Materials and Design 33 (2012) 523–528

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Static and dynamic mechanical properties of poly(vinyl chloride) loaded with aluminum oxide nanopowder

M. Abu-Abdeen *

Physics Department, College of Science, King Faisal University, Alhasa, P.O. B 400, 31982, Saudi Arabia
Physics Department, College of Science, Cairo University, Giza, Egypt

ARTICLE INFO

Article history:
Received 23 January 2011
Accepted 29 April 2011
Available online 5 May 2011

Keywords:
Polymer matrix
Mechanical
Nanopowder
PVC
Rheological properties
DMA

ABSTRACT

A series of nanocomposites from poly(vinyl chloride) loaded with different concentrations of Al_2O_3 nanopowder was prepared. The tensile mechanical properties of these composites were studied at different temperatures namely; stress–strain curves. The elastic modulus was calculated and found to decrease with increasing both filler loading and temperature. The strain at a certain stress at different temperatures was studied and the thermal activation energy for polymer chains was calculated. The complex viscosity as well as the storage modulus was found to decrease with increasing the filler loadings at different frequencies. The relaxation time of the polymer matrix was calculated and found to independent on the concentration of the filler but it decreased linearly with increasing frequency. The glass transition temperature was found to increase with increasing both filler loading and frequency.

1. Introduction

Poly(vinyl chloride) PVC is one of the most important polymers used these days, since it has many applications in medical equipments, pipes as well as some machine elements [1]. Developments of the mechanical properties as well as other properties were achieved by adding inorganic filler phases throughout different processing techniques. Many studies reported the effect of different inorganic fillers in the nano-scale on the polymer host properties. PVC/inorganic nanocomposites based on silica [2], calcium carbonate [3], montmorillonite [4,5], and titania [6] and calcium carbonate [7,8] have been previously reported.

The study of the mechanical properties of polymer composites have made it desirable to choose these materials over traditional materials for numerous types of applications, such as binder constituents in explosives, load-bearing components, and jet engine modules. As the uses of polymer composites increase, an understanding of the mechanical behavior of these materials becomes vital for creating innovative and economical designs for various components. Polymer composites have more complicated properties as they display elastic and viscous responses at different strain rates and temperatures [9–11]. Young's modulus can be improved by adding inorganic fillers since it generally has a much higher stiffness than polymer matrices [12]. Stress transfer between the inorganic filler particles and the polymer matrix strongly affect the strength of the composite [13]. However, for poorly bonded micro-particles, strength reductions occur by adding particles [14].

Gibbs et al. [15] presented the general description of the nature of the glass transition temperature (T_g) of polymers. Different experimental techniques, including differential scanning calorimetry (DSC), dynamic mechanical thermal analysis (DMTA), and dielectric measurements are used for the determination of T_g [16–18]. The influence of various low dimensions particles, for example bismuth oxychloride and organic montmorillonite (MMT) on the glass transition temperature of PVC was reported [19,20]. Generally an increase of T_g as a function of nanoparticles contained was found, however for the MMT an intercalation related decrease of T_g was stated.

The aim of this work is to study the influence of Al_2O_3 nanoparticles with different ratios in PVC host on the tensile mechanical properties at different temperatures, rheological properties at different frequencies and DMTA properties.

2. Experimental

2.1. Materials

Poly(vinyl chloride) (PVC) used in this work was supplied from Sabic Company, Saudi Arabia. It was in the powder form (powder fraction of 90–120 μm, average size of 100 μm, density $\rho = 1.37$ g/cm^3) was used as a polymeric matrix for preparation

* Address: Physics Department, College of Science, King Faisal University, Alhasa, P.O. B 400, 31982, Saudi Arabia. Mobile: +966 551750385.
E-mail addresses: mmaabdeen@yahoo.com, maboabdeen@kfu.edu.sa

0261-3069/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.matdes.2011.04.059

of composites. Aluminum oxide Al_2O_3 nanopowder filler with particle size diameter less than 50 nm was delivered from Aldrich.

2.2. Polymer composites preparation

The filler (Al_2O_3) were embedded into the polymer matrix with the needed proportions by mechanical mixing. Mechanical mixture of the PVC and filler powder was further homogenized by grinding in a porcelain mortar to a visually homogeneous state. For more well dispersion of the filler, the composite powder was ball-milled with two milling balls (stainless steel, 12 mm diameter) under 20 Hz vibration condition for 2 min at room temperature. Homogenized composite was placed into a hot steel mold heated up to 160 °C and then pressed (hot compacted) during 5 min at 20 MPa with subsequent cooling of the mold in the air flow up to room temperature.

2.3. Tensile tests

The tensile tests were carried out on dumbbell-shaped specimens. The measurements were done at different temperatures of 25, 40, 60 and 80 °C on a Dynamic Mechanical Analyzer DMA Q800 (TA Instruments LLC, Delaware, USA) instrument with film clamps at a force rate of 1.5 N/min according to ASTM D 412 [21].

2.4. Rheological and dynamic mechanical

The mentioned DMA Q800 instrument was used through the rheological and dynamic mechanical studies. For these tests a film-clamp was used in dry mode. A slow heating rate of 1 °C/min was employed throughout to ensure that the sample was in thermal equilibrium with the instrument. The oscillating frequency was changed from 0.1 Hz to 200 Hz.

Rheological tests experiments were performed with the film under tension while the frequency is changed. A static pre-load force (0.01 N) was applied to the sample prior the dynamic oscillating force to prevent film buckling [22].

During measurement, the instrument was programed to maintain the static load at 125% of the force required to oscillate the sample. It is important that the film remained in its linear visco-elastic region during measurement (to ensure that the properties observed were independent of the deformation applied and truly reflected molecular motions), and so experiments were recorded maintaining constant strain. Generally, for thin polymer films, linear viscoelastic behavior can be assured with a strain less than 0.1%, and so this limit was used [22].

3. Results and discussions

3.1. Tensile properties

Figs. 1–5 present the stress–strain curves for PVC loaded with 0, 0.5, 1.0, 2.0 and 5.0 wt.% of aluminum oxide nanopowder different temperatures of 25, 40, 60 and 80 °C, respectively. The maximum stress reached in these figures is not the ultimate strength, but it is the maximum stress available for the instrument used. All composites at temperatures 25, 40 and 60 °C show straight lines relations between stress and strain in the studied range of stresses. This reflects the Hookean behavior of these composites at theses temperatures. One can differentiate between these figures at low strain using the inserts. At a temperature of 80 °C (which is close to the glass transition temperature of PVC), yielding of these materials takes place with yield stress values of 6.68, 7.77, 6.57, 5.89 and 6.49 MPa for samples loaded with 0, 0.5, 1.0, 2.0 and 5.0 wt.% of Al_2O_3, respectively.

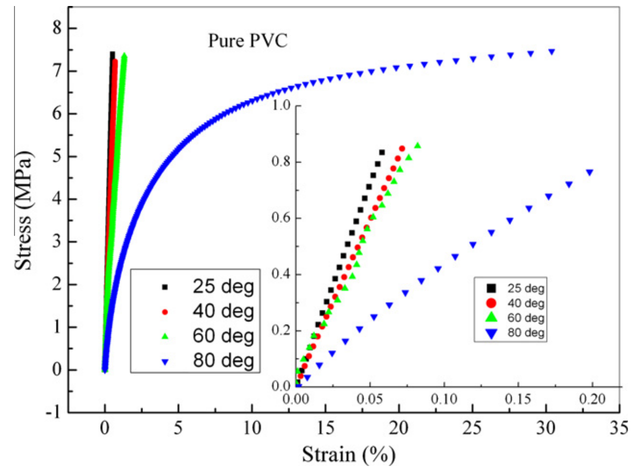

Fig. 1. Stress–strain curves for unloaded PVC at different temperatures.

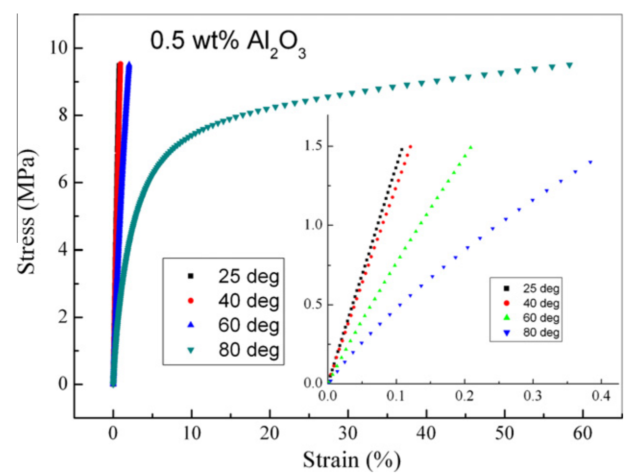

Fig. 2. Stress–strain curves for PVC loaded with 0.5 wt.% of Al_2O_3 nanopowder at different temperatures.

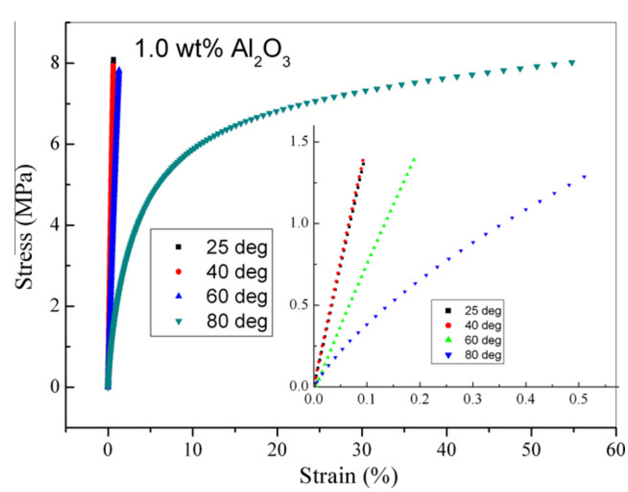

Fig. 3. Stress–strain curves for PVC loaded with 1.0 wt.% of Al_2O_3 nanopowder at different temperatures.

The inserts of the figures are used to calculate the elastic modulus E of these composites for the different samples and at