

On the characterization of tensile creep resistance of polyamide 66 nanocomposites. Part II: Modeling and prediction of long-term performance

Jing-Lei Yang^a, Zhong Zhang^{b,*}, Alois K. Schlarb^a, Klaus Friedrich^a

^a Institute for Composite Materials, University of Kaiserslautern, 67663 Kaiserslautern, Germany

^b National Center for Nanoscience and Technology, No. 2, 1st North Street Zhongguancun, 100080 Beijing, PR China

Received 10 January 2006; received in revised form 24 July 2006; accepted 24 July 2006

Abstract

The Part I of this study [Yang JL, Zhang Z, Schlarb AK, Friedrich K. Polymer 2006;47:2791–801] provided systematic experiments and general discussions on the creep resistance of polyamide 66 nanocomposites. To promote these works, here we present some modeling and prediction attempts in order to further understand the phenomena and mechanisms. Both a viscoelastic creep model named Burgers (or four-element model) and an empirical method called Findley power law are applied. The simulating results from both models agree quite well with the experimental data. An additional effort is conducted to understand the structure–property relationship based on the parameter analysis of the Burgers model, since the variations in the simulating parameters illustrate the influence of nanofillers on the creep performance of the bulk matrix. Moreover, the Eyring stress-activated process is taken into account by considering the activation volume. Furthermore, in order to predict the long-term behavior based on the short-term experimental data, both the Burgers and Findley models as well as the time–temperature superposition principle (TTSP) were employed. The predicting capability of these modeling approaches is compared and the Findley power law is preferred to be adopted. Master curves with extended time scale are constructed by applying TTSP to horizontally shift the short-time experimental data. The predicting results confirm the enhanced creep resistance of nanofillers even at extended long time scale.

© 2006 Elsevier Ltd. All rights reserved.

Keywords: Creep modeling; Creep prediction; Polymer nanocomposites

1. Introduction

In view of the fact that nanomaterials as fillers become the state-of-the-art in materials science, numerous studies have been carried out and many improved mechanical properties have been achieved with incorporations of nanofillers into polymer matrices [1]. However, the complex performance of polymer nanocomposites can only be understood deeply by combining experimental studies with effective modeling. Therefore, modeling and simulation of polymer-based nanocomposites have become an essential issue due to the demand for developing these materials to potential engineering applications. In the past years many modeling studies have been

carried out. Most of them have focused on the prediction of elastic modulus, interfacial bonding or load transfer for either carbon nanotubes [2–5] or spherical nanoparticles-filled polymers [6–10].

Moreover, for the long period of loading, e.g., creep or fatigue (must be taken into account in design, especially in aviation and automotive applications [11,12]), it is usual that the material must remain in service for an extended period of time, normally longer than it is practical to run creep experiments on the materials to be employed. Therefore, it is necessary to extrapolate the information obtained from relatively short-term laboratory creep tests in order to predict the probable behavior in service. However, to the best knowledge of the authors, no analytical and prediction work has been reported on the creep behavior of nanoparticle/thermoplastic composites up to now. Recent work of Sarvestani and Picu [13] proposed a network model to simulate the viscoelastic

* Corresponding author.

E-mail address: zhong.zhang@nanoctr.cn (Z. Zhang).

Nomenclature

a_T	temperature shift factor
C_1, C_2	constants in Eq. (13)
E_{tensile}	Young's modulus from static tensile test
E_K	modulus of the Kelvin spring in the Burgers model
E_M	modulus of the Maxwell spring in the Burgers model
ΔH	activation energy
k	Boltzmann constant
n	power in the Findley power law
R	universal gas constant
t	time
T	absolute temperature
T_g	glass transition temperature
T_{ref}	reference temperature

Greek symbols

ε_B	strain of the Burgers model
ε_F	strain of the Findley power law
ε_{F0}	time-independent strain in the Findley power law
ε_{F1}	time-dependent term in the Findley power law
ε_K	strain of the Kelvin unit in the Burgers model
ε_{M1}	strain of the Maxwell spring in the Burgers model
ε_{M2}	strain of the Maxwell dashpot in the Burgers model
$\dot{\varepsilon}_{II}$	fitted strain rate from the secondary creep stage
$\dot{\varepsilon}_B$	strain rate of the Burgers model
$\dot{\varepsilon}_E$	strain rate of Eyring creep process
$\dot{\varepsilon}_{E0}$	constant pre-exponential factor in Eq. (9)
$\dot{\varepsilon}_F$	strain rate of the Findley power law
$\dot{\varepsilon}_K$	strain rate of the Kelvin dashpot in the Burgers model
$\dot{\varepsilon}_{M2}$	strain rate of the Maxwell dashpot in the Burgers model
η_K	viscosity of the Kelvin dashpot in the Burger model
η_M	viscosity of the Maxwell dashpot in the Burger model
σ	stress applied in creep test
σ_0	initial stress applied in tensile creep test
τ	retardation time of the Kelvin unit in the Burgers model
v	activation volume in stress-activated Eyring process

behavior of nanoparticle/polymers. The rheology and shear viscosity of nanocomposites were simulated by taking into account the important roles of the lifetime of the polymer–filler junctions and the network of bridging segments. More recently Blackwell and Mauritz [14] reported the shear creep behavior of a sulfonated poly(styrene-*b*-ethylene/butylene-*b*-styrene)

(sSEBS)/silicate nanocomposite, the experimental data of which could be satisfactorily simulated by using a modified Burgers creep model. However, the shear creep experiments were conducted by using a dynamic thermal analyzer (DMA) within a very short time of 30 min and no further explanations and discussions of the results were given. Although the analytical work on the fluid viscoelasticity and the very short time creep of the nanocomposites presented some valuable points, some detailed explorations were needed for practical applications.

In our previous experimental studies, the creep behavior of a semicrystalline thermoplastic polyamide 66 (PA66) nanocomposites was systematically carried out at various temperatures and different stress levels [1,15]. The creep deformation and the creep rate of the matrix were reduced to different extents by the addition of various nanofillers. Significantly improved creep resistance broadens the research scope and, together with the enhanced crack initiation fracture toughness [16,17], will certainly extend the potential applications of nanocomposites. In addition, considering the design of nanocomposites for engineering applications, modeling and predicting work becomes a key issue. Thus, in the present study the modeling study based on experimental data by using traditional creep models [19,20] is conducted. An attempt to understand the structure–property relationship is carried out based on the parameter analysis of the Burgers model, since the variations in the simulating parameters illustrate the influence of nanofillers on the creep performance of the bulk matrix. Moreover, the Eyring stress-activated process [21] is taken into account by considering the activation volume. Furthermore, in order to predict the long-term behavior based on the short-term experimental data, both the Burgers and Findley models as well as the time–temperature superposition principle (TTSP) [21] were employed. Master curves with extended time scale are constructed by applying TTSP to horizontally shift the short-time experimental data. The predicting results confirm the enhanced creep resistance of nanofillers even at extended long time scale.

2. Theoretical background

2.1. Creep models

2.1.1. Burgers model

Among the numerous viscoelastic creep models, Burgers or four-element model [19,21] is widely used to analyze the viscoelasticity of materials, as illustrated in Fig. 1 with a Maxwell and a Kelvin unit connected in series. The constitutive equation for a Burgers model can be derived by considering the strain response under constant stress of each coupled element in series as depicted in Fig. 1. The total strain ε_B at time t is a sum of the strains in these three elements, where the spring and dashpot in the Maxwell model are considered as two elements, thus:

$$\varepsilon_B = \varepsilon_{M1} + \varepsilon_{M2} + \varepsilon_K \quad (1)$$

Download English Version:

<https://daneshyari.com/en/article/5186707>

Download Persian Version:

<https://daneshyari.com/article/5186707>

[Daneshyari.com](https://daneshyari.com)