Available online at www.sciencedirect.com

SCIENCE DIRECT

POLYMER TESTING

Polymer Testing 25 (2006) 481–491

www.elsevier.com/locate/polytest

Test Method

Determining the response of glass filled nylon under elevated rate multiaxial loading

Peter A. Gustafson, Anthony M. Waas*

Composite Structures Laboratory, University of Michigan, Ann Arbor, MI 48109, USA

Received 19 November 2005; accepted 14 February 2006

Abstract

A facility has been developed capable of high strain rate material characterization in multiaxial flexure. Using this novel equipment, a formulation of a glass filled nylon composite (Ultramid B3WG6 BGVW) has been tested in biaxial flexure at a variety of strain rates. For the material tested, the flexural modulus was shown to have no significant dependence on the rate of application of load. The measured modulus was found to be $\approx 3.9\,\text{GPa}$ over a range of 10^{-3}–$4.0\,\text{s}^{-1}$. A FE model was created and found to have an excellent correlation over the entire range of strain rate. The capabilities and limitations of the experimental facility are discussed.

Keywords: Nylon composite; Strain rate; Rate dependence; Multiaxial; Flexure

1. Introduction

Polymeric composites have become a significant material source in consumer products. For example, glass filled nylon has made a significant impact on the automotive industry. In automobiles, glass filled nylon composites are now used in intake manifolds, steering wheels, body panels, mirror housings, levers, seat frames, door handles, and door locks [1]. Automotive and other industrial applications for glass filled nylon 6 composites are growing due to its demonstrated performance, manufacturing, and cost benefits. In the year 2000, BASF reported that thermoplastics and composites increased by 4% in North America and 5–6% globally. Global use of nylon increased by 8–9% [2].

Due to its increased usage, it is important to understand the mechanical behavior of this class of materials, which have been shown to be strongly dependent on environmental and loading conditions. As further described in Section 2, characterization has shown the mechanical performance of glass filled nylon to be a strong function of temperature, moisture content, aging time, and load type. Additional studies have shown that the behavior of the matrix material (nylon 6) is dependent on the rate of application of load. Consequently, it is important to determine whether the nylon and glass fiber composite has a similar dependence on the loading rate.

Currently, a lack of specific and relevant material characterization causes significant assumptions to be made in modelling practice. Several of the

*Corresponding author. Tel.: +1 734 7648227; fax: +1 734 7630578.

E-mail address: dcw@umich.edu (A.M. Waas).

0142-9418/$ - see front matter
doi:10.1016/j.polymertesting.2006.02.004

common assumptions must be reexamined, based on the available literature. One example, discussed in the next section, is the assumption of constant modulus over all strain rates. Further, no suitable rate-dependent failure criterion has been verified in a non-uniaxial stress state. An effective constitutive model is essential for refinement of critical modelling steps in consumer product development including airbag deployment simulation, head and body impact simulation, vehicle crash worthiness simulation, as well as the simulation of many other high speed events. For glass filled nylon, engine backfire simulation is critical to the development of intake manifolds.

The present work presents an experimental setup capable of investigating the response of a material to flexure at moderate to high strain rates. Although the results presented focus on the flexural modulus of a specific material, the experimental framework is general. Future work with the experimental facility intends to investigate the combined effects of strain rate, temperature, and stress ratio on modulus, yield, and failure.

2. Background

2.1. General mechanical behavior of nylon and nylon matrix composites

This study presents an investigation of the flexural behavior of Ultramid B3WG6 BGVW, a product of BASF Corporation. This material is in common use in the automotive industry for intake manifolds, and is expected to exhibit a range of mechanical behavior based on environmental conditions and loading type. For example, similar materials have been reported to be temperature sensitive in modulus [3–6], ultimate strength [6,7], fatigue strength [7], and strain to failure [4]. Additionally, BASF and others report that nylon based materials are hygroscopic (moisture sensitive), where moisture acts as a plasticizer resulting in lower strain to failure [2], strength [4,6,8], stiffness [4,6,8], a decreased natural frequency [4], and a diminished number of cycles to failure [6]. Published data also shows that modulus is dependent on load type [1,9].

In addition to environmental and loading dependencies, there are time dependent changes in the chemical composition of nylon and nylon composites [10]. Ticona describes how the tensile modulus of glass reinforced nylon 6 decreases with time, eventually establishing an equilibrium level that is 70–85% of its original value [6]. This is true both in the neat nylon and the glass filled composite. BASF has reported that aging time has a negative effect on ultimate tensile strength and fatigue strength [7].

Despite recent interest and common usage, general information on the rate dependence of nylon composites is not widely available in the literature. Additionally, there is a lack of information regarding flexural loading, a specific loading type of great interest. This work provides a measured flexural modulus over a range of strain rates.

2.2. Strain rate dependence of nylon and nylon matrix composites

Hamouda and Hashmi provided quasi-static and dynamic stress strain curves for neat nylon 6, up to $10^4\,s^{-1}$ [11]. Walley et al. provided data on neat nylon 6 and nylon 6/6 at different rates, for both dry and wet conditions [10]. For nylon 6/6, Ahmad found that modulus and yield stress are functions of rate [12]. However, very little data are available for nylon matrix composites at different strain rates.

Conflicting results for similar materials make generalization difficult. For example, Sumita et al. found tensile modulus of nylon 6 to be an increasing function of strain rate [5], whereas Walley et al. found that high strain rates soften nylon [10]. Some of this discrepancy might be explained by the rates at which the experiments were accomplished. Indeed Walley et al. suggested that adiabatic conditions lead to increased temperatures, causing neat polymers to have an apparent softening with increasing strain rate [10]. This would imply that the material could soften or stiffen depending on the rate of strain, making testing in the range of interest critical to accurate models. Additionally, much of the available data are determined in compression [10], leaving significant gaps in knowledge of other loading regimes.

Limited published information is available for nylon matrix composites using Charpy and Izod impact testing, though this information is considered to be comparative and is unable to provide fundamental stress–strain behavior [12]. In one study, Laura et al. showed that glass fibers improves strength and stiffness but decreases ductility and impact strength [13]. The flexural modulus of reinforced nylon 6/6 has been shown to be strain history dependent, decreasing non-linearly in time