Polymer Testing 29 (2010) 1–6

Contents lists available at ScienceDirect

Polymer Testing

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

Test Method

Tensile fracture testing and energy evaluation of a light-cured composite resin

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ARTICLE INFO

Article history:
Received 3 July 2009
Accepted 14 August 2009

Keywords:
Fracture testing
Light-cured resin composite
PMMA
Brittle fracture
Elastic energy
Nonelastic energy
Fracture energy
Energy release rate
High-speed extensometer

ABSTRACT

The brittle fracture of a light-cured composite resin used in dental restoration was examined using a high-speed extensometer consisting of an optical fiber and a position-sensing detector (PSD). Single-edge-cracked specimens for tensile testing were fabricated by packing the composite between two rectangular plates of polymethyl methacrylate (PMMA). In order to study the dynamic effect of brittle fracture and the nonelastic effect of the material, the specimens were pin-loaded with a special jig so that they could split and fly apart in the loading direction after fracture. The flying height and residual deformation of the split specimen were measured to estimate the elastic energy E_e and nonelastic energy E_n, respectively. The fracture energy E_f required to create a new fracture surface was obtained by subtracting E_e and E_n from the external work U_{ex} applied to the specimen. The results showed that the ratio E_f/U_{ex} was about 32% for the composite specimen over a wide range of the fracture load, while it was about 45% for the PMMA specimen. The energy release rate G_f was also estimated using E_f. The results indicated that, although G_f increased with the fracture load, the increasing slope for the composite specimen was smaller than that of the PMMA specimen.

1. Introduction

Light-cured composite resins are widely used in dental restoration due to their ease of handling and aesthetic appearance. However, their mechanical strength and resistance to fracture differ markedly from metals traditionally used in restoration, creating a need to develop stronger and more reliable resin composites. In particular, the fracture behavior of composites needs to be carefully assessed to ensure their mechanical reliability. Fracture toughness is usually evaluated in terms of elastic fracture mechanical theory by measuring the crack length and the load or external work applied to a tensile-stressed or bending specimen. Several different types of specimen geometries and experimental methods have been proposed for fracture toughness evaluation of composites [1–4]. However, problems exist in both the light curing procedure as well as the inherent brittleness of the cured material that stems from the large content of inorganic powders and fillers, which make it difficult to fabricate standard-sized composite specimens as are required for fracture toughness evaluation. In addition, most polymers exhibit some nonelastic effects from viscoelastic and plastic deformation [5]. Brittle fracture also causes dynamic or inertia effects when a crack propagates dynamically within the specimen, as is commonly the case [6–25]. These effects also need to be taken into account when evaluating the fracture toughness of brittle materials. Nonetheless, quantitative appraisals of both effects on fracture toughness have seldom been undertaken due to the difficulties inherent in the experimental techniques currently used.

We have explored these issues by measuring brittle fracture in polymers using a tensile loading device we have developed [26–30]. This device consists of a high-speed extensometer that allows quantitative measurements to be made of the static and dynamic displacements near the

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0142-9418/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.polymertesting.2009.08.007

crack position in single-edge-cracked specimens. The elastic energy stored in the specimens was evaluated by determining the flying height of the half specimen following fracture. The dynamic response and residual deformation of the specimen were then measured to evaluate the dynamic and nonelastic effects. The external work applied to the specimen was partitioned into three components: the elastic energy, nonelastic energy, and fracture energy required to create a new fracture surface. The energy release rate for crack propagation was similarly evaluated by using these parameters and indicated that the dynamic and nonelastic effects play important roles in understanding brittle fracture behavior [26–30].

In this study, we evaluated the proposed experimental procedure using a light-cured resin composite. As outlined above, this material presents a problem in fabricating standard-sized specimens due to both light curing procedures and resulting brittleness. To obviate these difficulties, we fabricated a novel type of single-edge-cracked specimen by packing the composite between two rectangular PMMA plates. The nonelastic energy E_n arising from viscoelastic and plastic deformation was then measured using a high-speed extensometer that consisted of an optical fiber and a position-sensing detector (PSD). The elastic energy E_e was calculated from the kinetic energy of the split specimen by measuring the flying height following fracture. The external work U_{ex} was determined from the load and displacement applied to the specimen, and the displacement near the crack was obtained from the PSD. By subtracting E_e and E_n from U_{ex}, we could obtain the fracture energy E_f required to create the new fracture surface. For a fracture surface A_s, the energy release rate was evaluated using $G_f = E_f/A_s$ and correlated with the fracture load of the specimen. This paper discusses the applicability of the experimental method to light-cured resin composites by comparing results with those of reference PMMA specimens.

2. Specimen material and experimental methods

The light-cured resin composite used in this experiment was Clearfil AP-X, supplied by Kuraray Medical Ltd. This material is a cross-linked acrylic resin composed of about 85 wt% inorganic powders and fillers. It is widely used as a dental restorative material in clinical practice. To overcome the problems of fabricating standard-sized specimens from this material, as outlined above, our specimens had the geometry shown in Fig. 1(a), where the composite was packed between two rectangular plates of PMMA. We used PMMA because it has similar properties to the composite and adheres readily to the resin.

The specimens consisted of two rectangular PMMA plates (Sumipex E), 3 mm thick, 20 mm wide, and 90 mm long. Clearfil Tri-S Bond bonding agent (Kuraray Medical Ltd.) was applied to the end surfaces of the plates and irradiated using a Morita Jetlite 3000 light unit to cure the agent. The two plates were directionally aligned using two frames on a transparent 5 mm thick PMMA plate with a 10 mm clearance gap, and the composite was packed into the gap and irradiated with the light.

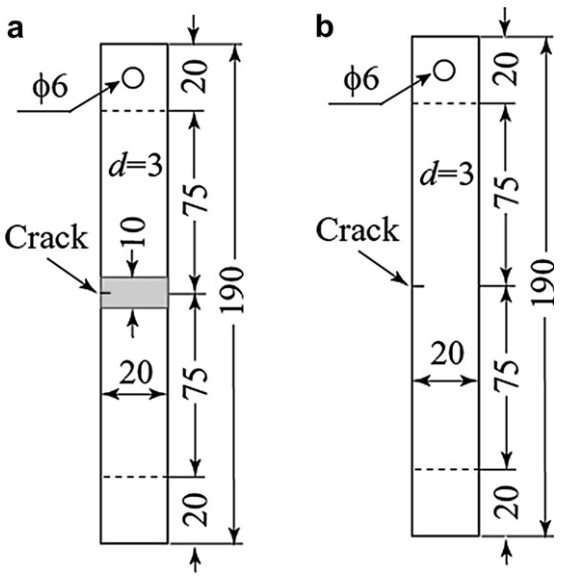

Fig. 1. Specimen geometries: (a) composite resin, (b) PMMA.

To prevent specimen curvature following the curing, the composite was irradiated eight times alternately from the top and bottom (four times of 5 s duration and four times of 10 s duration) followed by a further 10 s upon removal of the frames. The surface of the composite was then ground and polished flat. Each specimen was stored for 24 h in air at room temperature. The PMMA specimen shown in Fig. 1(b) was made to provide a comparison with the composite specimen.

The experimental procedure is illustrated in Fig. 2. The lower portion of the specimen was clamped rigidly and the upper part tightly confined with steel plate grips and a pin-shaped bolt and nut to satisfy the symmetry requirements. The specimen was then loaded at the pin. Fracture loading of the specimens was initiated at sharp pre-cracks of differing lengths ranging from 2 to 7 mm made by tapping

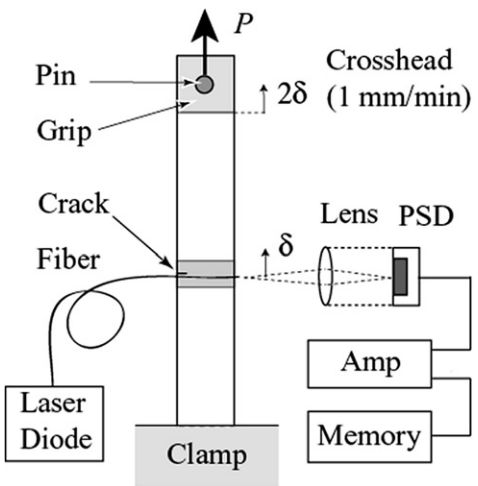

Fig. 2. Experimental setup.