Influences of short-fibre-reinforced resin composite thickness and curing time on its hardness and depth of cure

S Muchlisya, E Herda* and B Irawan

Department of Dental Materials, Faculty of Dentistry, Universitas Indonesia, Jakarta, 10430, Indonesia

*Email: ellyza_herda@yahoo.com

Abstract. Short-fibre-reinforced resin composite has been recently proposed as a potential substructure in restorative dentistry. This study aimed to analyze the effect of short-fibre-reinforced resin composite (SFRC) thickness and curing time on its hardness and depth of cure (DoC). Twenty-four specimens of SFRC (EverX PosteriorTM) were prepared in cylindrical molds of 6 mm diameter and two different thicknesses (4 and 5 mm; n = 12 each). Each thickness group was cured with 2-mm light-curing distance at an irradiance of 800 mW/cm² for 25 and 30 s (n = 6 each). Hardness was measured by Vickers hardness test, and DoC was obtained by calculating the hardness ratio of the bottom-to-top surface (%). Data were statistically analyzed by one-way analysis of variance. In conclusion, the thickness and curing time had significant effect on the hardness and DoC of SFRC as a substructure.

1. Introduction

The particulate resin composite is the most commonly used restorative material in dentistry, owing to its ability to bind to hard tooth tissues through its adhesive, esthetic, and conservative preparation techniques [1]. Several resin composites including resin composites with fibre reinforcement (fibre–resin composites) have been developed [2]. In the field of dentistry, fibre–resin composites have been used as removable denture, fixed denture, and orthodontic retainer as well as in periodontal splinting and repairing of cracked porcelain veneer [2–4]. Based on the length and orientation, the fibres are categorized as unidirectional continuous, bidirectional continuous, multidirectional continuous, unidirectional discontinuous and random discontinuous types [5]. Recently, a discontinuous random fibre–resin composite, or short-fibre–resin composite (SFRC), was developed as a substitute for dentin or substructure. Previous studies have shown that SFRC has a fracture-retardant level equivalent to that of dentin and almost twice that of other resin composites; therefore, SFRC can be used as a substructure topped with a particulate resin composite for posterior tooth restoration [6–8].

The polymerization of resin composites is performed using visible light obtained from light-curing unit (LCU) [9]. To achieve successful hardening of resin composites, an optimal polymerization reaction is required. Ideally, during the polymerization reaction, all monomers change into polymer chains. The number of monomers converted into polymer chains is referred to as the degree of conversion. Several factors may affect this degree of conversion such as the irradiance of LCU, exposure duration, and distance between the resin surface and ends of LCU [10–13]. Several studies have proven that the degree of conversion can affect the physical, mechanical, biocompatibility, and stability of resin composites. Therefore, the degree of conversion plays an important role in determining the clinical success of restoration [10,14,15].
In the restoration process, it is desirable to polymerize the resin composite until the bottom surface. The thickness of the resin composite that has been successfully polymerized using a certain light is called the depth of cure (DoC) [16]. DoC is affected by the post-cure period, resin composite type, resin composite color, translucency, resin composite thickness, irradiance distance, irradiance time, and the size and distribution of filler [9,17]. To achieve the optimal DoC, the resin composite thickness is generally kept at 2 mm, because the properties produced at this thickness are quite good. The gradual exposure technique with a thickness of 2 mm is called an incremental technique. The light exposure duration during polymerization depends on the type, thickness, and color of the resin composite as well as on the LCU used. The duration may vary from 20 to 60 s for restorations of 2-mm thickness [9,16,18]. To achieve an effective time of sieving, a bulk-fill particulate resin composite is used as a restoration material. The bulk-fill resin composite polymerization can be performed with a 4-mm thickness without any increment with the desired DoC [19]. However, although manufacturing procedures suggest a 4-mm direct sieve, several researchers are unsure about the DoC and whether the mechanical properties attainable will be maximum [19–21].

Several studies have reported that the DoC of a material can be measured according to the ISO 4049 2000 specifications or the upper and lower surface hardness ratio by the Vickers hardness test [4,19,21–24]. The DoC of a resin composite must be at least 0.8 (80%) for polymerization to be considered as optimal [22]. The resin composite surface hardness is reportedly affected by the incremental thickness of the resin composite material used [19]. Nogi et al. (2015) proved that the value of the DoC of bulk-fill resin of at least 0.8 (80%) through the Vickers hardness test was obtained with 4-mm thickness without incremental technique and that there was a significant difference in the exposure time [19]. Moharam et al. (2017) also showed the effect of different insertion techniques on two types of bulk-fill resin composites. They found a minimum DoC value of 0.8 (80%) in incremental insertion techniques as well as in bulk insertion techniques as deep as 4 mm with the Vickers hardness test. However, there was a decrease in the hardness value on the underside of the specimen by the bulk insertion technique, proving that the DoC was more optimal with the incremental technique than with the bulk insertion technique [24].

Tsujiimoto et al. (2016) studied the SFRC DoC random arrangement as a substructure with an irradiance of 600 mW/cm² for 30 s, reaching a depth of 4.02 mm with a DoC measurement based on the ISO 4049 2000 specification [25]. They showed that the DoC of SFRC was the same as that of bulk-fill resin composite, but better than that of the conventional resin composite [7]. According to the manufacturing statement (EverX Posterior™), the SFRC random arrangement as a substructure can be polymerized for 10–20 s with an incremental 700–1200 mW/cm² depth of 4 mm without incremental resin composite bulk-fill, with the DoC measurements based on the ISO 4049 200025 specifications. However, Anggia (2016) proved that SFRC polymerization of random arrangement as a 4-mm deep substructure with an irradiance of 800 mW/cm² for 20 s showed no expected DoC because it was still <0.8 (80%). Their results only reached 78.2% by measuring the ratio of hardness of the bottom-to-top surfaces. A DoC of 81% in another study was obtained only at an SFRC thickness of 3 mm [26]. Nadia (2016) also proved that the SFRC DoC random arrangement as a substructure was still not optimal despite testing at 24 h post-cure. The depth of the cure in the study was measured using the Vickers hardness test on a polymerized resin for 20 s at an irradiance of 800 mW/cm². In the measurement of the DoC with the Vickers hardness test, the indentation is given at every 0.3-mm distance interval, with a maximum number of five injuries per every interval of 0.3 mm. The test is performed until the resulting injuries has unknown angles, because the specimen surface is extremely soft. The optimal DoC is obtained when the value of the Vickers hardness test is at least 0.8 (80%) of the maximum value obtained. The results showed that the DoC reached 0.8 (80%) at only as deep as 3.93 mm [27].

According to Flury et al. (2012), measurement of the DoC of resin composites subjected to bulking is overestimated by the ISO 4049 2000 specifications, because the DoC value is extremely high compared with that obtained by the Vickers hardness test [21]. Until date, no research other than the DoC measurements based on the ISO 4049 2000 specifications has proven the optimal DoC at a
thickness of >3 mm with an irradiation of 20 s. Clinically, however, the dentin thickness has been reported to reach 5 mm [28]. Based on the reports by several studies, increasing the irradiance time can increase the total energy received by a resin composite; hence, an optimal DoC can be achieved [23,29–31]. Therefore, we conducted this study to determine whether increasing the irradiation time to 25 and 30 s with an irradiance of 800 mW/cm² can achieve an optimum DoC at 4- and 5-mm thicknesses through the SFRC surface hardness test as a substructure.

2. Methods

2.1. SFRC specimen creation

The specimens used in this study were prepared from SFRC (EverX Posterior™). Cylindrical specimens (6-mm diameter) with thicknesses of 4 and 5 mm were prepared. Briefly, the mold was first smeared with silicone oil. The SFRC paste was then removed from the gun and placed on top of the mixing slab. Next, the SFRC was stacked into the mold using a plastic filling. Mylar strips and glass preparations were placed on top of the mold to prevent oxygen inhibition [19]. Furthermore, 1-kg load pressure was applied for 30 s, which allowed the paste to fill the entire space uniformly and thoroughly, resulting in a smooth surface that was ready for irradiation [19]. Excess SFRC can be removed with plastic filling. SFRC already stacked was then removed from the mold and weighed using an analytical balance (Sartorius model CP224S). Finally, the SFRC was placed back into the mold and pressed with a 1-kg load for 30 s until a completely uniform surface with no excess SFRC was obtained on the mold surface.

2.2. Irradiation using LED LCU

Specimen sampling was performed using LED LCU (LITEX 695 LED Curing Unit; USA) for 25 and 30 s with 800 mW/cm² irradiance and 2-mm LCU tip distance from the SFRC surface using a plastic stopper. After irradiation, the specimens were removed from the mold using tweezers. The top and bottom surfaces of the specimen were then marked. The specimens were finally removed with tweezers and stored in plastic pots containing aquades for 24 h in an incubator (Incubig-TFT; JP SELECTA S.A) at 37°C until the surface hardness test [19].

2.3. Surface hardness testing

Hardness testing was performed on the top and bottom surfaces of the specimens by a Vickers hardness tester (Zwick-Roell Microhardness Tester; Germany). The specimen was placed on the top of a thinly lined glass slab and lightly pressed into the plastic using a press tool. The specimen was then placed on a microhardness tester workbench. Indenter Vickers is diamond-based, with a 200-g load strung at a residence time of 15 s on the specimen surface. This sequencing was performed nine times at different sites on each of the upper and lower specimen surfaces with symmetrical indentation results, not exceeding the field of view and well spaced out to accurately represent the average of each surface’s hardness. Measurements were performed to obtain a surface hardness value (Vickers Hardness Number/ VHN) of six specimens for each specimen group [19].

2.4. Measurements of DoC

The DoC measurements were performed after the lower and upper VHNs were obtained. The DoC was calculated from the ratio of surface hardness with the following formula [19]:

\[
\text{Vickers Hardness Ratio (VHR)} = \frac{\text{Lower Surface Hardness Value}}{\text{Upper Surface Hardness Value}} \times 100\%.
\]
2.5. **Processing and analysis of data**

Processing and data analysis were performed by one-way analysis of variance (ANOVA) to determine the effect of SFRC thickness and the time of exposure for surface hardness. A post-hoc test was then performed to compare the average pairs of values and ANOVA test results [19].

3. **Results**

The results of the study of SFRC with thicknesses of 4 and 5 mm and radiation times of 25 and 30 s at an irradiance of 800 mW/cm² from a radiation distance of 2 mm are given in Table 1.

| Thickness (mm) | Curing Time (s) | Mean of Surface Hardness ±SD (VHN) |
|---------------|-----------------|-----------------------------------|
|               | Upper           | Lower                             |
| 4             | 25              | 57.70 ± 0.41*A                    | 45.65 ± 0.24*C                   |
|               | 30              | 58.50 ± 0.31*B                    | 47.41 ± 0.17*D                   |
| 5             | 25              | 57.65 ± 0.31*A                    | 26.50 ± 0.25*E                   |
|               | 30              | 58.52 ± 0.26*B                    | 35.13 ± 0.18*F                   |

*Numbers with the same letters show no significant difference, and numbers with different letters show a significant difference (p < 0.05).*

There was a difference in the mean VHN within each group by the SFRC thickness and different irradiation time (Table 1). The mean VHN in the treatment group on a 4-mm thick resin with a radiation time of 25 s was 57.70 ± 0.41 VHN and that of 30 s was 58.50 ± 0.31 VHN. The 5-mm thick resin group with a radiation time of 25 s had 57.65 ± 0.31 VHN and that of 30 s had 58.52 ± 0.26 VHN. The mean lower VHN of the treatment group on a 4-mm thick resin with a radiation time of 25 s was 45.65 ± 0.24 VHN and that of 30 s was 47.41 ± 0.17 VHN, while that on a 5-mm thick resin with a radiation time of 25 s was 26.5 ± 0.25 VHN and that of 30 s was 35.13 ± 0.18 VHN. The mean VHN and SFRC standard deviation can be seen in the form of bar charts in Figure 1.

![Mean of Short Fiber-Reinforced Resin Composite Surface Hardness](image)

**Figure 1.** Mean of upper and lower surface hardness of short-fibre-reinforced resin composite in different thickness and curing times.
Prior to one-way ANOVA, normality and homogeneity tests were performed on all four groups. The result of normality test by Shapiro–Wilk test showed data of all groups distributed normally (p > 0.05). Homogeneity test provided data for all homogeneous groups (p > 0.05).

Next, all four groups of SFRC were statistically analyzed by one-way ANOVA to detect any significant difference in the mean VHN between the four treatment groups at a significance level of 0.05. The one-way ANOVA test results are given in Table 2.

Table 2. One-way ANOVA test results of mean of short-fibre-reinforced resin composite surface hardness.

| Surface | Article I. | Sum of Squares | dF | Mean Square | F | Sig. |
|---------|------------|----------------|----|-------------|---|------|
| Upper   | Between Groups | 4.177          | 3  | 1.392       | 12.889 | 0.000* |
|         | Within Groups  | 2.160          | 20 | 0.108       | Article II. | Article III. |
|         | Total         | 6.337          | 23 | 571.360     | Article IV. | Article V. |
|         | Between Groups | 1714.080       | 3  | 12766.939   | 0.000* |
| Lower   | Within Groups  | 0.895          | 20 | 0.045       | Article VII. | Article VIII. |
|         | Total         | 1714.975       | 23 | 1073.337    | |

*p<0.05

As seen in Table 2, the mean VHN of the upper and lower surfaces of the resin composite showed significant differences (p < 0.05) between the groups. A post-hoc LSD test was conducted to identify any significant differences between the surface hardness of each group (Table 3).

Table 3. Post-hoc test results of mean of surface hardness of short-fibre-reinforced resin composite.

| Independent Variable | Upper Surface | Lower Surface |
|----------------------|---------------|---------------|
|                      | Mean Difference (I-J) | Sig. | Mean Difference (I-J) | Sig. |
| 4 mm, 25 s           | −0.05556       | 0.773 | −0.05556       | 0.773 |
| 5 mm, 25 s           | 0.05556        | 0.773 | 19.14815*      | 0.000* |
| 5 mm, 30 s           | −0.81481*      | 0.000* | 10.51852*      | 0.000* |
| 4 mm, 25 s           | 0.79630*       | 0.000* | 1.75926*       | 0.000* |
| 4 mm, 30 s           | 0.85185*       | 0.000* | 20.90741*      | 0.000* |
| 5 mm, 30 s           | −0.01852       | 0.923 | 12.27778*      | 0.000* |
| 4 mm, 25 s           | −0.05556       | 0.773 | −19.14815*     | 0.000* |
| 5 mm, 25 s           | −0.85185*      | 0.000* | −20.90741*     | 0.000* |
| 5 mm, 30 s           | −0.87037*      | 0.000* | −8.62963*      | 0.000* |
| 4 mm, 25 s           | 0.81481*       | 0.000* | −10.51852*     | 0.000* |
| 5 mm, 30 s           | 0.01852        | 0.923 | −12.27778*     | 0.000* |
| 5 mm, 25 s           | 0.87037*       | 0.000* | 8.62963*       | 0.000* |

*p<0.05

The results of post-hoc LSD test revealed significant differences (p < 0.05) between the treatment groups of thicknesses 4 and 5 mm and irradiation time of 25 and 30 s (Table 3). However, with the same irradiation time, no significant difference (p > 0.05) was found in the mean VHN of the resin composite despite differences in the thickness (4 and 5 mm) and irradiation time (25 and 30 s). However, significance difference (p < 0.05) was noted in the mean VHN between these groups on the lower surface of the resin composite.
The results of the DoC measurements by calculating the upper and lower surface hardness ratios of SFRC are given in Table 4.

**Table 4.** Depth of cure of short-fibre-reinforced resin composite in different of thickness and curing time.

| Thickness (mm) | Curing Time (s) | Depth of Cure ± SD |
|---------------|-----------------|--------------------|
| 4             | 25              | 0.79 ± 0.0033*A    |
|               | 30              | 0.81 ± 0.0066*B    |
| 5             | 25              | 0.46 ± 0.0035*C    |
|               | 30              | 0.60 ± 0.0034*D    |

*Numbers with different letters show significant differences (p < 0.05)

Table 4 shows the DoC of SFRC with a time of irradiation of 25 s at 4-mm thickness to be 0.79 ± 0.0033 (79.11% ± 0.33%) and at 5-mm thickness to be 0.46 ± 0.0035 (45.97% ± 0.35%). Conversely, with a 30-s exposure, a DoC of 0.81 ± 0.0066 (81.04% ± 0.66%) was achieved at a thickness of 4 mm and that of 0.60 ± 0.0034 (60.03% ± 0.34%) was achieved at a thickness of 5 mm. The DoC SFRC are provided in the form of a bar chart in Figure 2. One-way ANOVA was performed to detect the significant differences, as shown in Table 5.

**Figure 2.** Depth of cure of short-fibre-reinforced resin composite in different of thickness and curing time.

**Table 5.** One-way ANOVA test results of depth of cure of shot-fibre-reinforced composite.

| Sum of Squares | dF | Mean Square | F       | Sig.       |
|----------------|----|-------------|---------|------------|
| Between Groups | 5002.823 | 3 | 1667.608 | 8513.145 | 0.000* |
| Within Groups  | 3.918   | 20 | 0.196   | Article XII. | Article XI |
| Total          | 5006.741 | 23 | Article XIV. | Article XV. | Article XVI |

*p<0.05
Table 6. Post-hoc LSD test results of short-fibre-reinforced resin composite

| Independent Variables | Mean Difference (I-J) | Sig. |
|-----------------------|-----------------------|------|
| 4 mm, 25 s            | 4 mm, 30 s            | -1.93184* | 0.000* |
| 5 mm, 25 s            | 5 mm, 30 s            | 33.14075* | 0.000* |
| 5 mm, 25 s            | 4 mm, 25 s            | 19.07692* | 0.000* |
| 4 mm, 25 s            | 5 mm, 30 s            | 1.93184*  | 0.000* |
| 4 mm, 30 s            | 5 mm, 30 s            | 35.07259* | 0.000* |
| 5 mm, 25 s            | 5 mm, 30 s            | 21.00876* | 0.000* |
| 5 mm, 30 s            | 4 mm, 30 s            | -33.14075* | 0.000* |
| 5 mm, 30 s            | 4 mm, 25 s            | -35.07259* | 0.000* |
| 5 mm, 25 s            | 5 mm, 30 s            | -14.06383* | 0.000* |
| 5 mm, 30 s            | 4 mm, 25 s            | -19.07692* | 0.000* |
| 5 mm, 25 s            | 4 mm, 30 s            | -21.00876* | 0.000* |
| 5 mm, 25 s            | 5 mm, 30 s            | 14.06383*  | 0.000* |

*p<0.05

4. Discussions
We performed a surface hardness test to measure the DoC of SFRC with thicknesses of 4 and 5 mm and radiation times of 25 and 30 s at an irradiance of 800 mW/cm² and a radiation distance of 2 mm. Our results showed that the average SFRC VHN increased with an increasing irradiance time, both on the top and lower surfaces at thicknesses of 4 and 5 mm (Table 1, Figure 1).

During irradiation, polymerization reactions are affected by the light output, wavelength range, and irradiation time. Longer irradiation durations may increase the polymerization reaction of the resin composite, thereby creating the possibility of cross-linkage [32,33]. In addition, the exposure time affects the total energy received by the resin composite. The total energy (J/cm²) is the amount of irradiance received by the resin composite within a given time range. The total energy reaching the surface of the resin composite at the time of polymerization can affect the physical and mechanical properties of the material, one of which is surface hardness [21,29,34]. The maximum total energy at which the polymerization occurs is received by the upper surface of the SFRC. Hence, the mean VHNs of the SFRC with different irradiation times showed significant differences (p < 0.05), even at the same thickness, because the total received energy was different.

The total energy received by the resin composite was also affected by the radiation distance from the LCU tip [21,29,35,36]. The radiation distance creates an air-filled space between the ends of LCU and the upper surface of the resin composite. Air and resin composites have different refractive indices, which result in light refraction and a decrease in the total energy received by the resin composites [35,36]. Clinically, the SFRC as a substructure of the posterior tooth restoration should be coated with a particulate resin composite at the top, thereby creating a distance of irradiation of approximately 1–2 mm [25]. Lulu (2016) reported that the VHNs of SFRC with 0- and 2-mm irradiation distance were not significantly different [37,38].

The mean VHN of the bottom-to-top surface ratio of the SFRC decreased with increasing thickness. This decrease can be attributed to rays from the upper surface to the lower surface over a distance affecting the polymerization reaction of SFRC [21]. The incoming rays are disseminated at the meeting point between the matrix and filler due to the difference in the refractive index of each compound. The greater the distance traveled, the lower the irradiance with an increasing number, size, and shape of the irregular filler, causing an increased dissipation of light [39,40]. In addition, decrease in the hardness values can be caused by inadequate total energy so that the rays cannot reach the lower surface of the resin, because thicker specimens have more volume than thinner ones. Insufficient total energy in thicker specimens results in the formation of a non-polymerized resin; hence, the lower
surface of the specimen tends to be softer. The soft base of the specimen results in a lower VHN, which may affect the DoC of the resin [35,40].

We thus proved that SFRC thickness and irradiation time significantly affect the value of DoC obtained. The DoC value of 4-mm thickness with a radiation time of 25 s (total energy = 20 J/cm²) was 0.79 ± 0.0033 (79.11% ± 0.33%); by increasing the irradiance time to 30 s (total energy = 24 J/cm²), the DoC value exceeded 0.8 (80%), which is equal to 0.81 ± 0.0066 (81.04% ± 0.66%). Meanwhile, when the thickness was increased, the DoC value decreased significantly compared with that at 4-mm thickness. The DoC value of 5-mm thickness with a radiation time for 25 s (total energy = 20 J/cm²) was 0.46 ± 0.0035 (45.97% ± 0.35%); by increasing the irradiance time to 30 s (total energy = 24 J/cm²), the DoC value could be equalized to 0.60 ± 0.0034 (60.03% ± 0.34%).

The manufacturer (EverX Posterior™) claimed that the DoC can reach 4 mm with 700–1200 mW/cm² irradiation for 10–20 s (total energy = 14–24 J/cm²) [25]. Tsujimoto (2016) used an irradiance of 600 mW/cm² with a 30-s irradiation time (total energy = 18 J/cm²). The obtained DoC reached 4.02 mm by the measurement with the ISO 4049:2000 specification, which was an overestimation [21,24]. Anggia (2016) and Lulu (2016) used an irradiance of 800 mW/cm² for 20 s (total energy = 16 J/cm²) but could not produce a DoC of at least 0.8 (80%), as measured by the surface hardness ratio of the bottom-to-top surfaces using the Vickers hardness test. Anggia (2016) performed polymerization at 4-mm thickness to obtain a DoC of 78.20% ± 1%, whereas Lulu (2016) did not obtain the same DoC by performing irradiance at 0 and 2 mm distances [26,38]. In addition, Nadia (2016) used an irradiance of 800 mW/cm² for 20 s (total energy = 16 J/cm²) with a more accurate method of the Vickers hardness test, depth of cure value of at least 0.8 (80%) not yet reached 4 mm but only as deep as 3.93 mm [27].

The results of the above study were different because the total energy received by SFRC was lower than that received by SFRC in this study (total energy = 20 and 24 J/cm², respectively). In our study, the DoC value increased with the total energy received by SFRC. A DoC value of at least 0.8 (80%) was obtained for 4-mm thick resin with a 30-s irradiation time and an irradiance of 800 mW/cm² (total energy = 24 J/cm²). The total energy used in this study remained within the range recommended by the manufacturer (EverX Posterior™). If SFRC is used as a substitute for dentin of thickness >4 mm, it is best to use incremental techniques to achieve the optimal DoC.

Clinically, SFRC as a substructure is usually used for post-endodontic cavity restoration [25]. The total energy received during polymerization does not affect the pulp roof temperature because the tooth is non-vital. If SFRC is used for deep and vital cavity restorations, the total energy received may be greatly reduced due to the effect of thickness so that the temperature received by the pulp roof is within reasonable limits [41]. We found that to reach the DoC, an optimum total energy equaling 24 J/cm² was required. However, the total energy received on the inside of the SFRC or near the pulp was not as high as that received on the upper surface, as evidenced by the decreasing value of lower surface hardness.

5. Conclusions

It can be concluded that the thickness and curing time affected the hardness of the SFRC and the value of SFRC DoC. The DoC value differed significantly in SFRC thicknesses of 4 and 5 mm with a curing time of 25 and 30 s and irradiance of 800 mW/cm². The DoC value exceeding 0.8 (80%) was obtained at SFRC thickness of 4 mm, with a 30-s curing time and 800-mW/cm² irradiance.

6. References

[1] Van Noort, Richard 2002 Introduction to Dental Materials 2nd edition New York Mosby Elsevier 96 p 100–4
[2] Butterworth C, Ellakwa AE and Shortall A 2003 A fibre-reinforced composites in restorative dentistry Dent. Update 30 300–6
[3] Garoushi SK, Lassila LVJ and Vallittu PK Fibre-reinforced composite in clinical dentistry 2009
Chines J. Dent. Res. 12 7–14

[4] Vallittu PK 2013 Fibre-reinforced Composites (FRCs) as Dental Materials In Non-Metallic Biomater Tooth Repair Replace 53 352–74

[5] Mallick PK 2007 Fibre-reinforced composites materials manufacturing and design 3rd edition New York CRC Press p 49–50

[6] Garoushi S, Saifjonoja E, Vallittu PK and Lassila L 2013 Physical properties and depth of cure of a new short fiber reinforced composite Dent. Mater. 29 835–41

[7] Tsujimoto A, Barkmeier WW, Takamizawa T, Latta MA and Miyazaki M 2016 Mechanical properties, volumetric shrinkage and depth of cure of short fibre-reinforced resin composite Dent. Mater. J. 35 418–24

[8] Bijelic-donova J, Garoushi S and Vallittu PK 2013 Mechanical properties, fracture resistance, and fatigue limits of short fibre reinforced dental composite resin J. Prosthet. Dent. 115 95–102

[9] Powers J 2012 Craig’s restorative dental materials 13th edition Philadelphia Mo Elsevier/Mosby p 163–91

[10] Al-Ahdal K, Ilic N, Silikas N and Watts DC 2015 Polymerization kinetics and impact of post polymerization on the Degree of Conversion of bulk-fill resin-composite at clinically relevant depth Dent. Mater. 31 1207–13

[11] Rueggeberg FA, Caughman GB and Curtis JW 1994 Effect of light intensity and exposure duration on cure of resin composite Oper. Dent. 19 26–32

[12] Rueggeberg FA, Caughman WF, Curtis JW and Davis HC 1993 Factors affecting cure at depths within light-activated resin composites Am. J. Dent. 6 91–5

[13] Rueggeberg F and Jordan DM 1993 Effect of light-tip distance on polymerization of resin composites Int. J. Prosthodont. 6 364–8

[14] Schneider LFJ, Pfeifer CSC, Consani S, Prahl SA and Ferracane JL 2008 Influence of photoinitiator type on the rate of polymerization, degree of conversion, hardness and yellowing of dental resin composites Dent. Mater. 24 1169–77

[15] Abed YA, Sabry HA and Alrobeigy NA 2015 Degree of conversion and surface hardness of bulk-fill composite versus incremental-fill composite Tanta. Dent. J. 12 71–80

[16] Anusavice K, Phillips R, Shen C and Rawls H 2003 Phillips’ science of dental materials 11th ed. St. Louis, Mo: Elsevier/Mosby 400–32

[17] Moore BK, Platt JA, Borges G, Chu T-MG and Katsilieri I 2008 Depth of cure of dental resin composites: ISO 4049 depth and microhardness of types of materials and shades Oper. Dent. 33 408–12

[18] Heymann HO, Swift EJ and Ritter AV 2015 Sturdevant’s art and science of operative dentistry. Vol. 1542, CEUR Workshop Proceedings 33–6

[19] Nagi SM, Moharam LM and Zaazou MH 2015 Effect of resin thickness, and curing time on the micro-hardness of bulk-fill resin composites J. Clin. Exp. Dent. 7 e600–4

[20] Czasch P and Ille N 2013 In vitro comparison of mechanical properties and degree of cure of bulk fill composites Clin. Oral Investig. 17 227–35

[21] Flury S, Hayoz S, Peutzfeldt A, Häusler J and Lussi A 2012 Depth of cure of resin composites: is the ISO 4049 method suitable for bulk fill materials? Dent. Mater. 28 521–8

[22] Bouschlicher MR, Rueggeberg FA and Wilson BM 2004 Correlation of bottom-to-top surface microhardness and conversion ratios for a variety of resin composite compositions Oper. Dent. 29 698–704

[23] Akram S, Abidi SYA, Ahmed S, Meo AA and Qazi FUR 2011 Effect of different irradiation times on microhardness and depth of cure of a nanocomposite resin J. Coll. Physicians Surg. Pakistan 21 411–4

[24] Moharam L, El-Hoshy A and Abou-Elenein K 2017 The effect of different insertion techniques on the depth of cure and vickers surface micro-hardness of two bulk-fill resin composite materials J. Clin. Exp. Dent. 9 266
[25] GC Asia Dental EverX Posterior [Internet]. www.dibateb.com. 2016. Available from: http://www.dibateb.com/wp-content/uploads/2016/01/FAQ-everx-posterior.pdf [last accessed 30 April 2017]

[26] Effect of resin thickness on the depth of cure of fibre-reinforced resin composite as substructure. Andjani AN. A thesis submitted to Universitas Indonesia for the degree of bachelor of Dentistry. September: 2016

[27] Effect of post-cure and methods of measurement toward depth of cure fibre reinforced composite as substructure. Ninda NS. A thesis submitted to Universitas Indonesia for the degree of bachelor of Dentistry. September: 2016

[28] Wheeler’s 2009 Dental Anatomy, Physiology and Occlusion 9th Philadelphia W.B Saunders Company p 171–89

[29] Peutzfeldt A and Asmussen E 2005 Resin composite properties and energy density of light Cure J. Dent. Res. 84 659–62

[30] Emami N and Söderholm KJM 2003 How light irradiance and curing time affect monomer conversion in light-cured resin composites Eur. J. Oral Sci. 111 536–42

[31] Halvorson RH, Erickson RL and Davidson CL 2002 Energy dependent polymerization of resin-based composite Dent. Mater. 18 463–9

[32] Aravamudhan K, Rakowski D and Fan PL 2005 Variation of depth of cure and intensity with distance using LED curing lights Dent. Mater. 2 988–94

[33] Da Silva EM, Poskus LT, Guimarães JG, Barcellos AD, Fellows CE 2008 Influence of light polymerization modes on degree of conversion and crosslink density of dental composites J. Mater. Sci. Mater. Med. 1027–32

[34] Aguiar FH, Lazzari CR, Lima DA, Ambrosano GM and Lovadino JR 2005 Effect of light curing tip distance and resin shade on microhardness of a hybrid resin composite Braz. Oral Res. 19 302–6

[35] Dunne SM and Millar BJ 2008 Effect of distance from curing light tip to restoration surface on depth of cure of composite resin Prim. Dent. J. 15 147–52

[36] Lindberg A, Peutzfeldt A and van Dijken JW 2005 Effect of power density of curing unit, exposure duration, and light guide distance on composite depth of cure Clin. Oral Investig. 9 71–6

[37] Effect of light-curing distance on the depth of cure of fibre-reinforced composite as substructure. Lulu Sharfina. A thesis submitted to Universitas Indonesia for the degree of bachelor of Dentistry. September: 2016

[38] Shortcill AC, Palin WM and Burtscher P 2008 Refractive index mismatch and monomer reactivity influence composite curing depth J. Dent. Res. 87 84–8

[39] Arikawa H, Kanie T, Fujii K, Takahashi H and Ban S 2007 Effect of filler properties in composite resins on light transmittance characteristics and color Dent. Mater. J. 26 38–44

[40] Tsai PCL, Meyers IA and Walsh LJ 2004 Depth of cure and surface microhardness of composite resin cured with blue LED curing lights Dent. Mater. 20 364–9

[41] Yazici AR, Müftü A, Kugel G, Perry RD 2006 Comparison of temperature changes in the pulp chamber induced by various light curing units, in vitro Oper. Dent. 31 261–5