# Properties of dual-cure, bulk-fill composite resin restorative materials

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The purpose of this study was to compare the properties of 2 new dual-cure, bulk-fill restorative composite resins to those of a hybrid composite resin material. Depth of cure, fracture toughness, porosity, microleakage, and volumetric shrinkage properties were examined. With the exception of fracture toughness, significant differences were found among materials. Compared to the incrementally placed hybrid composite, the dual-cure, bulk-fill restorative composites in self-cured mode had unlimited depth of cure, similar fracture toughness and porosity formation, and greater polymerization shrinkage and microleakage.

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According to the literature, bulk placement of traditional composite resin restorative materials may result in poor polymerization in the more apical aspects of a restoration due to the inability of the light from the light-curing unit to penetrate these regions.[1,2] Recent developments in flowable and restorative composite resins have resulted in a greater total depth of cure—between 4 and 5 mm for some materials.[3,4] This improvement in the depth of cure may be due to greater translucency, increased photoinitiator content, or an additional photoinitiator type.[5] Manufacturers of new dual-cure composite resins—such as HyperFIL (Parkell, Inc) and Injectafil DC (Apex Dental Materials, Inc)—have claimed that their products can be placed in 1 layer to an unlimited depth.[6,7] Dual curing would eliminate the limitation of light attenuation and the need for incremental placement. According to its manufacturer,"HyperFIL eliminates the need for flowable liners and incremental curing."[6] The manufacturer of Injectafil DC claims that it "provides the ability to bulk fill all classes of restorations without worrying about shrinkage or voids."[7]

Dual-cure composite resins have been recommended for core build-ups and luting of all-ceramic restorations. The benefit of dual-cure resin materials is the ability to bulk fill the core build-up material and/or lute an opaque restoration while minimizing the risk of light attenuation that would disrupt the setting of the deepest portions of the resin material. Previous studies have suggested that dual-cure resins that are not exposed to the appropriate amount of light may not obtain maximum mechanical properties because the monomer does not achieve a high degree of conversion.[8,9] When limited to chemical curing, it has been observed that dual-cure resin cements have lower mechanical properties due to a lower degree of conversion.[10]

Historically, it has been recommended that restorative composite resins be placed in increments no greater than 2 mm in thickness, in order to attain an adequate amount of photopolymerization and contact with no more than 2 walls of the preparation so as to reduce the configuration factor (C-factor).[11] The C-factor is a ratio of bonded to unbonded surfaces. A lower ratio reportedly diminishes the polymerization shrinkage stress.[12] However, incremental placement could potentially introduce unwanted voids that would decrease the strength of the restoration.[13] Tjan et al demonstrated that the bulk filling of a composite resin would result in significant marginal discrepancies and should be avoided.[13] In a study of dentin cavity wall adaptation, Itoh et al found that the force of polymerization contraction was greater in light-cured composite resins than in chemically cured restorative composite resins.[14] The authors theorized that the marginal gap was caused by the rapid rate of polymerization of the light-cured composite.[14]

Polymerization contraction forces generated during light curing compete with the strength of the adhesive bond to tooth structure.[15] Polymerization shrinkage stresses at the adhesive interfaces occur regardless of the restorative technique employed and remain a significant factor in the failure of bonded restorations.[16] This shrinkage stress can potentially lead to the debonding of the composite resin from the tooth surface at the adhesive interface, forming a marginal gap that results in microleakage.[17,18] Despite the absence of a direct correlation between the in vivo success of restorative composite resin restorations and the extent of microleakage measured in vitro, microleakage still remains one of the main factors facilitating bacterial penetration into the tooth, thus allowing for the development of secondary caries.[19] Secondary caries is one of the leading causes of failure of restorative composite resin restorations.[18,20] Therefore, the evaluation and comparison of the microleakage of restorations placed incrementally or in bulk should reveal which material or method exhibits a superior degree of integrity at the adhesive interface.

Very limited research is available evaluating the basic properties of these new dual-cure composite restorative materials. In the present study, the properties of 2 dual-cure composites (HyperFIL and Injectafil DC) and a traditional hybrid composite with reported high mechanical properties (Filtek Z250, 3M ESPE) were compared (Table 1). The null hypothesis was that there would be no differences in the properties between the hybrid composite and the new dual-cure restorative resins, with or without light curing.

## Materials and methods

The protocol was approved by the Institutional Review Board, Wilford Hall Ambulatory Surgical Center, Joint Base San Antonio-Lackland, Texas. The following properties were evaluated: depth of cure, fracture toughness, internal porosity, microleakage, and volumetric polymerization shrinkage. There were 2 groups:

Table 1. Components of composite resin restorative materials used in the study.

| Composite (shade) | Type | Curing time | Resin | Filler | | | |
|---|---|---|---|---|---|---|---|
| | | | | Content | Wt% | Vol% | Particle size |
| HyperFIL (universal) | Nanohybrid | Light cure: 40 s<br>Self-cure: 4 min | Bis-EMA, UDMA, and other dimethacrylate monomers | Barium glass and silica | 70-75 | NA | 15 nm to 3.5 µm |
| Injectafil DC (A2) | Microhybrid | Light cure: 20 s<br>Self-cure: 3 min | Bis-GMA | Silica glass particles | 75 | NA | Submicron to 5 µm |
| Filtek Z250 (A2) | Microhybrid | Light cure: 20 s | TEGDMA, UDMA, Bis-EMA | Zirconia-silica particles | 82 | 60 | 0.01-3.5 µm<br>Average: 0.6 µm |

Abbreviations: Bis-EMA, ethoxylated bisphenol A dimethacrylate; Bis-GMA, bisphenol A glycidyl methacrylate; NA, not available; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.

group 1, a light-cured group consisting of subgroups HyperFIL (HF.LC), Injectafil DC (IF.LC), and Filtek Z250 (Z250); and group 2, a self-cured group consisting of subgroups HyperFIL (HF.SC) and Injectafil DC (IF.SC).

### *Depth of cure*

To determine the depth of cure, the restorative composite resins were tested with the scraping technique (ISO 4049).[21] Five specimens of each composite resin subgroup (n = 25) were created. A stainless steel split mold (Sabri Dental Enterprises, Inc), 4 mm in diameter × 14 mm in length, was placed on a plastic strip–covered glass slide on a standard white background. Each composite was injected into a mold, a plastic strip was placed, and the resin was condensed with a glass slide to displace excess resin. The glass slide was then removed.

The specimens from group 1 were immediately polymerized with a light polymerization unit (Bluephase G2, Ivoclar Vivadent, Inc) for the manufacturer's recommended curing time. The intensity of the light unit was assessed with a spectrophotometer (Resin Calibrator, BlueLight Analytics, Inc). The emitted light was analyzed during a 20-second curing cycle, and the following data were collected: mean irradiance, 1184 mW/cm$^2$; total energy density, 23.6 J/cm$^2$; energy density in the 360- to 420-nm spectrum, 4.8 J/cm$^2$; energy density in the 420- to 540-nm spectrum, 18.8 J/cm$^2$.

The uncured resin was immediately scraped with a plastic instrument starting from the deepest point on the underside of the mold until polymerized resin was reached. The resin was removed from the mold, and the length of the remaining polymerized material was measured with an electronic digital caliper and divided by 2 (according to the ISO 4049 standard).[21]

The specimens from group 2 were stored in darkness at 37°C in a laboratory oven (Model 20, GC America, Inc) for the manufacturer's recommended setting time and scrape tested in the same manner as the specimens from group 1. The mean depth of cure and standard deviation (SD) for each composite material were then calculated.

### *Fracture toughness*

Fracture toughness was determined by the single-edge notched-beam method. A knife-edged split (2.5 × 5.0 × 25.0 mm) stainless steel mold was placed on a plastic strip–covered glass slide. Fifty specimens (10 from each of the 5 composite resin subgroups) were made by inserting the restorative material in the mold until completely filled. Then the top surface of the mold was covered with a second plastic strip and glass slide to ensure that the end of the specimen was flat and parallel to the opposite surface of the mold.

One end of the specimen was exposed to the light polymerization unit for 20 seconds each in 5 separate overlapping increments. The mold was turned over, and the opposite side of the specimen was exposed to the light in a similar manner. The chemically cured restorative composite resins were similarly prepared but were not light cured. All specimens were allowed to polymerize for 24 hours in distilled water at 37°C in a laboratory oven.

The length of the notches in each specimen was measured under a microscope (Axio Zoom V16, Carl Zeiss Microscopy) at 16× magnification. The specimens were fractured in a universal testing machine (Model 5943, Instron Corp) at a crosshead speed of 1 mm/min, with the notch on the tensile side and the loading pin aligned with the notch. The load-deflection curves (load [$F$] vs deflection [$u$]) were recorded, and the height ($h$) and width ($w$) of the specimens were measured with an electronic digital caliper (Northern Tool). The fracture toughness value ($K_{IC}$) for each composite was calculated from measurements of the single-edge, notched-bend specimens with the following equation:

$$K_{IC} = \frac{3(a/w)^{1/2}\{1.99 - a/w(1 - a/w) \times [2.15 - 3.93(a/w) + 2.7(a/w)^2]\}FS}{2(1 + 2a/w)(1 - a/w)^{3/2}hw^{3/2}}$$

where $S$ was the span distance (20 mm) between supports and $a$ was the length of the notch. The mean and SD were calculated for each of the restorative materials.

### *Porosity*

Porosity was evaluated using proximal slot preparations in 50 extracted human third molars. The teeth were collected and stored in 0.5% chloramine-T and used within 6 months following extraction. The teeth were mounted in dental stone to a level 2 mm apical to the cementoenamel junction (CEJ). All specimens were created by 1 examiner to minimize interoperator differences and to ensure uniformity of fabrication. Carbide burs and hand instruments were used to prepare Class II

slot preparations on a proximal surface. The proximal slot preparation extended apically 0.5 mm past the CEJ. The occlusal and proximal surfaces were flattened to allow for a standardized 5-mm occlusogingival, 4-mm buccolingual, and 2-mm-deep axial slot preparation. Starting from the cervical margin, increments at 1 and 3 mm were marked in the preparation, first with a fine mechanical pencil and then with a fine black marker. All measurements were made with the electronic digital caliper.

The preparations were etched with 37.5% phosphoric acid for 15 seconds. The etchant on each preparation was rinsed off for 15 seconds with an air-water syringe and then air dried for 3 seconds without desiccation. A metal matrix band was placed around each preparation. Optibond FL primer (Kerr Corporation) was applied using a slight brushing motion for 15 seconds followed by air drying for 5 seconds. Next, the Optibond FL adhesive (Kerr Corporation) was applied with a light brushing motion for 15 seconds followed by air thinning for 3 seconds. The adhesive was then light cured for 20 seconds with the light polymerization unit. The tip of the light guide rested on the flattened occlusal surface of the tooth. Each of the 5 composite subgroups was used to restore 10 teeth.

Z250 (shade A2) was placed incrementally following the manufacturer's instructions. A 1-mm increment of composite was placed and light cured for 10 seconds. A 2-mm increment was placed and light cured for 10 seconds, and then another 2-mm increment was placed and light cured for 10 seconds.

HF.LC (universal shade) was placed in bulk in a single 5-mm increment and light cured for 40 seconds per the manufacturer's specifications.

IF.LC (shade A2) was placed in bulk in a single 5-mm increment and light cured for 20 seconds per the manufacturer's specifications.

HF.SC (universal shade) was placed in bulk in a single 5-mm increment and self-cured for 4 minutes per the manufacturer's specifications. IF.SC (shade A2) was placed in bulk in a single 5-mm increment and self-cured for 3 minutes per the manufacturer's specifications.

Table 2. Mean (SD) values for tested properties of composite resin restorative materials.

| Composite resin | Property | | | |
|---|---|---|---|---|
| | Depth of cure (mm) | Fracture toughness ($MPa^{½}$) | Porosity (%) | Microleakage (%) |
| HF.LC | 2.36 (0.10)[b] | 1.85 (0.17)[a] | 0.16 (0.36)[a] | 43 (30)[b] |
| HF.SC | Unlimited | 1.87 (0.26)[a] | 0.36 (0.26)[ab] | 48 (28)[b] |
| IF.LC | 2.06 (0.04)[c] | 1.83 (0.57)[a] | 0.28 (0.19)[ab] | 38 (27)[ab] |
| IF.SC | Unlimited | 1.61 (0.24)[a] | 0.43 (0.21)[b] | 39 (33)[ab] |
| Z250 | 3.57 (0.02)[a] | 1.81 (0.17)[a] | 0.69 (0.83)[b] | 22 (20)[a] |

Abbreviations: HF.LC, HyperFIL light-cured; HF.SC, HyperFIL self-cured; IF.LC, Injectafil DC light-cured; IF.SC, Injectafil DC self-cured; Z250, Filtek Z250.

For depth of cure, fracture toughness, and microleakage, subgroups with the same superscript letter per column are not significantly different ($P > 0.05$).

For percent porosity, subgroups with the same superscript letter are not significantly different ($P > 0.005$).

All restorative composite restorations were polished with a series of Sof-Lex discs (3M ESPE). The completed specimens were stored in a laboratory oven for 24 hours in distilled water at 37°C.

Restorations were scanned with a microcomputed tomography (μCT) unit (Skyscan 1172, Bruker microCT), and the recorded images were reconstructed (NRecon, version 1.4.4, Bruker microCT). Proprietary software (CT Analyzer, version 1.6.0.0, Bruker microCT) was used to analyze the images nondestructively to determine the percentage of porosity within the composite resin restorative material.

### Microleakage

The same 50 proximal slot restorations used to study porosity were used to evaluate microleakage after they had been scanned in the μCT unit. The teeth were thermocycled (Thermocycling Unit, Sabri Dental Enterprises, Inc) in water for 1000 cycles between 5°C (SD, 2°C) and 55°C (SD, 2°C), with a dwell time of 30 seconds at the minimum and maximum temperatures. After thermocycling, 2 coats of fingernail polish (Artistry, Ada) were applied to the entire tooth except for a 1-mm perimeter surrounding the restoration. The specimens were placed in a 0.5% basic fuchsin dye (Spectrum Chemical Mfg Corp) for 24 hours.

After the specimens were removed from the dye, the teeth were embedded in self-curing epoxy resin (Buehler) and allowed to set for 24 hours. The teeth were sectioned with 2 parallel cuts in the mesiodistal direction with a low-speed saw (IsoMet, Buehler). Four surfaces per tooth were analyzed (2 sides of each sectioned slice). Microleakage was evaluated by scanning the sections with a flatbed scanner (XP-800, Epson) and then importing the images into a software program (Image J, National Institutes of Health). The percentage of microleakage was determined by dividing the length of the microleakage by the length of the total bonded interface and multiplying by 100.

### Polymerization shrinkage

To determine polymerization shrinkage, approximately 2 $mm^3$ of composite resin was expressed from the respective container and placed on a pedestal in a video-imaging device (AcuVol, Bisco, Inc). Ten specimens of each subgroup were imaged from the side at a distance of 10 cm. The video camera digitized and analyzed the images with the image-processing software. The specimens from the light-cured group were maximally cured with the light polymerization unit for 40 seconds using the photopolymerization unit. Polymerization shrinkage was recorded at 1, 2, 3, 4, 5, and 10 minutes. The specimens from the self-cured group were prepared in a similar manner as the light-cured specimens but allowed to self-cure. The mean percentage of shrinkage and SD were calculated for each of the restorative materials.

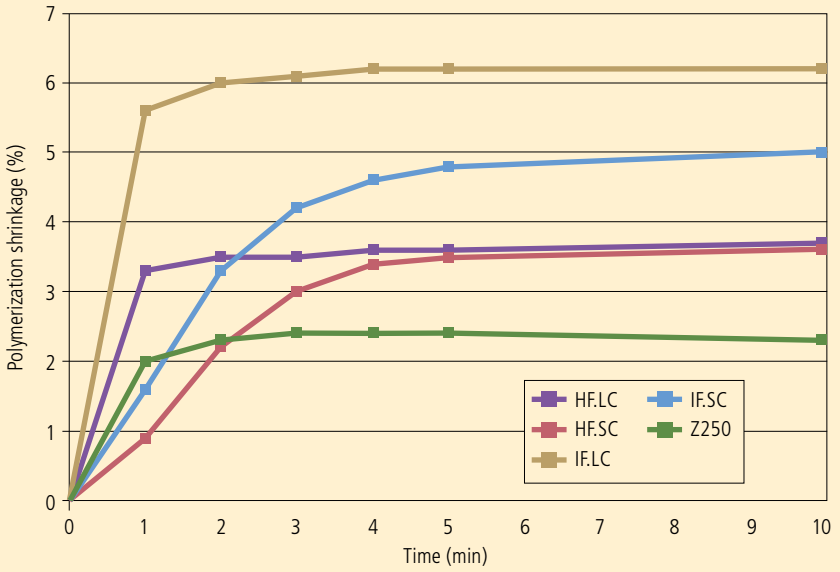
Table 3. Mean (SD) polymerization shrinkage (%) of composite resins over time.

| Composite resin | Time (min) 1 | 2 | 3 | 4 | 5 | 10 |
|---|---|---|---|---|---|---|
| HF.LC | 3.3 (0.4)[c] | 3.5 (0.4)[b] | 3.5 (0.4)[bc] | 3.6 (0.4)[b] | 3.6 (0.4)[b] | 3.7 (0.3)[b] |
| HF.SC | 0.9 (0.7)[a] | 2.2 (0.6)[a] | 3.0 (0.6)[ab] | 3.4 (0.6)[b] | 3.5 (0.7)[b] | 3.6 (0.7)[b] |
| IF.LC | 5.6 (0.5)[d] | 6.0 (0.5)[c] | 6.1 (0.5)[d] | 6.2 (0.5)[d] | 6.2 (0.7)[d] | 6.2 (0.5)[d] |
| IF.SC | 1.6 (0.3)[ab] | 3.3 (0.5)[b] | 4.2 (0.4)[c] | 4.6 (0.4)[c] | 4.8 (0.4)[c] | 5.0 (0.5)[c] |
| Z250 | 2.0 (0.5)[b] | 2.3 (0.6)[a] | 2.4 (0.6)[a] | 2.4 (0.6)[a] | 2.4 (0.6)[a] | 2.3 (0.7)[a] |

Abbreviations: HF.LC, HyperFIL light-cured; HF.SC, HyperFIL self-cured; IF.LC, Injectafil DC light-cured; IF.SC, Injectafil DC self-cured; Z250, Filtek Z250.

Subgroups with the same superscript letter per column are not significantly different ($P > 0.008$).

Chart. Polymerization shrinkage of composite resins over time.




Abbreviations: HF.LC, HyperFIL light-cured; HF.SC, HyperFIL self-cured; IF.LC, Injectafil DC light-cured; IF.SC, Injectafil DC self-cured; Z250, Filtek Z250.

### *Statistical analysis*

Data were analyzed to evaluate the effect of resin type per property using a 1-way analysis of variance (ANOVA) with Tukey post hoc testing for all 3 materials (in both curing modes) ($\alpha = 0.05$). Due to the large variability and nonnormal distribution of the data, percentage porosity was evaluated using Kruskal-Wallis and Mann-Whitney *U* post hoc tests. A Bonferroni correction was applied because multiple comparison tests were done simultaneously ($\alpha = 0.005$).

Polymerization shrinkage data were evaluated with a repeated-measures ANOVA to examine the effects of each composite subgroup over time ($\alpha = 0.05$). Significant differences were found among the subgroups based on type of composite resin ($P < 0.001$) and time ($P < 0.001$), but there were significant interactions ($P < 0.001$). The data were further analyzed with a 1-way ANOVA for each time period. A Bonferroni correction was applied because multiple groups were compared simultaneously ($\alpha = 0.008$).

## Results

Except for fracture toughness, significant differences were found among the subgroups for each property (Tables 2 and 3). The depth of cure for both HF.SC and IF.SC in group 2 was unlimited, or essentially 100% of the 14-mm-long mold; no composite material was removed after scraping of the specimens with the plastic instrument. After light activation, Z250 had the greatest mean depth of cure (3.57 mm; SD, 0.02 mm), a value that was significantly greater ($P < 0.05$) than those of HF.LC (2.36 mm; SD, 0.10 mm) and IF.LC (2.06 mm; SD, 0.04 mm). The scraping was completed immediately after light curing and removal of the composite specimens from the mold.

HF.LC had the lowest mean percentage of porosity formation (0.16%; SD, 0.36%), but the result was not significantly different from those of IF.LC (0.28%; SD, 0.19%) and HF.SC (0.36%; SD, 0.26%). Z250 had the greatest porosity formation (0.69%; SD, 0.83%), but the percentage was not significantly different from that of IF.SC, HF.SC, or IF.LC.

Z250 exhibited the least amount of microleakage (22%; SD, 20%), and the value was significantly less ($P < 0.05$) than those of HF.LC (43%; SD, 30%) and HF.SC (48%; SD, 28%), which were not significantly different from those of IF.LC (38%; SD, 27%) and IF.SC (39%; SD, 33%).

One minute after the start of polymerization, HF.SC had the lowest shrinkage (0.9%; SD, 0.7%), but the result was not significantly different from that of IF.SC (1.6%; SD, 0.3%). At that point, IF.LC had significantly greater shrinkage (5.6%; SD, 0.5%; $P < 0.008$) than the other 4 subgroups. Ten minutes after the start of polymerization, Z250 had significantly less shrinkage (2.3%; SD, 0.7%; $P < 0.008$) than the other 4 subgroups, while IF.LC had significantly greater shrinkage (6.2%; SD, 0.5%; $P < 0.008$) than the other 4 subgroups (Chart).

## Discussion

Very limited research has been published examining the properties of dual-cure composite resins such as Injectafil DC and HyperFIL. In this study, with the exception of fracture toughness, significant differences were found among the subgroups,

and the null hypothesis was rejected per property. The manufacturers of Injectafil DC and HyperFIL both claim that they are true bulk-fill composite resins, eliminating the need to incrementally fill the preparation.[6,7] Unlimited depth of cure was observed when both of the bulk-fill restorative materials were allowed to self-cure for the recommended time. However, the immediate depth of cure for both HyperFIL and Injectafil DC was 2.36 mm and 2.06 mm, respectively, when light cured for the curing time recommended by the manufacturer. A dental practitioner would have to wait 3-4 minutes after light curing to obtain complete chemical polymerization at greater depths in the restoration due to the attenuation of the light.

Depth of cure is variable, depending on the type of curing light, irradiance, and distance of the light guide from the restorative material. The ISO 4049 depth of cure test has been used in dental research since its conception in 1988 by the International Organization for Standardization.[21] However, the test is typically not utilized with dual-cure materials. As described previously, a metal mold was used to create the composite specimens. After light curing, the specimens were immediately removed from the mold and the uncured resin was scraped off with a plastic instrument. The length was measured and divided by 2 because the specimens were not polymerized maximally.[22]

The ISO 4049 standard has been shown to overestimate the depth of cure compared to hardness testing.[23-25] Tiba et al determined the Knoop hardness numbers of traditional, bulk-fill flowables and high-viscosity composites (including HyperFIL) at both the top and bottom surfaces.[26] HyperFIL had a bottom-to-top hardness ratio of 87%. A hardness ratio of 80% or greater is considered adequate polymerization.[25]

Since one of the leading causes of composite failure is fracture of the material, an important property for a restorative composite resin is fracture toughness, which indicates the relative resistance to crack propagation from the surface, or inherent flaws in the materials.[27] Restorative composite resins with higher fracture toughness values may be able to withstand higher stress levels and therefore may have improved clinical outcomes.[28] The fracture toughness of both HyperFIL and Injectafil DC, whether light or self-cured, was not significantly different from that of the light-cured Filtek Z250. Filtek Z250 has been shown in laboratory studies to have excellent mechanical properties and is often used as the gold standard for comparison with other types of restorative composite materials.[29] The fracture toughness values for Filtek Z250 were similar to the other bulk-filled composite resins tested.[30] A separate study found that HyperFIL had significantly greater fracture toughness values than most of the other light-cured, bulk-filled composite resins tested.[26]

Laboratory studies evaluating the efficacy of incremental versus bulk filling with traditional light-cured composite restorative materials have been somewhat equivocal, with higher shrinkage stress and cuspal deflection in some studies but reduced cuspal deflection in others.[31] Incremental layering may allow greater flow during curing with additional free surface area. However, incremental curing of large horizontal segments allows greater light-activated polymerization and potentially more shrinkage stress, while smaller (less than 2 mm), oblique increments that contact no more than 2 walls have historically been shown to reduce polymerization shrinkage stress. Little clinical evidence exists to support one particular restorative composite resin application method over another.[32] Slower polymerization shrinkage—as found with the new dual-curing restorative materials—could, in theory, lower the stress applied to the tooth interface and decrease marginal gap formation. Shrinkage stress was not evaluated in this study and more research needs to be conducted. Both IF.SC and HF.SC had a slower rate of polymerization shrinkage during the first 3-4 minutes compared to IF.LC and HF.LC. However, the polymerization shrinkage after 10 minutes for the IF.LC and the IF.SC specimens (6.2% and 5.0%, respectively) closely resembles the greater shrinkage exhibited by other commercially available flowable composites when compared to restorative composites.[33] Both HF.LC and HF.SC had significantly less polymerization shrinkage (3.7% and 3.6%, respectively; $P < 0.008$) than IF.LC and IF.SC, but both dual-cure materials had significantly more polymerization shrinkage ($P < 0.008$) than did Z250 (2.3%). Tiba et al found the polymerization shrinkage of HyperFIL to be 3.5%, significantly greater than that of many of the other light-cured, bulk-filled restorative materials tested.[26] The self-cured restorative composite resins displayed a significantly greater polymerization shrinkage that, coupled with the high C-factor of the cavity form, would likely generate significantly higher polymerization stress, along with increased marginal gap formation. The polymerization shrinkage stress of self-cured restorative resins would need to be tested before a clinical recommendation can be made.

Incremental placement may increase the chance of incorporating voids in the restorative composite resin and therefore increase the potential for greater microleakage and lower mechanical properties. The results from the current study showed that use of the incremental placement technique for Z250 resulted in a greater percentage of internal porosity, but the differences among subgroups, except for HF.LC, were not statistically significant. Currently there is limited published research on the use of μCT to evaluate the internal porosity of composite materials. More research is needed to examine the relationship between internal porosity and the success of composite resin restorations.

When a Class II cavity preparation that has cervical margins beyond the CEJ is restored with restorative composite resin, it becomes more difficult to obtain predictable adhesion to the cementum surface. The slot preparations restored with Z250 were layered with an initial 1-mm increment that was light cured and followed by two additional 2-mm light-cured increments. The C-factor (ratio of bonded to unbonded surfaces) was greater with the dual-cure materials than with the incrementally placed Z250 composite. An increased C-factor has been shown to increase polymerization shrinkage stress that may contribute to gap formation along the marginal interface.[34] The higher C-factor and polymerization shrinkage may have contributed to the greater microleakage percentage found in both the dual-cure composites compared to Z250, although the difference was only

significant for HyperFIL. However, both Injectafil and HyperFIL had increased flowability compared to the relatively viscous Z250. The increased flowability of the dual-cure composite materials may have provided greater adaptation to the walls of the preparation, potentially reducing microleakage.

Laboratory studies are needed to evaluate other properties, such as color stability and wear resistance. Further research is necessary to evaluate the clinical performance of dual-cure composite resins marketed as a posterior restorative material before they can be recommended for general use.

## Conclusion

Compared to the incrementally placed composite (Filtek Z250), the new dual-cure, bulk-fill restorative composite resins (HyperFIL and Injectafil DC) in self-cure mode had unlimited depth of cure along with similar fracture toughness and porosity formation. However, they also exhibited greater polymerization shrinkage and microleakage.

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## Disclaimer

The views expressed in this study are those of the authors and do not reflect the official policy of the US Air Force, the Department of Defense, or the US government. The authors do not have any financial interest in the companies whose materials are discussed in this article.

## References

1. Rueggeberg FA, Caughman WF, Curtis JW Jr. Effect of light intensity and exposure duration on cure of resin composite. *Oper Dent.* 1994;19(1):26-32.
2. Giachetti L, Scaminaci Russo D, Bambi C, Grandini R. A review of polymerization shrinkage stress: current techniques for posterior direct resin restorations. *J Contemp Dent Pract.* 2006;7(4):79-88.
3. Lazarchik DA, Hammond BD,Sikes CL, Looney SW, Rueggeberg FA. Hardness comparison of bulk-filled/transtooth and incremental- filled/occlusally irradiated composite resins. *J Prosthet Dent.* 2007;98(2):129-140.
4. Jackson RD. New posterior composite materials improving placement efficiency. *Compend Contin Educ Dent.* 2012;33(4):292-293.
5. Moorthy A, Hogg CH, Dowling AH, Grufferty BF, Benetti AR, Fleming GJ. Cuspal deflection and microleakage in premolar teeth restored with bulk-fill flowable resin-based composite base materials. *J Dent.* 2012;40(6):500-505.
6. Parkell, Inc. *HyperFIL* [promotional material]. http://www.parkell.com/Products/Detail.aspx?prod=351. Accessed January 12, 2016.
7. Apex Dental Materials,Inc. *Injectafil DC* [promotional material]. http://apexdentalmaterials.com/injectafil/. Accessed January 13, 2016.
8. Hasegawa EA, Boyer DB, Chan, DC. Hardening of dual-cured cements under composite resin inlays. *J Prosthet Dent.* 1991:66(2):187-192.
9. El-Mowafy OM, Rubo MH. Influence of inlay/onlay thickness on hardening of dual-cured resin cements. *J Can Dent Assoc.* 2000;66(3):147.
10. Braga RR, Cesar PF, Gonzaga CC. Mechanical properties of resin cements with different activation modes. *J Oral Rehabil.* 2002;29(3):257-262.
11. Klaff D. Blending incremental and stratified layering techniques to produce an esthetic posterior composite resin restoration with a predictable prognosis. *J Esthet Restor Dent.* 2001;13(2):101-113.
12. Summitt JB, Robbins JW, Hilton TJ, Schwartz RS, eds. *Fundamentals of Operative Dentistry, a Contemporary Approach.* 3rd ed. Chicago: Quintessence Publishing; 2006.
13. Tjan AH, Bergh BH, Lidner C. Effect of various incremental techniques on the marginal adaptation of class II composite resin restorations. *J Prosthet Dent.* 1992;67(1):62-66.
14. Itoh K, Yanagawa T, Wakumoto S. Effect of composition and curing type of composite on adaptation to dentin cavity wall. *Dent Mater.* 1986;5(2):260-266.
15. Carvalho RM, Pereira JC, Yoshiyama M, Pashley DH. A review of polymerization contraction: the influence of stress development versus stress relief. *Oper Dent.* 1996;21(1):17-24.
16. Oliveira LC, Duarte S Jr, Araujo CA, Abrahão A. Effect of low-elastic modulus liner and base as stress-absorbing layer in composite resin restorations. *Dent Mater.* 2010;26(3):e159-e169.
17. Davidson CL, de Gee AJ, Feilzer A. The competition between the composite-dentin bond strength and the polymerization contraction stress. *J Dent Res.* 1984;63(12)1396-1399.
18. Ferracane JL. Buonocore Lecture. Placing dental composites—a stressful experience. *Oper Dent.* 2008;33(3):247-257.
19. Ferracane JL, Mitchem JC. Relationship between composite contraction stress and leakage in Class V cavities. *Am J Dent.* 2003;16(4):239-243.
20. Larson TD. The clinical significance and management of microleakage. Part 1. *Northwest Dent.* 2005;84(1):23-25.
21. International Organization for Standardization. *ISO 4049: Dentistry—Polymer-Based Restorative Materials.* Geneva: ISO; 2009.
22. DeWald JP, Ferracane JL. A comparison of four modes of evaluating depth of cure of light-activated composites. *J Dent Res.* 1987;66(3):727-730.
23. Garcia D, Yaman P, Dennison J, Neiva G. Polymerization and depth of cure of bulk fill flowable composite resins. *Oper Dent.* 2014;39(4):441-448.
24. Flury S, Hayoz S, Peutzfeldt A, Husler J, Lussi A. Depth of cure of resin composites: is the ISO 4049 method suitable for bulk fill materials? *Dent Mater.* 2012;28(5):521-528.
25. Moore BK, Platt JA, Borges G, Chu TM, Katsilieri I. Depth of cure of dental resin composites: ISO 4049 depth and microhardness of types of materials and shades. *Oper Dent.* 2008;33(4):408-412.
26. Tiba A, Zeller GG, Estrich CG, Hong A. A laboratory evaluation of bulk-fill versus traditional multi-increment-fill resin-based composites. *J Am Dent Assoc.* 2013;144(10):1182-1183.
27. Jun SK, Kim DA, Goo HJ, Lee HH. Investigation of the correlation between the different mechanical properties of resin composites. *Dent Mater J.* 2013;32(1):48-57.
28. Elbishari H, Silikas N, Satterthwaite J. Filler size of resin-composites, percentage of voids and fracture toughness: is there a correlation? *Dent Mater J.* 2012;31(4):523-527.
29. Lien W, Vandewalle KS. Physical properties of a new silorane-based restorative system. *Dent Mater.* 2010;26(4):337-344.
30. Garoushi S, Säilynoja E, Vallittu P, Lassila L. Physical properties and depth of cure of a new short fiber reinforced composite. *Dent Mater.* 2013;29(8):835-841.
31. Kwon Y, Ferracane J, Lee I. Effect of layering methods, composite type, and flowable liner on the polymerization shrinkage stress of light cured composites. *Dent Mater.* 2012;28(7):801-809.
32. Ferracane JL. Resin composite—state of the art. *Dent Mater.* 2011;27(1):29-38.
33. Tiba A, Charlton DG, Vandewalle KS, Cohen ME. Volumetric polymerization shrinkage of resin composites under simulated intraoral temperature and humidity conditions. *Oper Dent.* 2005;30(6):696-701.
34. Braga RR, Ballester RY, Ferracane JL. Factors involved in the development of polymerization shrinkage stress in resin composites: a systematic review. *Dent Mater.* 2005;21(10):962-970.