

EFFECT OF LAYERING METHODS, COMPOSITE TYPE, AND FLOWABLE LINER ON THE POLYMERIZATION SHRINKAGE STRESS OF LIGHT CURED DENTAL COMPOSITES

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1 Introduction

Composite restoration has become an essential part of everyday dental practice with the improvement in dental adhesive system, the increase in patients' esthetic demand and more emphasis on preservation of tooth structure. However, Polymerization shrinkage and its associated stress still remains a main drawback of composite restoration in dentistry [1, 2].

Polymerization shrinkage causes stress at the interface between a tooth and a restoration as the modulus of composite increases during curing. This stress manifests as bond failure, cuspal flexure, enamel microcrack, pulpal irritation and secondary caries due to bacterial infiltration, and post operative sensitivity, which in turn can lead to restoration failure and require re-restoration [3, 4].

Clinical strategies suggested to minimize shrinkage stress of composites include incremental filling technique, soft-cure or pulse-delay cure method, and the use of low-modulus intermediate liner such as flowable composites to absorb shrinkage stress [2, 4, 5]. However, conflicting results have been reported regarding the efficacy of the methods.

Measurement of cuspal deflection is a useful way for evaluating polymerization shrinkage stress, but the use of extracted teeth for cuspal deflection measurement can produce significant discrepancies among specimens due to the lack of standardizing the anatomical and histochemical characteristics of each individual tooth [6].

This study measured cuspal deflection in real time during composite curing, using aluminum blocks with a cavity. The aim of this study was to investigate the effect of layering methods, flowable composite liner, and the use of low shrinking silorane-based composite on the polymerization shrinkage stress of light cured dental composites.

2 Materials and Methods

2.1. Cuspal deflection measurement instrument

Two LVDT (Linear variable differential transformer) probes (AX-1, Solartron Metrology, West Sussex, UK) were set on two XYZ tables (Micro motion technology, Bucheon, Korea) with three attached micrometers (Mitutoyo, Kawasaki, Japan) (Fig. 1). Cuspal deflection was detected by the LVDT probes and the measured value was stored on a computer using a data acquisition board (PCI-6024, National Instruments, Austin, TX, USA) and a data acquisition and analysis software Labview (National instruments). The sensitivity of the LVDT probes exceeded $0.1 \mu\text{m}$ in the range of $\pm 1 \text{ mm}$. Calibration was carried out to set the output voltage to 10 mV for each $1 \mu\text{m}$ of displacement.

2.2. Specimen preparation

Twenty four aluminum blocks ($10 \times 8 \times 30 \text{ mm}$) with a cavity [$6 \text{ (W)} \times 8 \text{ (L)} \times 4 \text{ (D)} \text{ mm}$] were fabricated using a milling machine, creating two remaining cusps [$2 \text{ (T)} \times 8 \text{ (L)} \times 4 \text{ (H)} \text{ mm}$] (Fig. 2a). The inside of the cavity was air-abraded with $50 \mu\text{m}$ Al_2O_3 powder and thoroughly rinsed with water using a three-way syringe.

Composites used for filling the cavities were a methacrylate-based universal hybrid composite (Z250: 3M ESPE, St. Paul, MN, USA), a flowable composite (Z350 flowable: 3M ESPE), and a silorane-based composite (P90: 3M ESPE). Scotchbond multipurpose adhesive (3M ESPE) was applied prior to placement of methacrylate-based composites (Z250 and Z350 flowable) and P90 system adhesive was applied prior to silorane-based composite (P90). The adhesive was light cured for 10 s using a LED light curing unit (S10: 3M ESPE), and the light intensity was 1200 mW/cm^2 . An acrylic case with two notches on cuspal wall sides were fabricated and placed on the aluminum blocks to

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prevent the composite from being pushed out of the cavity during layering, and to position the LVDT probes precisely on the cusps (Fig. 2b).

2.3. Composite filling and measurement of cuspal deflection

The required amount of composites to fill the cavity was calculated from the density of the composites and the volume of the cavity, and the equal amount of composites for each cavity was ensured by weighing the material before use. The aluminum blocks were randomly divided into four groups and filled with composites by one of following protocols (Fig. 3).

Group 1 (Bulk filling): Z250 was placed in one bulk and light cured from the upper surface for 20 s, the mesial side for 20 s, the distal side for 20 s, and the upper surface for 20 s again (total 80 s).

Group 2 (Incremental filling): Z250 was placed in four incremental layers. Each increment was light cured perpendicular to the surface for 20 (total 80 s).

Group 3 (Incremental filling with flowable liner): First layer was filled with Z350 flowable composite in 1 mm thickness, followed by three incremental layers with Z250. Each increment was light cured for 20 s as done in group 2 (total 80 s).

Group 4 (Incremental filling with silorane-based composite): P90 was placed in four incremental layers. Each increment was light cured for 20 s as done in group 2 (total 80 s).

In incremental placement groups (groups 2, 3 and 4), the composite was equally divided into four portions. Measurement of cuspal deflection was initiated 30 s prior to light curing to obtain a base line and continued up to 2000 s at a rate of 2 data points/s. The amounts of cuspal displacement measured from both cusps were added to produce total deflection. Six measurements were performed for each group at temperature of $25 \pm 0.5^\circ\text{C}$. The data was analyzed by ANOVA and Tukey's post hoc test ($\alpha=0.05$).

2.4. Measurement of the axial shrinkage strain and flexural modulus of composites

In order to investigate the effect of polymerization shrinkage and modulus of composites on the cuspal deflection, the axial shrinkage strain and flexural modulus of the composites were measured using a "modified bonded disc method" [7] and a universal testing machine, respectively (Fig. 4). A fixed

amount of composite was pressed between a slide glass and a flexible cover glass (Marienfeld, Germany) using a metal wire with 0.5 mm diameter as a spacer, producing a disc-shaped specimen 0.5 mm in thickness and 6.0 mm in diameter. The tip of a LVDT probe was placed on the center of the cover glass and set to zero point. A base line was obtained for 20 s, and then curing light was irradiated for 20 s. The output voltage from the LVDT was stored on a computer using a data acquisition device (PCI-6024, National instrument, Mopac Expwy, Austin, TX, USA) at a rate of 10 data points/s for 10 min to determine the axial shrinkage of composites.

Bar type specimens for flexural strength test were prepared by filling composites into stainless steel mold with $2 \times 2 \times 30$ mm space, and light cured in three portions for 30 s each, and stored in distilled water at 37°C for 24 h. The width and depth of the specimens were measured, and flexural modulus was obtained by performing 3 point flexural test according to ISO 4049. Specimens were installed on a universal testing machine (4465, Instron, U.S.A), load was applied at the rate of 0.5 mm/min (distance between the two bases = 20 mm), and the stress-strain curve was measured. The flexural modulus was calculated from the slope of stress-strain curve. Five specimens were tested for each composite.

2.5. Measurement of the compliance of the cusp of aluminum block

The weight of 15.3 kg was applied to the point 1, 2, and 3 mm from the cusp tip of aluminum blocks and displacement of the cusp was measured using a LVDT probe ($n=10$). The compliance was obtained from the measured load-strain relationship.

3 Results

3.1. Cuspal deflection during composite filling

Representative cuspal deflection curves vs. time are shown in Fig. 5 a-d. Cuspal deflection increased rapidly with the beginning of light curing and most of the cusp displacement occurred within 500 s, and gradually increased thereafter. In bulk filling group (group 1), 50% of the total cuspal deflection occurred within 40 s after initiation of light curing. In incremental filling groups (group 2-3), the amount of deflection increased in a stepwise manner.

The mean values of cuspal deflection in group 1-4 were 18.2 (1.54), 14.5 (0.47), 16.2 (1.10), and 6.6 (0.44) μm , respectively, at 2000 s after initiation of measurement (Fig. 6). The cuspal deflection in the incremental filling group was significantly lower than that in the bulk filling group ($P<0.001$). The incremental filling group with flowable liner showed higher cuspal deflection than the incremental filling group without flowable liner ($p=0.035$). The deflection of the incremental filling group with silorane-based composite (P90) was significantly lower than that in the incremental filling group with methacrylate-based composite (Z250) ($P<0.001$).

3.2. Axial shrinkage strain and flexural modulus of composites

The axial shrinkage strains of composites were 4.12% (Z350 flowable), 2.28% (Z250), and 1.05% (P90). The flexural modulus of composite was the highest in Z250 (13.6 GPa), followed by P90 (10.1 GPa), and the lowest in Z350 flowable (7.6 GPa).

3.3. Compliance of the cusp of aluminum block

The compliance of the cusp of aluminum block at the points 1, 2 and 3 mm from the cusp tip were 0.19, 0.09 and 0.05 $\mu\text{m}/\text{N}$, respectively.

4 Discussion

Cuspal deflection in the incremental filling group was significantly lower than that in the bulk filling group, which corroborates the previous studies [5, 6]. It is widely accepted that polymerization shrinkage stress is affected by the C-factor (bonded surface area/un-bonded surface area) of the cavity; an increase of C-factor makes it difficult to compensate shrinkage stress by flow [7, 8]. C-factor of each layer in the incremental filling group was lower than that in the bulk filling group, and the total amount of cuspal deflection summed from all increments was still lower than that of bulk filling group.

Polymerization shrinkage stress causing cuspal deflection is primarily dependent upon the amount of polymerization shrinkage strain and elastic modulus of composite, and the higher the compliance of cusp is, the higher cuspal deflection occurs. According to the study by Min et al. [9], shrinkage strain is the major factor determining

stress when the instrument compliance is high, whereas shrinkage stress is proportional to the product of shrinkage strain and elastic modulus of composite when the instrument compliance is low. In our study, the compliance of the cusp of aluminum block with a large cavity is high; P90 with low-shrinkage produced less shrinkage stress, resulting in lower cusp deflection.

Incremental filling group with flowable composite liner (group 3) showed higher cuspal deflection than that without flowable liner (group 2). This phenomenon could be explained by that high shrinkage strain of flowable composite is a major factor in producing stress in a high compliance situation. It is speculated that the stress absorption by the flowable liner with low elastic modulus due to its lower filler content could not compensate for the effect of high shrinkage strain of the material caused by its higher resin content.

The compliance of the aluminum block at the middle of the cusp is 0.09 $\mu\text{m}/\text{N}$. From this compliance and the measured cuspal deflection, the polymerization shrinkage forces exerted on the cavity wall in groups 1-4 are estimated 202.2 N (20.6 kgf), 161.1 N (16.4 kgf), 180.0 N (18.4 kgf), and 73.3 N (7.5 kgf), respectively.

The effect of difference in cavity compliance, thickness of flowable liner, use of RMGI (resin modified glass ionomer) liner, and light curing methods on the cuspal deflection should be investigated in further studies.

5. Conclusion

Polymerization shrinkage stress can be reduced by the incremental filling technique and the use of low shrinking composite to obtain optimal clinical outcomes. Flowable composite lining under conventional composite layering could not reduce polymerization shrinkage stress in terms of cuspal deflection.

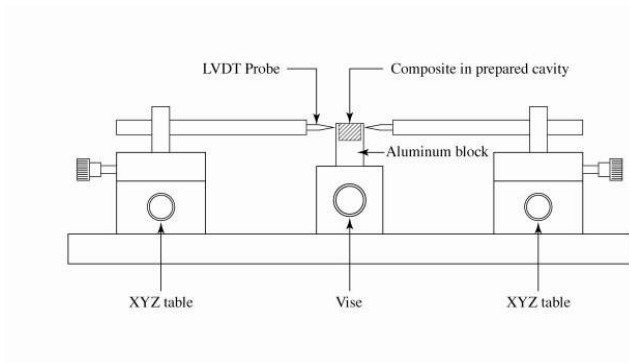


Fig.1. Schematic diagram of instrument for measurement of cuspal deflection.

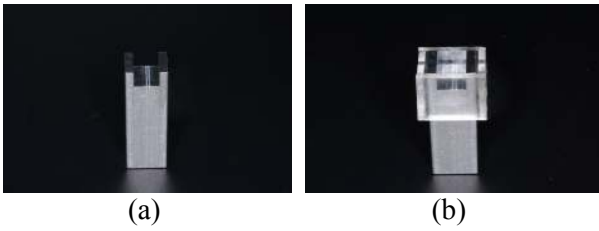


Fig.2. (a) Machined aluminum block with a cavity, (b) Aluminum block in the acrylic cap with two notches for probe positioning.

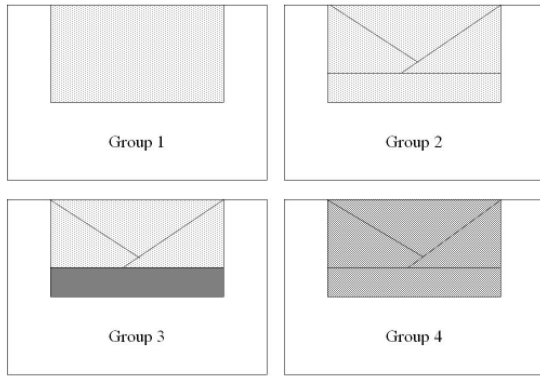


Fig.3. Four filling groups. Group 1: Bulk filling with Z250, Group 2: Incremental filling with Z250, Group 3: Incremental filling with Z250 and Z350 flowable liner, Group 4: Incremental filling with P90.

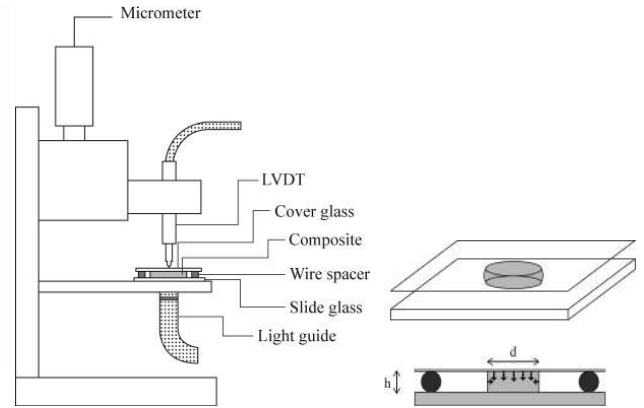
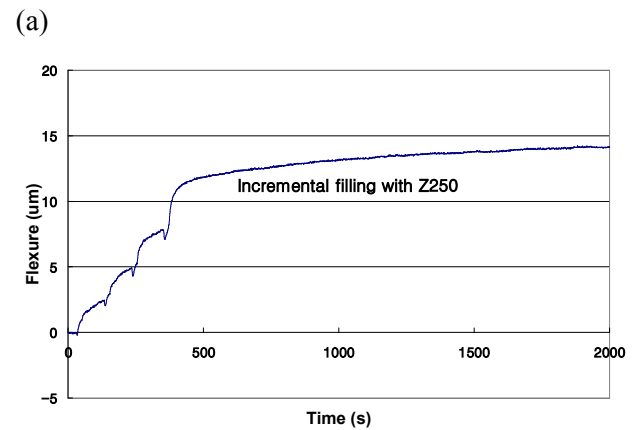
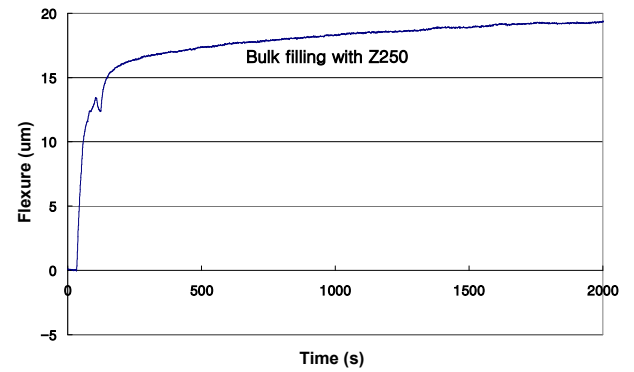
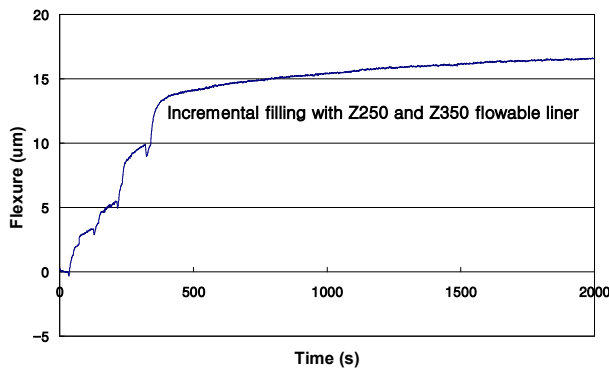


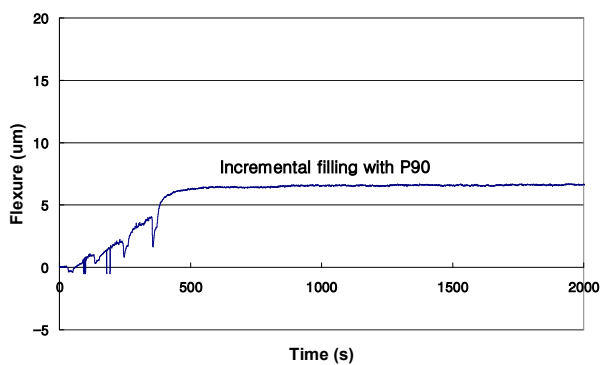
Fig.4. (a) Schematic diagram of axial shrinkage measuring instrument using modified "bonded disc method." (b) Specimen geometry in modified "bonded disc method", h: thickness of disc-shaped composite, d: diameter of composite.



(b)



(c)



(d)

Fig.5. Representative curves of cuspal deflection as a function of time. (a) Group 1: Bulk filling with Z250, (b) Group 2: Incremental filling with Z250, (c) Group 3: Incremental filling with Z250 and Z350 flowable liner, (d) Group 4: Incremental filling with P90.

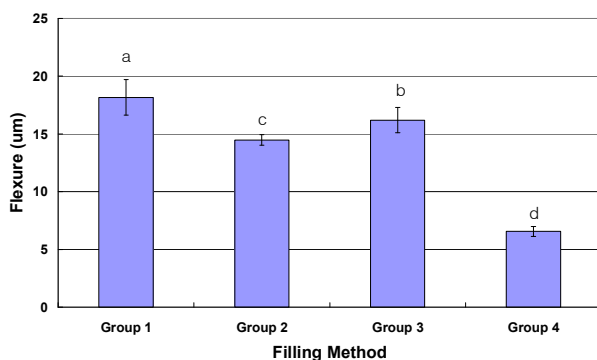


Fig.6. Mean values of cuspal deflection for each group at 2000 s.

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