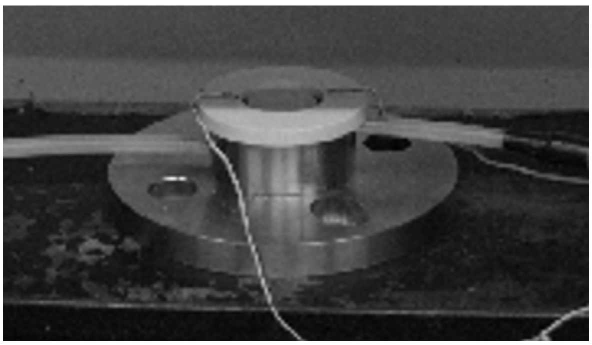

Fig. 1. Special chamber used to condition the sample temperature, one thermocouple is fixed on top of the sample and the other one on the bottom.