Experimental Studies of Composite Shrinkage of Dental Restorations

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Abstract

Dental composites are light-curable resin-based materials with an inherent defect of polymerization shrinkage which may cause tooth deflection and debonding of restorations. The shrinkage behaviors of dental composites under four different light curing regimens were investigated by using digital image correlation (DIC) method. Experimental results showed that the shrinkage in unbonded restorations has the greatest shrinkage strain on the top surface. The bonded restorations did not show a typical centripetal shrinkage patterns as their unbonded restorations, and had greater downward displacements. Vertical curing at regular intensity caused the greatest shrinkage strain. Low-intensity curing reduced overall shrinkage at cervical margin, but did not prevent debonding after storage. Oblique curing caused asymmetric shrinkage with less deformation at tooth-shielded side and reduced shrinkage due to the attenuated polymerization rate rather than guided shrinkage direction. This studies may provide useful information for clinical usage, and further stress analysis by numerical methods.

Keywords

Dental composite • Polymerization shrinkage • Digital image correlation • Light curing • Displacement field

1 Introduction

Dental composites are light-curable resin-based materials. During the light curing process, serial free radical reaction induces polymerization of resin monomers, and the composites hardened after light exposure for 20–60 s. Dentists can manipulate the composite at liberty and have a rapid cure on demand. However, polymerization causes volumetric shrinkage strains ranging from 2 to 6% [1], which can cause many clinical problems associated with composite restorations.

Contemporary dental composites rely on etching-adhesive procedures to bond to enamel and dentin surfaces. Polymerization of dental composites causes internal contraction stress that may cause bonded tooth deflection or debonding of dental composites from the tooth in some weakly linked areas [2].

Various approaches have been used to measure the contraction stress or track its location, such as a modified linometer [3] or photoelastic methods [4]. It is possible to determine the influences of resin composition, dental cavity configuration, or light curing mode, on the development of contraction stress in clinical situations. Alternative

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T. Vo Van et al. (eds.), *6th International Conference on the Development of Biomedical Engineering in Vietnam (BME6)*, IFMBE Proceedings 63, https://doi.org/10.1007/978-981-10-4361-1_11

experimental methods measure the tensile strains and displacements on the tooth surface [5] to assess the implicit shrinkage kinetics. However these approaches do not reveal the magnitudes and distributions of contraction stress, and may be affected by individual differences among tooth specimens.

As a non-contacting optical technique, Digital image correlation (DIC) measures full-field displacements of a deformed object by pattern matching of object images in different states [6, 7]. Recently DIC technique has been used to investigate the contraction behaviors of dental composites. DIC has been applied to measure the displacement and displacement gradients (strains) of dental composites to study the polymerization shrinkage behaviors [8, 9].

More studies to modulate the polymerization shrinkage or redirect the shrinkage direction to enhance the resin–tooth adaptation have been reported. Some investigators found that modified regimens to allow pre-gel flow of composites could reduce the contraction stress [10] and improved marginal adaption [11]. Other results showed that modulation of light energy intensity does not change the shrinkage strain significantly [12]. Realization of the polymerization kinetics may aid in regulating shrinkage and the associated stress. The objective of this study was to apply a simplified approach, DIC, to investigate the polymerization shrinkage behaviors of dental composites with different light curing regimens.

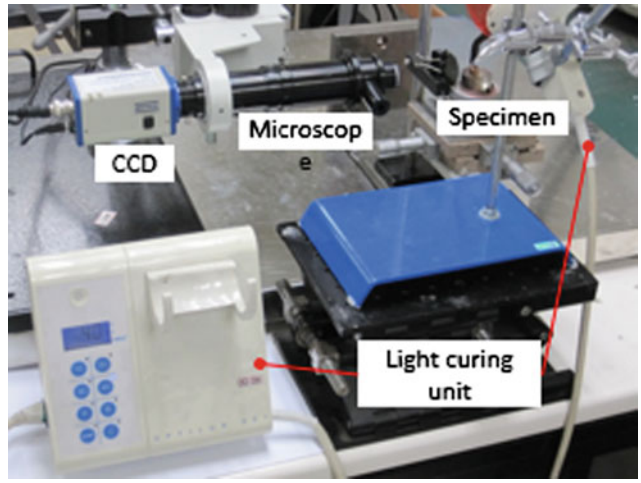

Fig. 1 Photograph of the DIC experimental setup

2 Materials and Methods

The DIC measurement system used was composed of a CCD camera with resolution of 640 × 480 pixels, and an optic Zoom microscope. A DIC program, Vic-2D, was used to determine the shrinkage displacement on the composite restoration surfaces. The image grabbed having a resolution of 8.13 μm/pixel. A sub-image size of 41 × 41 pixels was chosen to calculate the displacement of a certain point.

A photograph of the DIC experimental setup is shown in Fig. 1. Thirty-two human molars of similar sizes and forms were used in this study. After extraction, the teeth were mounted in acrylic resin vertically with the roots embedded 2 mm below the cementoenamel junction. Each tooth was prepared with a box-form cavity of 3(W) × 3(D) × 3(H) mm. In the bonded case, the cavity surfaces were treated with regular dental adhesives, but treated with a Vaseline gel in the unbonded case to allow free shrinkage. A dental composite Z250 (3 M/ESPE) was used to fill the prepared cavities.

The surfaces of the restoration and neighboring tooth were sprayed by black paint. The tooth was placed on the jig and the unpolymerized composite image was taken as the reference image. The deformed images were taken after the restorations were irradiated with their respective curing regimens. The experimental images were fed into computer and analyzed by the DIC program.

These teeth were assigned to four groups that receive different light curing protocols of regular light intensity of 500 mW/cm^2 for 40 s (group R), low intensity of 300 mW/cm^2 for 40 s (group L), and step curing by a low initial intensity of 100 mW/cm^2 for 10 s followed by a boost in intensity of 600 mW/cm^2 for 30 s (group S), and oblique curing at low light intensity (group Lo), respectively. The light curing system was a quartz-tungsten-halogen light curing unit.

For the expression of the DIC measurements, the lower left corner of the restoration was assigned as the origin of the XY image plane (Fig. 2(a)). To further description of the shrinkage behaviors, a virtual shrinkage center was defined as the place where the displacement was minimal. The locations of shrinkage center were also examined and compared for the bonded and unbonded cases.

3 Results and Discussion

The displacement fields of the restorations under various light curing regimens are illustrated in Fig. 2. The bulk of the composite restoration shrank centripetally. The shrink patterns vary with the light curing regimens, and the shrinkage centers can be observed.

The shrinkage strain on the top (ε_T) and bottom (ε_B) of unbonded cases were calculated and listed in Table 1. It can be found that ε_T of group R showed a significantly higher value than groups S, L, and Lo. There were no significant differences among the four groups for the shrinkage strain ε_B.

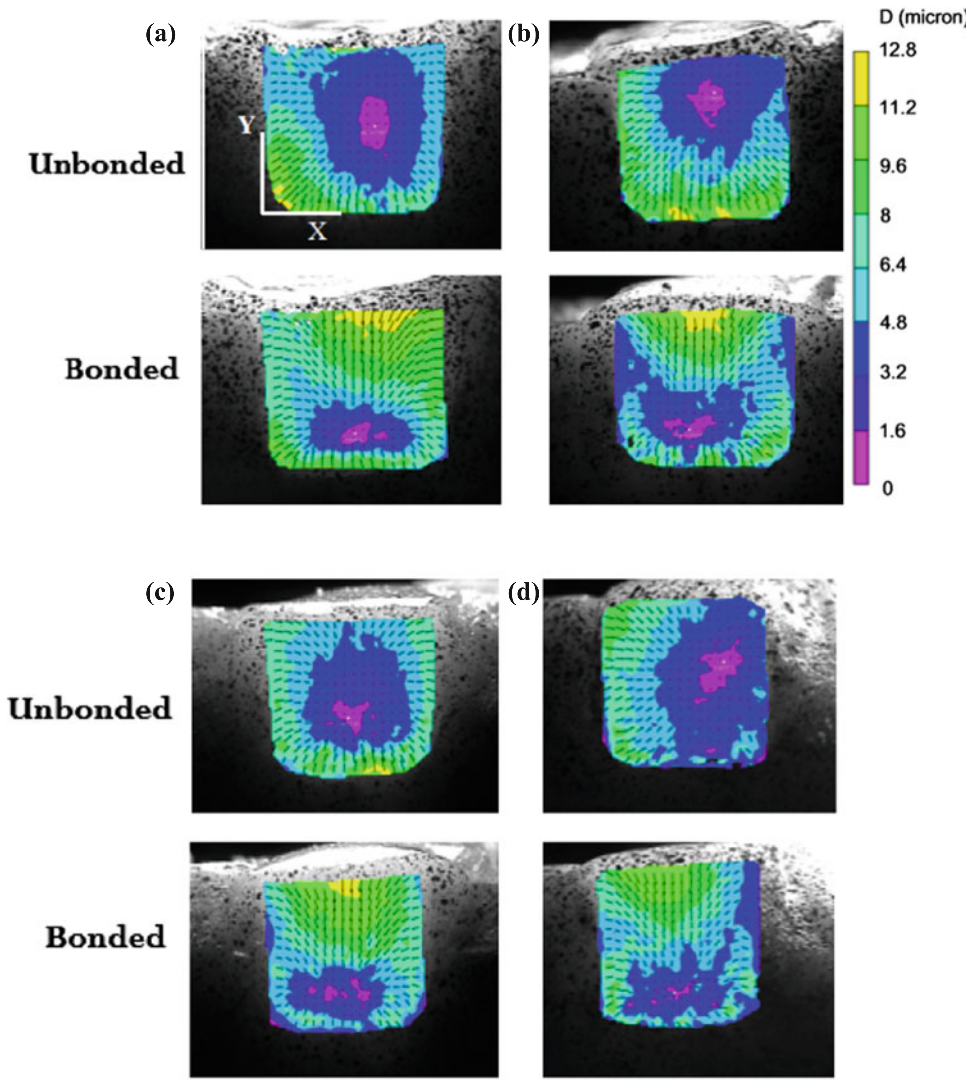

Fig. 2 Displacement field of dental composites caused by polymerization shrinkage: **a** regular light curing, **b** step light curing, **c** vertical low light curing, and **d** oblique low light curing. The *black arrows* indicate the shrinkage direction. *White dot* indicates the shrinkage center

Table 1 Mean (SD) linear shrinkage rate in unbonded restoration

Group	ε_T	ε_B
R	0.45 (0.08)	0.35 (0.05)
L	0.38 (0.09)	0.29 (0.11)
S	0.33 (0.06)	0.35 (0.05)
Lo	0.33 (0.06)	0.34 (0.05)

The locations of the shrinkage centers are plotted as shown in Fig. 3. It can be seen that group S showed the highest average location (Y = 2.09 mm) and group L has the lowest position (Y = 1.47 mm). However, with oblique light curing, the center location can be raised to 1.82 mm.

In the bonded cases, the shrinkage of all four groups also directed inward but did not follow standard centripetal patterns, and were different from their respective unbonded cases. The minimal shrinkage areas appeared as lines instead of centers. For group Lo, the shrinkage centers shifted to the buccal side. The locations of the shrinkage centers were lower than that in the unbonded cases for all four groups. The shrinkage of group R, L and S ranged from 10.5 to 11.5 µm on the top surfaces, and ranged from 9.6 to 11.7 µm on the bottom ones. For oblique lighting group Lo, the shrinkage was reduces to 8.6 µm on the top surfaces, and 7.8 µm on the bottom, respectively. Further examination of the displacements on four boundaries did no present any significantly asymmetric patterns, and were not affected by the light directions (Fig. 4).

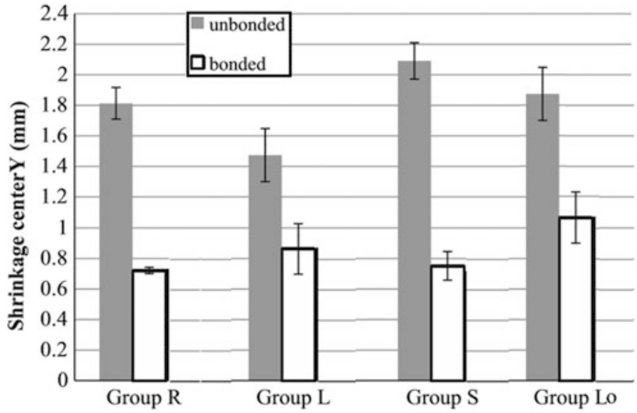

Fig. 3 Locations of shrinkage centers found on images

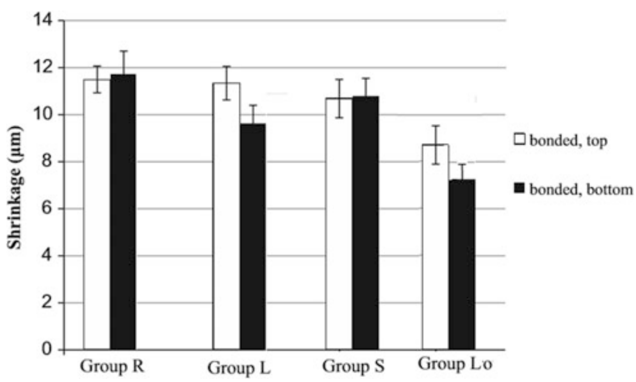

Fig. 4 X-direction shrinkages at the *top* (Y = 3) and *bottom* (Y = 0) in bonded restorations

4 Conclusions

Polymerization shrinkage of dental composite was measured by using DIC techniques. The effects of light curing (intensity and direction) on the shrinkage patterns and contraction behaviors of dental composites was investigated. The results showed that the shrinkage in unbonded restorations has the greatest shrinkage strain on the top surface. The unbonded restorations show a typical centripetal shrinkage patterns. However, in the bonded cases, the shrinkage also directed inward but did not follow standard centripetal patterns, and were different from their respective unbonded cases. Low-intensity lighting yielded reduced and homogeneous shrinkage, but did not prevent debonding. Oblique lighting caused asymmetric shrinkage deformation and the tooth shielding effect reduced the contraction. The polymerization shrinkage behaviors of dental composites studied may provide useful information for clinical usage, and further stress analysis by numerical methods.

Acknowledgements This study was supported by Research Grant NSC-101-2320-B006-003-MY3 from the National Science Council, Taiwan.

References

1. Labella R, Lambrechts P, Van Meerbeek B, Vanherle G (1999) Polymerization shrinkage and elasticity of flowable composites and filled adhesives. Dent Mater 15(2):128–137
2. Cabrera E, de la Macorra JC (2007) Polymerization shrinkage influences microtensile bond strength. J Dent Res 86(3):227–231
3. Feilzer AJ, Degee AJ, Davidson CL (1993) Setting stresses in composites for 2 different curing modes. Dent Mater 9(1):2–5
4. Ernst CP, Meyer GR, Klocker K, Willershausen B (2004) Determination of polymerization shrinkage stress by means of a photoelastic investigation. Dent Mater 20(4):313–321
5. Meredith N, Setchell DJ. (1997) in vitro measurement of cuspal strain and displacement in composite restored teeth. J Dent 25(3–4):331–7
6. Sutton MA, Mcneill SR, Jang JS, Babai M (1988) Effects of subpixel image-restoration on digital correlation error-estimates. Opt Eng 27(10):870–877
7. Sutton MA, Yan JH, Tiwari V, Schreier HW, Orteu JJ (2008) The effect of out-of-plane motion on 2D and 3D digital image correlation measurements. Opt Lasers Eng 46(10):746–757
8. Chuang SF, Chen TY, Chang CH (2008) Application of digital image correlation method to study dental composite shrinkage. Strain 44(3):231–238
9. Chuang SF, Chang CH, Chen TYF (2011) Contraction behaviors of dental composite restorations—finite element investigation with DIC validation. J Mech Behav Biomed 4(8):2138–2149
10. Hofmann N, Denner W, Hugo B, Klaiber B (2003) The influence of plasma arc vs. Halogen standard or soft-start irradiation on polymerization shrinkage kinetics of polymer matrix composites. J Dent Res 31(6):383–393
11. Yoshikawa T, Burrow MF, Tagami J (2001) A light curing method for improving marginal sealing and cavity wall adaptation of resin composite restorations. Dent Mater 17(4):359–366
12. Yap AUJ, Ng SC, Kiow KS (2001) Soft-start polymerization: influence on effectiveness of cure and post-gel shrinkage. Oper Dent 26(3):260–266