



Short Communication

The unusual effect of temperature on stress relaxation and mechanical creep of polycarbonate at low strain and stress levels

M. Abu-Abdeen *

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

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ABSTRACT

The effects of temperature, strain level during stress relaxation tests and stress level during mechanical creep tests on the viscoelastic characteristics of polycarbonate films were investigated. When the testing temperature increased the un-relaxed elastic modulus was found to increase during relaxation tests (at low strain levels <2.0%) and the initial strain was found to decrease during creep tests (at low stress levels <20 MPa), in an unusual behavior. A transition from poly-domain to a more coiled and more entangled chains poly-domain configuration took place at low strain and stress levels. At high strain and stress levels ($\geq 2.0\%$ and ≥ 20 MPa) a usual behavior of the un-relaxed stress and initial strain was observed and a transition from poly-domain to mono-domain configuration took place. The thermal energy required for the transition from poly-domain to another poly-domain and from poly-domain to the mono-domain during both relaxation and creep tests were calculated. Besides, both the relaxation and creep strengths were calculated and studied.

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1. Introduction

Polymers are widely used in many engineering applications so knowledge of their mechanical properties is important. Most polymers exhibit time-dependent mechanical behavior, usually referred to as viscoelasticity. Stress relaxation, creep and dynamic loading tests are the commonly used techniques to measure this viscoelastic behavior. The main idea of either stress relaxation or creep denotes the process of the establishment of static equilibrium in a physical or a physico-mechanical system. Its rate depends on the probability of the transition of the system from one stage of equilibrium to another [1]. The viscoelastic behavior of polymeric materials can be influenced by many factors such as temperature [2], physical aging [3,4], pressure [5], solvent concentration [6], strain [7] and stress level [8–10].

The ideal polymer behaves like a perfect Hookean spring. When it is under constant stress or strain, the resulting deformation remains constant as long as it is strained, and so it is time independent. When the stress or strain removed, the deformation returns to zero instantaneously, and the material recovers its original dimensions. Hence, no change in the deformation is observed during stress relaxation or creep experiments of an ideal polymer [11]. Similarly, for cases in which the applied stresses or strains are sufficiently small to have

a negligible effect on the material's properties, Boltzmann superposition principle can be used to predict the deformation of linear viscoelastic polymeric solids subjected to arbitrary time-dependent deformations [12].

However, at higher stresses or strains, most polymers exhibit nonlinear viscoelastic behavior due to the fact that stresses change the distribution of relaxation times to shorter times. A modification to the Boltzmann superposition principle has been proposed to account for the effects of elevated stresses and strains [12,13].

The present work reports the effect of temperature on the un-relaxed stress, relaxation strength, initial strain and creep strength at different strain and stress levels during stress relaxation and creep tests, respectively.

2. Experimental

2.1. Material and preparation

Polycarbonate resin (product by ACROS ORGANICS Company, New Jersey (USA), MW 64,000) was dissolved in dichloromethane and stirred at 30 °C using the magnetic stirrer for 2 h. This viscous solution was casted in a glass petri dish (dia. of 10 cm). The solvent was evaporated at room temperature for 24 h and placed inside oven at 40 °C for 2 h and a sheet of polycarbonate with thickness of 0.1 mm was formed.

* Address: Physics Department, College of Science, King Faisal University, P.O.B. 400, Alhasa 31982, Saudi Arabia. Tel.: +966 35800000x1885.

E-mail addresses: mmaabdeen@yahoo.com, maboabdeen@kfu.edu.sa

2.2. Stress relaxation tests

The stress relaxation tests were carried out on 0.1 mm thick, 5.0 mm width and 30 mm length samples. The measurements were done on a Dynamic Mechanical Analyzer DMA Q800 (TA Instruments LLC, Delaware, USA) instrument with tension film clamps. The strain level was adjusted at a 0.3% and the temperature was equilibrated at 298 K. Sample was then left isothermally at this temperature for 5 min. After that, sample was strained suddenly to the previously adjusted strain level and the variation of stress was recorded with time for 20 min. Then, the strain was removed and the temperature was equilibrated at another higher temperature of 308 K and the process was repeated at same strain level of 0.3%. The experiment was repeated at other high temperatures of 318, 328 and 328 K and same strain level 0.3%. The experiment was repeated using other samples and stress relaxation was tested at other strain levels of 0.5%, 1.0%, 2.0% and 4.0%. Note that the temperature was incrementally increased in steps for each strain level.

2.3. Creep tests

Creep tests were carried out on sample films with same dimensions mentioned in stress relaxation tests using same DMA Q800 instrument with same tension film clamps. Stress level was adjusted at 2.0 MPa and the temperature was equilibrated at 298 K. Sample was then left isothermally at this temperature for 5 min. After that, sample was suddenly loaded with the stress level previously adjusted and the variation of strain was recorded with time for 20 min. Then, stress was removed and the temperature was equilibrated at another higher temperature of 308 K and the process was repeated at same stress level of 2.0 MPa. The experiment was repeated at other high temperatures of 318, 328 and 328 K and same stress level 2.0 MPa. The experiment was repeated using other samples and creep tests were done at other stress levels of 10, 15, 20 and 25 MPa. Note that the temperature was incrementally increased in steps for each stress level.

3. Results and discussions

3.1. Stress relaxation

Figs. 1 and 2 present stress relaxation curves at different strain levels of 0.3%, 0.5%, 1.0%, 2.0% and 4% and at successive accumulated steps of temperature increments 10 °C followed by 20 min

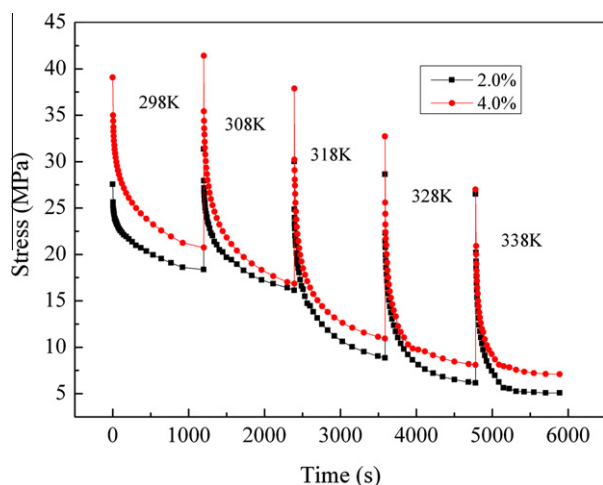


Fig. 1. Stress relaxation of polycarbonate at different high strain levels and at different temperatures.

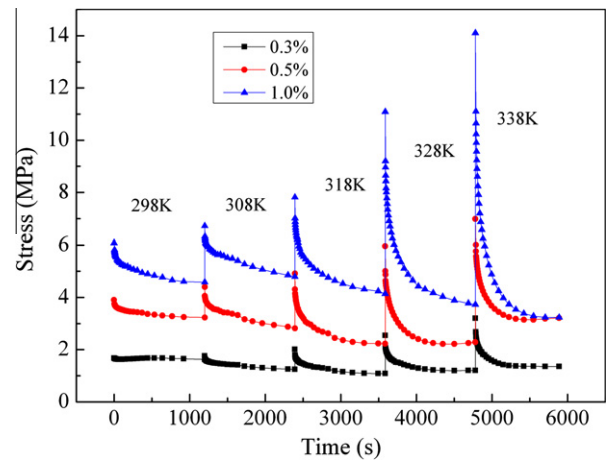


Fig. 2. Stress relaxation of polycarbonate at different low strain levels and at different temperatures.

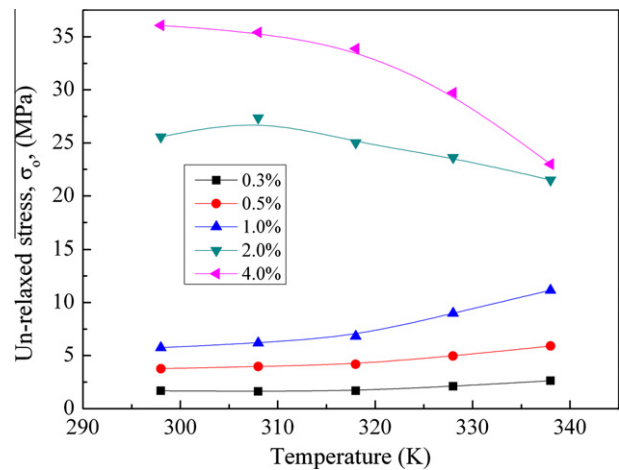


Fig. 3. Temperature dependence of the un-relaxed stress of polycarbonate at different strain levels.

stress relaxation. At high strain levels ($\geq 2.0\%$ Fig. 1) a usual and expected relaxation behavior is observed. It is found that the un-relaxed stress, σ_o , decreases by 13.07 and 4.06 MPa at strain levels of 4.0% and 2.0%, respectively when the temperature is changed from 298 to 338 K. This, consequently, corresponds to a decrease in the un-relaxed elastic modulus ($E_o = \sigma_o/\epsilon$, where ϵ is the strain level) by 326.75 and 203 MPa at the mentioned strain levels in same temperature range. Besides, σ_o increases from 25.71 to 36.1 MPa as the strain level increases from 2.0% to 4.0% at 298 K. The corresponding values of E_o are 1.286 and 0.903 GPa, respectively. The decrease in E_o with increasing strain level is due to yielding of the material and the presence of plastic deformation.

At strain levels less than 2.0% (0.3%, 0.5% and 1.0%) a transition from the usual to unusual behavior is detected for the dependence of the un-relaxed stress on temperature as shown in Fig. 2. The un-relaxed stress increases by 0.95, 2.13 and 5.44 MPa at strain levels of 0.3%, 0.5% and 1.0% as the temperature is changed from 298 up to 338 K. The changes in the un-relaxed modulus corresponding to these changes in σ_o are 316, 426 and 544 MPa, respectively. Fig. 3 shows the dependence of the un-relaxed stress on temperature at different strain levels. Opposite behaviors are clearly observed at strain levels $\leq 1.0\%$ and $\geq 2.0\%$.

Ortiz et al. [14] assumed that liquid crystal elastomers have a poly-domain configuration at low strains and make a transition to a mono-domain at high strains. The poly-domain configuration

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