Dental Materials Journal 25(3): 503−508, 2006

# Effect of Incremental Filling Technique on Adhesion of Light-cured Resin Composite to Cavity Floor

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Received January 13, 2006/Accepted June 9, 2006

The purpose of this study was to evaluate the effect of various incremental filling techniques on adhesion between composite and cavity floor using light-cured resin composite. Black ABS resin and hybrid resin composite were used as mold materials − instead of dentin − for the preparation of cavities, and standardized to 5×5×5 mm. Each cavity was then treated with a bonding system (Clearfil SE bond). Resin composite (Clearfil Photo Core) was placed on the bonding resin using different incremental filling techniques or in bulk and irradiated for a total of 80 seconds using a halogen light unit. Specimens were subjected to the micro-tensile bond test at a crosshead speed of 1 mm/min. Data were analyzed by two-way ANOVA. The results indicated that an incremental filling technique was more effective in improving adhesion to the cavity floor than a bulk filling technique.

Key words: Incremental filling, Micro-tensile, Resin composite

## INTRODUCTION

In recent years, cavities of various sizes have been filled with light-cured resin composite[1−3]. If the cavity increases in size, the volumetric shrinkage of resin composite also increases. Polymerization shrinkage cannot be avoided, and the development of adhesive systems involves a constant battle against this problem. Polymerization shrinkage induces contraction stress in the polymerized resin composite, which could weaken the adhesion at the composite-dentin interface[4−9]. Many factors affect polymerization shrinkage: size of restoration, C-factor of cavity, and filling technique (incremental or bulk).

Incremental placement of light-cured resin composite has been evaluated using various techniques. Several studies using the gap test have suggested that an incremental filling technique reduced contraction stress and contributed to preventing gap formation[10−12]. However, some authors have questioned the notion that contraction stress can be reduced using an incremental filling technique and modeled using photoelastic stress analysis or finite element analysis, and thus suggested that this technique did not eliminate microleakage[13−15]. Despite the conflicting views of detractors, the favorable effect of incremental filling techniques on the microtensile bond strength of light-cured composite has been reported. Santos, *et al.*[16], for example, reported that an incremental technique resulted in higher bond strength than a bulk filling technique. On the other hand, other studies on different filling techniques have not detected any difference in bond strength[12,17] − which implies that further studies are required in this field.

In the evaluation of micro-tensile bond strength, many standardized cavities are required. However, it is too difficult to prepare identical cavities 5 mm or more in depth in permanent teeth. In other words, another material should substitute for dentin with due considerations to both elastic modulus and adhesive property. In the current study, ABS resin and hybrid composite were employed instead of dentin. Since ABS resin mold has a lower elastic modulus than human dentin[18], a hybrid composite which has a higher elastic modulus than human dentin was used to contrast with ABS resin.

The objective of this study was to evaluate the effect of various incremental filling techniques on the adhesion between composite and cavity floor using standardized cavities. The null hypothesis was that filling technique did not affect the bond strength to cavity floor.

## MATERIALS AND METHODS

Black ABS resin (Table 1) or hybrid composite (Estenia C&B, Table 1) molds were used instead of dentin cavities since it was necessary to standardize the cavity form and size in this study. Both wall and floor of each cube-shaped cavity were standardized to 5×5×5 mm using a diamond point under copious air-water spray (Fig. 1). Cavity surface was then finished with a fine diamond point using a high-speed handpiece. With the ABS resin cavity, a self-etching primer (Clearfil SE bond, Table 1) was applied to the cavity surface for 20 seconds and then gently air-dried for five seconds. With the hybrid composite cavity, all surfaces — except for the cavity walls and floor — were colored black with oil paint. The oil painting application was repeated so that the cavity was exposed to the minimum influence of light through the cavity walls as with the black ABS resin. After which, the cavity was treated with the self-etching primer mixed with the same amount of a silane coupling agent (Clearfil Porcelain Bond Activator, Table 1). Then, a thin layer of bonding resin (Clearfil SE bond, Table 1) was applied to each surface and irradiated for 10 seconds using a curing light unit (Cure Master, Yoshida, Tokyo, Japan) with a power output of 830 mW/cm$^2$.

The resin composite (Clearfil Photo Core, Table 1) was placed on the bonding resin in two or three increments as follows. In the case of two increments, the volumetric ratio of the first and second increments was 2:1, 1:1, or 1:2 (Fig. 2). In the case of three increments, each increment was similar in volume (Fig. 2). The amount of each increment was determined by measuring the height of resin paste after measuring the height to which the control cavity was to be filled. In all groups, the inner surface of the cavities was completely covered with the first increment. The unbonded surface of the first increment was then covered with the second increment in a similar manner. Each increment was irradiated for a total of 80 seconds. In group 2-1, the first and second increments were irradiated respectively for 80×2/3 (*ca.* 53 seconds) and 80×1/3 seconds (*ca.* 27 seconds). In group 1-1, each increment was irradiated for 40 seconds. In group 1-2, the first and second increments were irradiated for 80×1/3 (*ca.* 27 seconds) and 80×2/3 seconds (*ca.* 53 seconds). In group 1-1-1,

Table 1 Material used

| Material | | Manufacturer | Batch No. | Chemical composition | Elastic modulus (GPa) |
|---|---|---|---|---|---|
| Mold material (Shade) | ABS resin (Black) | Nihon Extron, Tokyo, Japan | | acrylonitrile butadiene styrene (ABS) | 2.3 |
| | Estenia C&B (DC4) | Kuraray Medical, Tokyo, Japan | 0001AA | Polyurethane methacryl monomer, methacrylic acid series monomer, surface-treated glass powder, surface-treated aluminum microfiller | 28.6 |
| Bonding system | Clearfil SE Bond | Kuraray Medical, Tokyo, Japan | 11345 | Primer: MDP[1], HEMA[2], photoinitiator, water, functional monomer<br><br>Bond: MDP, HEMA, Bis-GMA[3], microfiller, water, functional monomer | |
| | Clearfil Porcelain Bond Activator | Kuraray Medical, Tokyo, Japan | 0153AA | Bis-MPEPP[4], MPS[5] | |
| Restorative material | Cleafil Photo Core | Kuraray Medical, Tokyo, Japan | 2046AA | silanated silica, silanated barium glass, Bis-GMA, CQ[6] | |

[1]MDP: 10-methacryloxydecyl dihydrogen phosphate
[2]HEMA: 2-hydroxyethyl methacrylate
[3]Bis-GMA: Bisphenol A diglycidyl methacrylate
[4]Bis-MPEPP: Bis[(4-methacryloxypolyethoxy) phenyl] propane
[5]MPS: γ-methacryloxypropyl trimethoxy silane
[6]CQ: camphorquinone

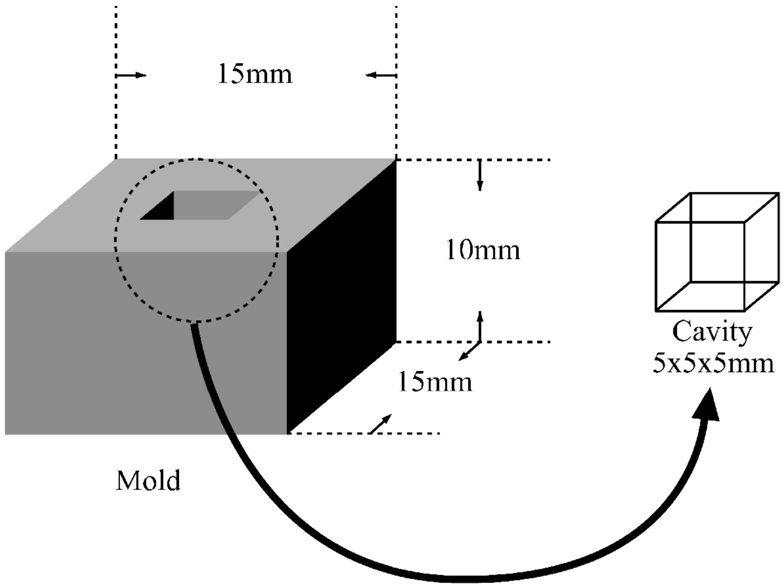


Fig. 1 Schematic illustration of the mold and cavity.

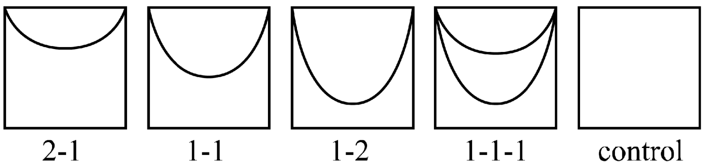


Fig. 2 Schematic illustration of each incremental technique. In the case of two increments, the volumetric ratio of the first and the second increment was 2: 1(2-1), 1: 1(1-1), or 1: 2(1-2). In the case of three increments, each increment was similar in volume (1-1-1).

each increment was irradiated for 80 × 1/3 seconds (*ca.* 27 seconds). The control group was bulk-filled and irradiated for 80 seconds. All specimens were stored in water at 37℃.

After 24 hours, a diamond saw (Leitz 1600 saw microtome, Ernst Leitz, Wetzlar, Germany) under copious water lubrication[19,20] was used to serially section the specimens perpendicular to the bonded surfaces, creating three or four slabs of about 0.7 mm in thickness. The specimens were trimmed to an hour-glass shape, with the narrowest portion (ca. 1 $mm^2$) located at the adhesive interface on the cavity floor[19,20] using a diamond point under copious air-water spray. Finishing was carried out using a superfine diamond point in a high-speed handpiece. Trimmed specimens were then mounted on the arms of a testing apparatus using a cyanoacrylate adhesive (Zapit, MDS Products, Corona, CA, USA) and subjected to micro-tensile testing (EZ-test, Shimadzu, Tokyo, Japan) at a crosshead speed of 1 mm/min.

Fracture mode of the specimen was examined visually using a stereomicroscope (Olympus Colposcope, Olympus Optical Japan, Tokyo, Japan) with ×3 magnification after the tensile test was completed.

Fracture patterns were classified into one of four categories as listed below (Table 2): I — Interfacial failure occurring between adhesive resin and mold; II — Failure that occurred 50% or more within the adhesive resin; III — Failure that occurred 50% or more within the composite; IV — Failure that occurred 50% or more within the mold.

Data were analyzed using the Statistical Package for Social Science (SPSS ver.11 for Windows), a software for statistical procedures. Two-way analysis of variance (ANOVA) was employed, as well as Dunnett's T3 test, at a level of 95%.

Number of specimens was 15 for each group. Fracture mode results were compared for differences with respect to filling technique for each material. These comparisons were analyzed using the chi-squared test at a level of 99%.

Table 2 Micro-tensile bond strength and fracture modes of each group

| Group | Microtensile bond strength, Mean ± SD (MPa) | Fracture mode | | | |
|---|---|---|---|---|---|
| | | I | II | III | IV |
| ABS resin mold control | 14.8±3.1[a] | 15 | 0 | 0 | 0 |
| ABS resin mold 2-1 | 18.1±5.0[a,b] | 15 | 0 | 0 | 0 |
| ABS resin mold 1-1 | 22.1±3.1[b,c] | 15 | 0 | 0 | 0 |
| ABS resin mold 1-2 | 22.3±4.1[b,c] | 14 | 1 | 0 | 0 |
| ABS resin mold 1-1-1 | 25.9±4.9[c] | 12 | 3 | 0 | 0 |
| Hybrid composite mold control | 8.4±12.7[a] | 15 | 0 | 0 | 0 |
| Hybrid composite mold 2-1 | 23.5±14.6[a,b,c] | 11 | 4 | 0 | 0 |
| Hybrid composite mold 1-1 | 42.9±12.1[d] | 1 | 6 | 0 | 8 |
| Hybrid composite mold 1-2 | 46.4±12.0[d] | 0 | 6 | 0 | 9 |
| Hybrid composite mold 1-1-1 | 54.9±14.6[d] | 0 | 3 | 0 | 12 |

Same superscripts after micro-tensile bond strength values denote no significant differences at $p=0.05$.
Fracture patterns were classified into one of four categories: I — Interfacial failure occurring between adhesive resin and mold; II — Failure that occurred 50% or more within the adhesive resin; III — Failure that occurred 50% or more within the composite; IV — Failure that occurred 50% or more within the mold.

## RESULTS

Micro-tensile bond strength results of resin composite to ABS resin and hybrid composite molds are summarized in Table 2.

Two-way ANOVA revealed that bond strength was influenced by both mold material ($F=82.57$, $p<0.0001$) and filling method ($F=41.61$, $p<0.0001$). There was a significant interaction between the independent variables of filling method and mold material ($F=16.79$, $p<0.0001$).

Groups 1-1, 1-2, and 1-1-1 had significantly higher mean bond strength than the control group for each mold. There were no significant differences between 2-1 and control groups of both molds, while other groups of hybrid composite showed high micro-tensile bond strength values.

Fracture modes are shown in Table 2. None of the specimens in the ABS resin mold groups failed cohesively in composite and mold. Further, there were no statistically significant differences in fracture mode among the ABS resin groups ($\chi^2=8.98$, $p>0.01$). As for the hybrid composite mold groups, none of the specimens failed cohesively in composite, while some specimens in the 1-1, 1-2, and 1-1-1 groups failed cohesively within hybrid composite mold. It should also be noted that there were statistically significant differences among the hybrid composite groups in fracture mode ($\chi^2=64.61$, $p<0.01$).

## DISCUSSION

Esthetic restorations are now in high demand for posterior teeth[21], and deeper cavities have been restored with direct resin composite in clinical practice[22,23]. Improvements in the mechanical properties of resin composite have permitted their use with greater reliability[1]. Regarding adhesion, light-cured bonding systems for direct composite restorations perform better than adhesive systems which are bonded to dual-cured resin cements for indirect restorations[24−26]. This is one reason why the cavity size for a direct restoration is expected to be larger. However, some problems plaguing composite-dentin bonding — which have already been noted — still persist. One of which is the contraction stress of composite restorations, a chief cause of adhesive failures at the interface between dentin and resin composites[27,28].

It is a commonly held belief that incremental filling techniques are capable of increasing the degree of conversion on the cavity floor and reducing stress concentration at the tooth interface when a light-activated resin composite is employed[11,29]. Incremental filling techniques are expected to ensure satisfactory polymerization of light-cured composite resins in deep preparations[30]. After evaluation of the caries lesion, the cavities of molars may become deep because of the formation of secondary dentin or reparative dentin. In the case of endodontically treated teeth, the cavities may also become very deep. However, few studies have examined the incremental filling technique using a cavity 5 mm or more in depth. It is not easy to standardize such a large cavity using intact human or bovine teeth. In addition, it has been pointed out that bond strength could be influenced by the orientation of dentinal tubules[31] as well as the depth or age of dentin[32−34]. Nonetheless, the cavity form should be standardized when bond strength alone to the cavity floor is to be evaluated. In the current study, black ABS resin blocks and hybrid composite were employed instead of human or bovine teeth to exclude the confounding dentinal varieties mentioned above. Black molds were used in order to eliminate the influence of light through the cavity wall.

A hybrid composite mold which has a higher elastic modulus than human dentin was used in contrast with ABS resin which has a lower elastic modulus than human dentin[18]. No specimens in the ABS resin mold groups failed cohesively in composite or mold, while cohesive failure within the hybrid composite mold was detected in the hybrid composite mold groups. This difference in fracture mode might have been caused by the inherent bonding mechanism of each material. There was van der Waals' force at the bonding interface in both molds. In addition to the force, silane treatment could have effectively worked for the hybrid composite mold groups. However, the control group of hybrid composite mold had a lower micro-tensile bond strength value than that of ABS resin mold, though translucent resin composite (Clearfil Photo Core) was used in order to be highly polymerized in bulk. This finding suggested that a cavity with a low elastic modulus could compensate the voluminal loss due to the contraction stress of resin composite.

The concept of C-factor[35] is based on the condition that a bond is established with a rigid, restored tooth structure. An incremental filling technique ought to be effective in reducing the C-factor value[28,36]. In the current study, when the increment volume was low, the unbonded area was larger and the C-factor became correspondingly lower for that filling method. In the case of the first increment, the unbonded area was larger than that of the bulk filling method, while the bonded surface areas were equal to each other. In the situation where the first increment was effective in reducing the C-factor value, an incremental filling technique could be a viable approach to reducing contraction stress[12]. Groups 1-2 and 1-1-1 showed the lowest C-factor value of the first increment while the control group showed the highest. If the first increment volume decreased in amount, the C-factor value also decreased accordingly. Such a difference in C-factor value might have affected the bond strength in each group. Although 1-1-1 and 1-2 groups showed a similar C-factor value for the first increment, 1-1-1 groups exhibited higher mean bond strength than 2-1 groups, while there were no significant differences between 1-2 and 2-1 groups for ABS resin mold. These results might have been due to the second increment's differing C-factor value between 1-1-1 and 1-2 groups.

The aim of this study was to investigate if the bond strengths of 1-1, 1-2, 1-1-1 groups to the cavity floor were higher than using a bulk filling technique. The first increment of composite on the polymerized bonding layer might have played the most important role with regard to adherence to the cavity floor. The first increment would undergo less volumetric shrinkage than the bulk filled material. In addition, the subsequent increment could fill any space resulting from contraction of the preceding increment[10]. Moreover, a thin first incremental layer could provide a high degree of conversion and improved physical properties on the cavity floor[37]. This would result in an improved bond strength to the cavity floor[38]. These factors — that aided to resist any reduction in bond strength to the cavity floor — could thus be extrapolated to human dentin, which has an elastic modulus between ABS resin and hybrid composite.

In conclusion, it was suggested that an incremental filling technique could be more effective in improving adhesion to the cavity floor than a bulk filling technique.

## ACKNOWLEDGEMENTS

This study was supported in part by a grant (No. 17791351) from the Ministry of Education, Culture, Sports, Science and Technology of Japan, as well as by a grant for the Center of Excellence Program for Frontier Research on Molecular Destruction and Reconstruction of Tooth and Bone at Tokyo Medical and Dental University.

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