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Test method

A test procedure for separating viscous recovery and accumulated unrecoverable deformation of polymer under cyclic loading

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ABSTRACT

After uniaxial tension and creep tests, asymmetric stress cycle tests have been performed on two polycarbonate (PC) materials with different molecular weights at room temperature. The effects of stress level (mean stress and stress amplitude) and time-dependent factors (stress rate and peak hold time) on ratcheting were studied. To separate the contributions of viscous recovery and accumulated unrecoverable deformation, a new test procedure has been proposed and performed on polycarbonate. The results demonstrate that the proposed test procedure is suitable for separating the viscous recovery and accumulated unrecoverable deformation. The study clearly shows that, for PC, both the viscous recovery and the accumulated unrecoverable deformation cannot be neglected for cyclic loading; previous viscous deformation has significant influence on the following cyclic accumulated deformation.

1. Introduction

Polymeric materials have been extensively used for structural purpose, for example, PC is widely applied in the automotive and aerospace industry in protective devices because of its good mechanical and optical properties. As a structural material, the polymer is subjected to many complicate loading cases, such as creep [1,2], cyclic loading [3–5] and scratch [6,7], etc. The study of time-dependent behavior is very important for the polymeric structure under long-term loading.

The creep behavior of polymer has drawn much attention for its importance in engineering applications. The creep behavior of polyester under tensile loading has been studied [4]. The compressive creep of PMMA and POM subjected to different stress levels was also considered [8]. A multiple compressive creep test was performed [1,2] for PTFE and nylon to study the influence of prior creep history on the subsequent creep deformation. The time-stress equivalence under creep loading was investigated for polycarbonate [9]. The inverse relaxation was found both in the unloading part of tension-unloading, creep test and the cyclic loading test [1,8,10].

Ratcheting, i.e., accumulated inelastic deformation in the cyclic loading with nonzero mean stress [11–18], is very common in engineering applications. The response of polymers subjected to cyclic loading has been studied in the engineering design and safety assessment. The influence of time-dependent factors and applied stress level for polyester and its composites has been investigated [4]. The uniaxial and multiaxial ratcheting behavior of PTFE at room temperature was considered [19,20]. It was found that the torsional ratcheting strain depends on constant axial stress and loading history. For PEI, a post-yield ratcheting test was performed [3], the ratcheting behavior after the yield point is much more apparent than that of the typical ratcheting

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test. The influences of stress history and stress rate history on the ratcheting strain of cerium oxide filled vulcanized natural rubber were discussed [21]. The uniaxial ratcheting behavior of PTFE at elevated temperature was studied [22], the effects of temperature, stress levels and their history were clearly demonstrated.

Actually, the creep and ratcheting deformation always occur simultaneously. The combined effect of creep and ratcheting on the deformation accumulation during cyclic loading has to be studied. The influence of torsional strain cycle on axial creep was studied [20]. It was proved that the creep recovery part has significant influence on the fatigue life for polycarbonate [23]. For the interaction of creep and ratcheting of metal matrix composites, it was found that prior creep restrains the evolution of ratcheting, while the damage caused by prior ratcheting benefits the evolution of creep deformation [24]. A good attempt was made to separate the contribution of creep and ratcheting in the cyclic accumulation of the inelastic strain of metal [25,26]. While those research efforts are important to understand the combined effect of creep and ratcheting on the accumulated deformation, there is no such discussion for polymeric materials.

To clarify the individual effect of creep and ratcheting for polymer under cyclic loading, a new test procedure after performing typical uniaxial tension, creep and ratcheting tests is proposed in this work. Following this procedure, a series of tests were performed on PC. The individual contributions from viscous recovery and accumulated unrecoverable deformation are discussed. It is believed that the experimental study can be of considerable help for understanding the time-dependent behavior and further work constructing constitutive models for PC.

2. Experiment

2.1. Material and equipment

Commercially available polycarbonate, PC NOVAREXR7030R and 7020PJ (Mitsubishi Engineering-Plastics Corp, Japan), with different molecular weights have been utilized. All specimens were injection molded in planar dumbbell shape (thickness: 4 mm) with same gauge area (80 mm * 10 mm). Physical properties of 7030R and 7020PJ are listed in Table 1.

The tests were carried out using a MTS858 BIONIX test machine. The axial strain was measured by a MTS tensile extensometer (634.31F-24) with a 20 mm gauge length.

2.2. Tension, creep and ratcheting tests

To understand the material behavior, typical mechanical tests, uniaxial tension, creep and ratcheting, were performed.

Table 1
Physical properties of PC 7030R and 7020PJ.

Polymer	ρ (g/cm^3)	MFR (g/10 min)	M_W ($\times 10^3$)	M_n ($\times 10^3$)	M_z ($\times 10^3$)	M_W/M_n
7020 PJ	1.20	15	38.9	21.0	58.7	1.858
7030R	1.20	4.2	56.1	29.8	84.6	1.883

The loading curves of creep and ratcheting tests are shown as Fig. 1a and b, respectively. Different stress rates (10 MPa/s and 1 MPa/s, see in Table 2) and different peak stress hold times (0 s and 60 s) were used for the ratcheting tests. The influence of mean stress (50 ± 10, 40 ± 10, 30 ± 10) and stress amplitude (30 ± 10, 30 ± 15, 30 ± 20) were also tested. All tests were conducted at room temperature.

2.3. Separation test of viscous recovery and accumulated unrecoverable deformation

In order to identify the individual contribution of viscous recovery and accumulated unrecoverable deformation, a new test procedure is proposed. The loading curve of the proposed test is illustrated in Fig. 2. Different from the typical ratcheting test with similar peak hold time (Δt_{peak}) and valley hold time (Δt_{valley}), the proposed procedure uses much longer Δt_{valley} than Δt_{peak}. While the peak hold was designed to enhance the creep and possible ratcheting deformation simultaneously, the valley hold was to allow the viscous deformation to recover as much as possible. After cyclic loading, the stress level is kept at zero for up to 7 h to allow further recovery of the viscous deformation. Ideally, only the accumulated unrecoverable deformation is left, and hence can be separated from the total deformation.

The detailed loading procedure is listed in Table 2 (denoted as Case 1, Case 2 and Case 3). Different peak

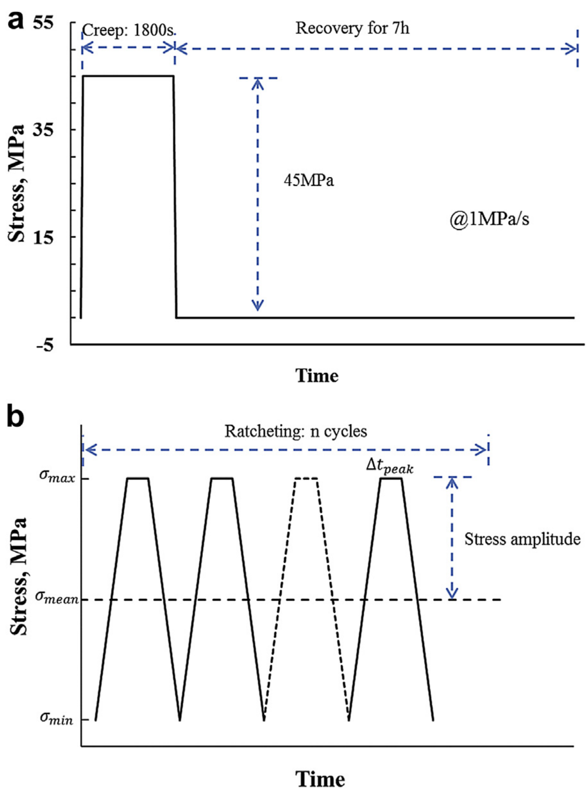

Fig. 1. Loading Schemes: (a) Creep test with a hold time. (b) Classical ratcheting.