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Measuring the residual stress in dental composites using a ring slitting method

Jeong Won Park[a,*], Jack L. Ferracane[b]

[a]*Department of Conservative Dentistry, School of Dentistry, Kyungpook National University, 101, Dongin-dong 2-ga, Joong-gu, 700-422 Daegu, South Korea*
[b]*Department of Restorative Dentistry Division of Biomaterials and Biomechanics, Oregon Health & Science University, Portland, OR, USA*

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Summary *Objectives*. The objective of this experiment was to employ the ring slitting method for the measurement of the residual stress (RS) produced in dental composite materials after polymerization. This study was designed to determine the effect of slitting and measuring time on the residual stress.

Methods. Rings were made in a split brass mold from three composites (Z100/3MESPE; Herculite/Kerr; Heliomolar/Ivoclar) and cured in a Triad II (Dentsply). Two points were scribed, and the rings were slit at either 1 h (Early-group) or 24 h (Delayed-group) after curing the composite. The change in the distance between the scribed points was measured using an image analyzer system at both 1 and 24 h after slitting. From the measured change, circumferential RS was calculated and statistically analyzed with ANOVA/Tukey's ($P<0.05$). The degree of conversion of each composite at 1 and 24 h was measured with FTIR and analyzed using Student's t-test ($P<0.05$).

Results. In general, the residual stress (range = 0.42–2.84 MPa) was highest for Z100 and lowest for Heliomolar, but this depended upon the test conditions. The early cut (1 h slitting), 24 h measurement groups showed the highest residual stress values.

Significance. This study, describes a ring slitting method to measure residual stress generated in dental composites during and after curing. The stress of composite can be affected by the cutting and measurement time.

Introduction

The polymerization of all resin-based composites is accompanied by volumetric shrinkage. Under normal conditions when the composite is bonded to cavity walls, this contraction results in the development of stress as the elastic modulus of the material becomes significant. This stress may result in a deformation of the overall structure. While some of the stress may quickly relax, some will remain within the hardened composite structure during and after polymerization is complete.

* Corresponding author. Tel.: +82 53 420 5931; fax: +82 53 426 8958.
E-mail address: pjw@knu.ac.kr (J.W. Park).

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It is hypothesized that the stresses generated by the setting dental composite restoration may primarily be responsible for adhesive failures of the bond between the restoration and the tooth surface [1,2]. Essentially, the development of the adhesive bond and the production of contraction stress are in 'competition'. Thus, many investigators have focused studies on methods to reduce contraction stresses in dental composites [3–5] by altering light-curing techniques [6–9], composite placement methods [10,11], and composite formulation [12–16].

While the generation of contraction stress has been studied extensively, there are few examples of studies on the measurement or the effect of residual stress in the dental composite after polymerization [17]. There are numerous examples in the non-dental literature in which these residual stresses have been shown to have an effect on the physical and mechanical properties of composite structures [18–23]. Therefore, a better understanding of the production and effect of residual stress in composites may be helpful to understand the clinical performance of dental composites.

Residual stress has been defined as 'a stress that exists in the bulk of a material without application of an external load (including gravity) or other source of stress, such as a thermal gradient' [24]. When a force is applied to a structure in which a residual stress is already present, the total stress produced may surpass the stress limitations of the material, causing premature structural failure or fracture of adhesive bonds. It is likely that residual stress at surfaces may also result in reduced resistance to wear or surface cracking. This emphasizes the importance of the evaluation of residual stress in predicting the failure mode and the resistance of a material to the propagation of cracks [25].

In crystalline or semi-crystalline materials, residual stress may be measured with diffraction techniques. The measurement is more difficult for amorphous materials, like highly entangled or cross-linked polymeric structures. Several alternative techniques, such as layer removal, direct strain gage application, and ring slitting are available for determining macroscopic residual stresses in polymers and resin-based composites. These techniques are used with pipes or ring-shaped structures. The layer removal method has been used to estimate the radial residual stress component of pipes and ring structures. This technique involves removal of successive surface layers of material, followed by measurement of the resulting curvatures. A limitation of this method is the fact that the removal of layers is likely to disturb the true stress state of the remaining material [25]. Chaoui et al. [18] suggested that the strain gage analysis method provides more practical values for residual stress than does the layer removal or conventional ring slitting methods. However, the technique requires precise placement of the strain gages and also involves the removal of material [26].

An alternative technique for measuring residual stress in a ring is to slit the structure and measure the resulting dimensional change. Both the layer removal and the ring slitting method detect the circumferential strain in a circular material [27]. These methods are based on the proportionality relationship between the original diameter (d_0) and the tangential strain (ε_θ).

Seif et al. [26] applied a laser speckle imaging technique to both the layer removal and the ring slitting methods in order to determine residual stress distribution in thick-walled plastic pipes. They developed an empirical formula based on combining layer removal with the laser speckle technique. Subsequently, they applied the method to thin-walled cylinders using the slitting technique. More recently, Seif et al. [28] improved their measurement technique using computerized image analysis. This approach has the stated advantage of simplicity and greater sensitivity.

The objective of this experiment was to utilize the ring slitting method reported by Seif et al. [28], for the measurement of the residual stress produced in three different dental composite materials during polymerization. The study was designed to determine the effect of time between polymerization and measurement (slitting after 1 vs 24 h) in order to investigate the effect of continued polymerization, and between early and delayed slitting (1 vs 24 h after curing) in order to investigate the effect of stress relaxation. The degree of conversion of the composites was also measured at each time period since, the residual stress was expected to be a function of the extent of the curing reaction.

Materials and methods

Materials

Three commercial dental composites were evaluated (Table 1). The composites were chosen because they have been used in previous studies in this laboratory and have been shown to have different volumetric contractions and elastic moduli, and produce differing levels of contraction stress [29].