International Journal of Biomedicine 15(4) (2025) 736-740
http://dx.doi.org/10.21103/Article15(4)_OA15

ORIGINAL ARTICLE

Dentistry

INTERNATIONAL JOURNAL OF BIOMEDICINE

Impact of Increment Thickness, Preheating and Light Exposure Duration on Surface Hardness of Bulk-Fill Composite Cured in Covered Slot

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Abstract

Background: Experimental methods for evaluating composite filling materials and their use are essential for achieving reliable, predictable clinical results in tooth restoration. This study aimed to evaluate the impact of bottom increment thickness, preheating, and light exposure duration on microhardness and depth of cure of bulk-fill resin composite after polymerization in a covered slot.
Methods and Results: A total of 32 filling samples were made using Tetric® N-PowerFill 2 bulk-fill resin composite material (Ivoclar Vivadent AG). Composite filling samples were made in opaque plastic molds with isosceles trapezoidal slots. The slot was 1.5 mm wide. The lower and upper bases of the trapezoid were 3 and 6 mm, respectively. The height of the trapezoidal slot was 5 mm. Filling samples were divided into 8 groups of 4 each. All trapezoidal slots were filled with 2 successive layers of different thicknesses. In Groups 1, 3, 5, and 7, the height of the bottom horizontal layer was ~1 mm, the top horizontal layer ~ 4 mm. In Groups 2, 4, 6, and 8, the height of the bottom horizontal layer was ~ 4 mm, the top horizontal layer ~ 1 mm. Every layer was cured individually. In Groups 1, 2, 5, and 6, the light exposure for each layer was 20 sec, while in Groups 3, 4, 7, and 8, it was 40 sec. Filling samples in Groups 1, 2, 3, and 4 were made from a room-temperature composite (22-24 °C). In Groups 5, 6, 7, and 8, the material was polymerized after heating in the slot up to 55-60 °C. Photoactivation was performed with the Valo X LED lamp (Ultradent, USA) in standard mode. The surface microhardness of composite filling samples was assessed using the Vickers hardness tester after exposure to light and storage in a dark container for 24 hours. Measurements were performed using a "ПМТ-3" tester with an indenter at a 50 g load for a 15-second dwell time. Indentations were made in a linear order at levels of 0.5, 1.5, 2.5, 3.5, and 4.5 mm from the top surface.
Doubling the photoactivation time of the room-temperature composite from 20 seconds to 40 seconds increased the Vickers hardness number (VHN) of composite fillings at depths of 1.5, 2.5, 3.5, and 4.5 mm by 55%, but mostly insignificantly. The only difference of ~1.6 times was noted in the VHN at a depth of 4.5 mm between the filling samples from Group 3 and Group 2 (P=0.0071), indicating the importance of both low increment thickness and prolonged irradiance. The surface hardness of fillings at 0.5 mm in samples from Groups 1, 2, 3, and 4 was relatively high and did not show significant statistical differences among them. It was another confirmation of the crucial importance of close light source adjustment to the surface of light-cured material. Photoactivation of a heated composite material in a covered slot had certain advantages over using a room-temperature composite, as demonstrated by the VHN of filling samples at different depths. For example, at all depths, the VHN of composite fillings in Group 8 was statistically greater than in Group 2, regardless of the thickness of the bottom increment. Moreover, the difference increased with depth, from 1.4 (P=0.0431) [at 0.5 mm] to 1.8 (P=0.0001) [at 4.5 mm]. However, it was noteworthy that prolonged irradiance of a 4 mm-thick layer of resin composite is beneficial and may offset the low polymerization kinetics of a room-temperature filling material.
Conclusion: Lowering the thickness of the bottom layer of bulk-fill composite, along with its preheating and prolonged photoactivation, cumulatively contributed to a significant increase in depth of cure and microhardness of filling samples made in a covered slot. (**International Journal of Biomedicine. 2025;15(4):736-740.**)

Keywords: bulk-fill resin composite • preheating • covered slot • class II restorations

For citation: Melkumyan TV, Sheraliyeva SSh, Khabadze ZS, Makeeva MK, Seeberger GK, Musashaykhova ShK, Kamilov NKh, Inoyatova DA, Dadamova AD. Impact of Increment Thickness, Preheating and Light Exposure Duration on Surface Hardness of Bulk-Fill Composite Cured in Covered Slot. International Journal of Biomedicine. 2025;15(4):736-740. doi:10.21103/Article15(4)_OA15

Introduction

The optimal physical and aesthetic properties of modern composite filling materials have significantly widened the indications for direct dental restorations. However, despite the widespread acceptance, the high probability of suboptimal polymerization is one of the main reasons for unsatisfactory tooth treatment and the poor state of composite restorations.[1,2] The desirable degree of conversion of light-cured composites can be achieved by placing the tip of the light source as close as possible to the surface of the light-cured resin to ensure light transmission through the composite layer to its deepest areas, initiating polymerization.

It is clear that the light intensity emitted by the curing device gradually decreases as it penetrates deeper into the composite material. As a result, the degree of conversion of the resin monomers gradually decreases with increasing distance from the irradiated surface. A low degree of conversion worsens the physical properties of composite restorations and promotes the release of unreacted monomers, which can pose a potential threat to pulp cells and the oral mucosa.[3,4]

In restorative dentistry, the evaluation of surface microhardness is used to predict the wear resistance of any restorations subject to occlusal loading. However, only for direct composite materials is the bottom-to-top ratio of surface microhardness measured, given its great clinical value. Thus, it has been accepted that a favorable prognosis for the composite restoration remains possible when the ratio equals 0.8 or 0.85. In contrast, lower values do not guarantee the mechanical and chemical stability of the filling.[5]

Numerous factors influence the depth of cure. These include the type of composite resin, its color and transparency, the layer thickness and distance from the radiation source, the size and distribution of the filler particles, the intensity and exposure time of the material, the wavelength of the light, and the temperature of the composite.[2,4,6,7]

Temperature is known to affect the rate of chemical reactions significantly. Therefore, preheating composite materials before light-curing has become popular at times in modern restorative dentistry. A wide variety of methods and devices have been designed and proposed for heating. Most studies have demonstrated a significant impact of preheating on conversion rate and microhardness of composite fillings.[8]

However, despite the significant opportunity to improve the strength and chemical stability of composite restorations, the preheating method has not been widely adopted due to several clinical issues. Among them, the predominant stickiness of heated composite to instruments during placement of the material into the cavity and the rapid loss of temperature have been emphasized, which significantly reduced the feasibility of using this method for direct restorations.[9]

On the other hand, there is a large amount of experimental data indicating a high degree of conversion and microhardness of the top and bottom surfaces of composite filling samples that were light-activated at 55-60 ºC.[8] A high degree of conversion of resin composite materials contributes to a better seal, prevents leakage and the occurrence of secondary caries, promotes the vitality of the tooth, and prevents pulp alterations. Those are specific goals that are difficult to achieve in the direct restoration of Class II cavities with dental composites.[5]

Filling deep tooth cavities in contact areas and the lack of a light source close to the surface of the resin composite create unfavorable conditions for adequate polymerization of the restorative material.[5] To achieve optimal conversion of a composite in poorly illuminated areas, bulk-fill resin materials can be used, thanks to a greater depth of cure supported by the polymer matrix's special properties, the quality of filler particles, and an advanced initiator system.

However, despite significant supportive data indicating the efficacy of bulk-fill composites in the restoration of large and deep tooth cavities, the issue of depth of cure for this type of composite remains under discussion.[8]

Given the indisputable priority of high conversion of composite materials and the high prevalence of disruptive factors, the development of new methods and techniques for the application of light-cured materials remains relevant.

This study aimed to evaluate the impact of bottom increment thickness, preheating, and light exposure duration on microhardness and depth of cure of bulk-fill resin composite after polymerization in a covered slot.

Materials and Methods

Composite filling samples were made in opaque plastic molds with isosceles trapezoidal slots (Figure 1). The slot was 1.5mm wide. The lower and upper bases of the trapezoid were 3 and 6 mm, respectively. The height of the trapezoidal slot was 5mm. Before inserting the filling material into the mold, the slot's outer surface was covered with a metal strip matrix spanning its entire height to prevent side light from entering and to ensure unidirectional light-curing of the composite from above (Figure 2).

Fig.1. *Plastic molds with trapezoidal slots for a composite material.*

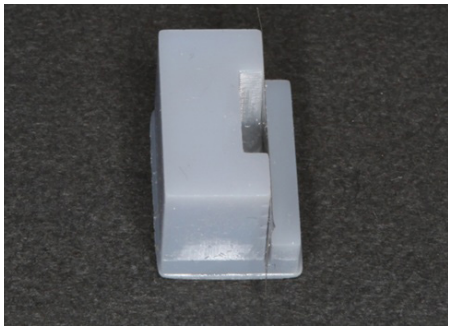

Fig.2. *Plastic mold with a trapezoidal slot covered with a metal strip.*

Photoactivation was performed with the Valo X LED lamp (Ultradent, USA) in standard mode. Filling samples were made using Tetric® N-PowerFill 2 bulk-fill resin composite material (Ivoclar Vivadent AG). They were divided into 8 groups of 4 each. All trapezoidal slots were filled with 2 successive layers of different thicknesses. In Groups 1, 3, 5, and 7, the height of the bottom horizontal layer was ~1 mm, the top horizontal layer ~4 mm (Figure 3). In Groups 2, 4, 6, and 8, the height of the bottom horizontal layer was ~ 4 mm, the top horizontal layer ~ 1 mm (Figure 4). Every layer was cured individually. In Groups 1, 2, 5, and 6, the light exposure for each layer was 20 sec, while in Groups 3, 4, 7, and 8, it was 40 sec. Filling samples in Groups 1, 2, 3, and 4 were made from a room-temperature composite (22-24 °C). In Groups 5, 6, 7, and 8, the material was polymerized after heating in the slot by applying the heating device's working part to the surface of the metal matrix. The material was heated to 55-60 °C and kept at this temperature during photoactivation.

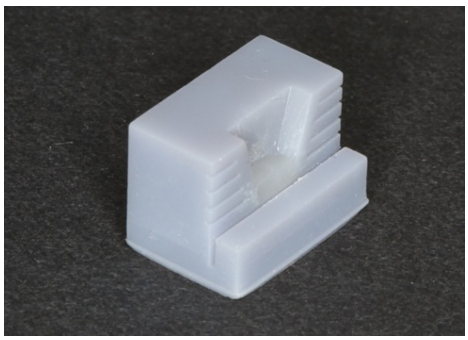

Fig. 3. *Plastic mold with a trapezoidal slot filled with the bottom horizontal layer ~ 1 mm.*

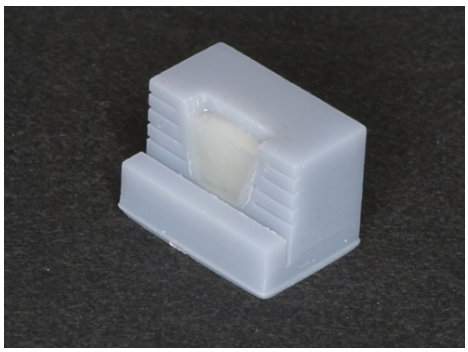

Fig. 4. *Plastic mold with a trapezoidal slot filled with the bottom horizontal layer ~ 4 mm.*

The surface microhardness of composite filling samples (n=32) was assessed using the Vickers hardness tester after exposure to light and storage in a dark container for 24 hours. Measurements were performed using a "ПМТ-3" tester with an indenter at a 50 g load for a 15-second dwell time. Indentations were made in a linear order at levels of 0.5, 1.5, 2.5, 3.5, and 4.5 mm from the top surface. Three indentations were made at each level.

The Vickers hardness number (VHN) was calculated according to the following formula: $VHN = 1.854 \times (F/D^2)$, where F is the applied load (kg), and D is the mean diagonal of the indentation (mm), which yields the VHN units (kg/mm^2).

Statistical analysis was performed using the statistical software package SPSS version 21.0 (Armonk, NY: IBM Corp). For descriptive analysis, results are presented as mean ± standard deviation. Multiple comparisons were performed with one-way ANOVA with Tukey's pairwise comparisons. The probability value of $P<0.05$ was considered statistically significant.

Results

Depth of cure was expressed as the ratio of the microhardness numbers of the top and bottom layers of the fillings and was presented as a percentage.

Analysis of data on the surface hardness of filling samples cured in a covered slot showed that the depth of cure of the bulk-fill composite material depends on the thickness of the bottom layer, the material temperature, and the duration of photoactivation.

At a depth of 4.5 mm, the VHN of composite fillings in Group 1 was 1.3 times greater than in Group 2. These samples were made from a room-temperature composite, and photoactivation of each layer was performed for 20 seconds. However, the thick first increment in Group 2 samples may have prevented light from reaching deeper portions of the composite, which could explain its low conversion, but without statistical significance (Table 1). Also, at the same depth, the VHN of composite fillings in Group 6 was 1.8 times greater than in Group 2, with statistical significance ($P=0.0001$). It should be noted that the samples from Group 6 were made in a similar layering sequence to those from Group 2, but they were heated to 55-60 °C and maintained at this temperature for 20 seconds during photoactivation. Moreover, the bottom-to-top ratio of surface hardness in Group 5 filling samples was ~95%, whereas in Group 2 samples, it was ~71%.

Doubling the photoactivation time of the room-temperature composite from 20 seconds to 40 seconds resulted in an increase in the VHN of composite fillings at depths of 1.5, 2.5, 3.5, and 4.5 mm up to 55%, but mostly insignificantly. The only difference of ~1.6 times was noted in VHN at a depth of 4.5 mm between the filling samples from Group 3 and Group 2 ($P=0.0071$), indicating the importance of both low increment thickness and prolonged irradiance. Also, increased light exposure of the resin composite contributed to improvements in the bottom-to-top ratio of surface hardness in samples from Groups 3 and 4, reaching 93% and 98%, respectively.

The surface hardness of fillings at 0.5mm in samples from Groups 1, 2, 3, and 4 was relatively high and did not show significant statistical differences among them. It was another confirmation of the crucial importance of close light source adjustment to the surface of light-cured material.

Photoactivation of a heated composite material in a covered slot had certain advantages over using a room-temperature composite, as demonstrated by the VHN of filling samples at different depths. For example, at all depths, the VHN of composite fillings in Group 8 was statistically greater than in Group 2, regardless of the thickness of the bottom

increment. Moreover, the difference increased with depth, from 1.4 (P=0.0431) [at 0.5 mm] to 1.8 (P=0.0001) [at 4.5 mm]. However, it was noteworthy that prolonged irradiance of a 4 mm-thick layer of resin composite is beneficial and may offset the low polymerization kinetics of a room-temperature filling material. Also, the bottom-to-top ratio of surface hardness of fillings in samples of Groups 5, 6, 7, and 8 ranged from 91% to 96%, which could be of great clinical value.

Discussion

Experimental methods for evaluating composite filling materials and their use are essential for achieving reliable, predictable clinical results in tooth restoration. Although there are only 5 classes of tooth lesions, each clinical situation has its own characteristics that can significantly affect the quality of direct restorations and the treatment outcome.

According to many studies, a low conversion rate of light-cured materials is often observed in the restoration of Class II lesions.[5,10-12] Narrow and deep cavities that prevent the normal transmission of light through the thickness of the filling material are the main reasons for insufficient composite polymerization.

Polymerization of light-cured resin composite in a covered slot most closely resembles the clinical situation of Class II restoration, guarantees a unidirectional transmission of a light beam, and can be considered as the most suitable and feasible laboratory technique to serve the purpose of the present study.[12]

In conclusion, lowering the thickness of the bottom layer of bulk-fill composite, along with its preheating and prolonged photoactivation, cumulatively contributed to a significant increase in depth of cure and microhardness of filling samples made in a covered slot.

Table 1.

Surface hardness of composite filling samples measured at different depths after photo activation in a covered slot.

Depth (mm)	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Statistical data
0.5	40.2 ±2	38.9 ±7.6	46.6 ±11	43.6 ±7.3	52.4 ±6.3	55.1 ±7.3	54.4 ±5.8	55.8 ±6.1	F=3.8345; P=0.0062 P_{1-2}=1.0000; P_{1-3}=0.8975; P_{1-4}=0.0068; P_{1-5}=0.2676; P_{1-6}=0.0997; P_{1-7}=0.1312; P_{1-8}=0.0750; P_{2-3}=0.7789; P_{2-4}=0.9786; P_{2-5}=0.1706; P_{2-6}=0.0583; P_{2-7}=0.0782; P_{2-8}=0.0431; P_{3-4}=0.9985; P_{3-5}=0.9356; P_{3-6}=0.6871; P_{3-7}=0.7680; P_{3-8}=0.6010; P_{4-5}=0.6506; P_{4-6}=0.3334; P_{4-7}=0.4080; P_{4-8}=0.2676; P_{5-6}=0.9993; P_{5-7}=0.9999; P_{5-8}=0.9968; $P_{6-7=}$1.0000; P_{6-8}=1.0000; P_{7-8}=1.0000
1.5	36.2 ±4.5	39.9 ±5.7	45.9 ±3.2	49.9 ±8.9	49.7 ±6.4	62 ±5.4	55.9 ±6.4	61.8 ±7.5	F=9.2634; P=0.0000 P_{1-2}=0.9886; P_{1-3}=0.3831; P_{1-4}=0.0759; P_{1-5}=0.0833;P_{1-6}=0.0001; P_{1-7}=0.0033; P_{1-8}=0.0001; P_{2-3}=0.8643;P_{2-4}=0.3470; P_{2-5}=0.3708; P_{2-6}=0.0009; P_{2-7}=0.0243; P_{2-8}=0.0010; P_{3-4}=0.9822; P_{3-5}=0.9867; P_{3-6}=0.0231; P_{3-7}=0.3470; P_{3-8}=0.0256; P_{4-5}=1.0000; P_{4-6}=0.1554; P_{4-7}=0.8643; P_{4-8}=0.1690; P_{5-6}=0.1427; P_{5-7}=0.8442; P_{5-8}=0.1554; P_{6-7}=0.8544; P_{6-8}=1.000; P_{7-8}=0.8738
2.5	36.1 ±5.5	32.3 ±4.6	42.9 ±3.8	44.9 ±7.9	47.2 ±7.4	53.2 ±6	52.1 ±7.4	55.7 ±9.3	F=6.0841; P=0.0004 P_{1-2}=0.9914; P_{1-3}=0.8333; P_{1-4}=0.5921; P_{1-5}=0.3142; P_{1-6}=0.0262; P_{1-7}=0.0439; P_{1-8}=0.0077; P_{2-3}=0.3678; P_{2-4}=0.1851; P_{2-5}=0.0720; P_{2-6}=0.0040; P_{2-7}=0.0070; P_{2-8}=0.0011; P_{3-4}=0.9999; P_{3-5}=0.9825; P_{3-6}=0.4023; P_{3-7}=0.5397; P_{3-8}=0.1715; P_{4-5}=0.9996; P_{4-6}=0.6574; P_{4-7}=0.7911; P_{4-8}=0.3458; P_{5-6}=0.9031; P_{5-7}=0.9644; P_{5-8}=0.6314; P_{6-7}=1.0000; P_{6-8}=0.9994; P_{7-8}=0.9938
3.5	32.4 ±4.7	31.5 ±5.8	40.9 ±5.4	43.5 ±8.3	44.3 ±7.4	50.3 ±6.5	51.2 ±7.8	52.1 ±8.7	F=5.3548; P=0.0009 P_{1-2}=1.0000; P_{1-3}=0.6706; P_{1-4}=0.3561; P_{1-5}=0.2772; P_{1-6}=0.0243; P_{1-7}=0.0159; P_{1-8}=0.0104; P_{2-3}=0.5572; P_{2-4}=0.2682; P_{2-5}=0.2036; P_{2-6}=0.0159; P_{2-7}=0.0104; P_{2-8}=0.0067; P_{3-4}=0.9994; P_{3-5}=0.9965; P_{3-6}=0.5572; P_{3-7}=0.4463; P_{3-8}=0.3456; P_{4-5}=1.0000; P_{4-6}=0.8565; P_{4-7}=0.7654; P_{4-8}=0.6581; P_{5-6}=0.9181; P_{5-7}=0.8475; P_{5-8}=0.7541; P_{6-7}=1.0000; P_{6-8}=0.9990; P_{7-8}=1.0000
4.5	35.5 ±2.8	27.5 ±3	43.2 ±4.9	42.7 ±8.2	49.7 ±2.8	50.4 ±6.9	52.1 ±3	50.3 ±7.4	F=10.5695; P=0.0000 P_{1-2}=0.4295; P_{1-3}=0.4762; P_{1-4}=0.5574; P_{1-5}=0.0181; P_{1-6}=0.0117; P_{1-7}=0.0040; P_{1-8}=0.0125; P_{2-3}=0.0071; P_{2-4}=0.097; P_{2-5}=0.0001; P_{2-6}=0.0001; P_{2-7}=0.0000; P_{2-8}=0.0001; P_{3-4}=1.0000; P_{3-5}=0.6724; P_{3-6}=0.5574; P_{3-7}=0.3036; P_{3-8}=0.5739; P_{4-5}=0.5904; P_{4-6}=0.4762; P_{4-7}=0.2449; P_{4-8}=0.4922; P_{5-6}=1.0000; P_{5-7}=0.9979; P_{5-8}=1.0000; $P_{6-7=}$0.9998; P_{6-8}=0.9907; P_{7-8}=0.9997
B/T, %	88	71	93	98	95	91	96	90	

Competing Interests

The authors declare that they have no competing interests.

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