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Optical characteristics of short fiber-reinforced composite in bilayered structure

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Abstract

Purpose: The aim of this in vitro study was to optically evaluate required thickness of particulate filled composite (PFC) used on top of short fiber-reinforced composite (SFRC) in direct bilayered composite structure.

Materials and Methods: Three groups of SFRC materials were studied: everX Flow Dentin (eXD), everX Flow Bulk (eXB) and everX Posterior (eXP) (all materials from GC, Tokyo, Japan). Samples were made in 4 mm deep cavities in transparent molds with a SFRC substructure and a PFC veneer (GC G-ænial Universal Injectable A3) on top. Six different SFRC-PFC ratio combinations were tested with each SFRC material to find out the required PFC thickness where the human eye cannot detect the underlying SFRC material compared to PFC reference cylinder. The used PFC thicknesses were 2.0, 1.5, 1.2, 1.0, 0.7 and 0.5 mm. Test samples (n=5 /thickness /material) were made in two steps and colours were optically measured with a spectrophotometer (CM-700d, Konica-Minolta, Tokyo, Japan).

Results: In all SFRC materials color change values (ΔE) acted almost inversely proportionally to PFC thickness ($R^2 > 0.85$). All three tested SFRC materials had a statistically significant difference in ΔE-values, when veneering PFC thickness was 1.0 mm ($p < 0.05$). In the groups where PFC material thickness was 2.0 mm, the flowable SFRCs (eXD and eXB) showed statistically significant difference compared to packable SFRC (eXP) ($p < 0.05$).

Conclusion: The thickness of veneering PFC affects the optical properties of bilayered restorations. The thickness of PFC should be taken into consideration, when using bilayered SFRC structures in highly aesthetic areas.

Key words: Optical characteristics, short fiber reinforced composite, biomimetic composite restoration, bilayered composite restoration, color change

Introduction

Although composite restorations have been created to improve aesthetics of restorations in anterior teeth, they have turned out to be suitable also for posterior teeth. Especially the use of composites in the posterior area has been favorable because it saves tooth tissue in comparison to the amalgam technique[1]. The most common reasons for failure in the posterior direct composite restorations are caries and fractures[2]. Several factors may cause fracture of composite restoration. Material properties have big influence on the longevity of a restoration. The use of glass fibers as reinforcement in a composite resin matrix instead of particulate fillers, improves the materials mechanical properties such as fracture toughness, load bearing capacity and flexural strength, both in flowable and packable compositions[3,4,5,6]. Due to improved, more dentine-like characteristics, these short fiber-reinforced composite (SFRC) materials, have more natural fracture mode compared to particulate filled composite (PFC). However, layering with dentine-like SFRC and PFC respectively has shown benefits on the microleakage compared to bare SFRC.[7] At this biomimetic mode (Figure 1) SFRC acts as dentine and PFC acts as enamel.

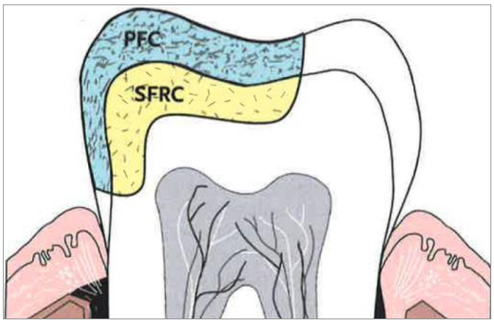

Figure 1. *Schematic drawing of a tooth with a biomimetic, bilayered composite restoration: lost dentine is replaced by high toughness SFRC (short fiber-reinforced composite) which is covered by a wear-resistant enamel-replacing PFC (particulate filled composite). Drawing modified from book: Clinical guide to principles of fiber-reinforced composites in Dentistry by Vallittu and Özcan[8].*

Biomimetic (from Greek; bios= life, mimesis= imitation) use of dental composites has changed the nature of fracture failures of dental compositions. Besides higher fracture resistance of SFRCs, the mimetic use of them as dentine replacing materials, has led to fractures that are more often restorable (66,7-75%), compared to non-SFRC restorations (25 %). SFRCs seems to change the form of fracture from vertical to horizontal securing the root from vertical fracture. When fracture abuts to the crown, the re-restoration is more often possible.[9]

A quite recently introduced study explored the effect of changing the volume ratio of SFRC-PFC. The study showed that the load-bearing capacity of the restorations increased linearly when PFC thickness decreased. Nevertheless, according to the same study the PFC layer still defends its place. When failing, the biomimetic structure, i.e. the bilayered structure, showed delamination of PFC instead of cracking, as occurred with plain SFRC or PFC. In consequence of previous factors, the study concludes that mechanically optimal PFC thickness in a biomimetic restoration is from 0.5 to 1 mm.[10]

Also it has been presented that the total color impression on the layered restorations could be shown to be dependent on the sample thickness and the translucency of the single layers of enamel and dentine materials[11].

When evaluating the color of a dental material, it is meaningful to highlight not only the color shade but also lightness. One way to determine color, is a CIELAB color space defined by the International Commission on Illumination (abbreviated CIE). At the CIELAB color space, color is determined with three parameters: L* for lightness and a* and b* for four colors of human vision. The color change (ΔE) can be calculated as followed:

$$\Delta \mathrm{E} = [(L_{1*} - L_{2*})^2 + (a_{1*} - a_{2*})^2 + (b_{1*} - b_{2*})^2]^{½},$$

where 1* refers to sample 1 and 2* to sample 2.

Although color shade and color change are possible to measure exactly, the human eye cannot detect color variance that precise. Color definition is a skill that we can improve by training. The smallest color difference that can be observed with human eye is called perceptibility threshold (PT). A 50:50% perceptibility threshold is reached, when half of the observers detects color difference while the other half doesn’t. In a situation where half of the observers accepts the color difference while the other half is of the opinion that the restoration requires color corrections, a 50:50% acceptability threshold (AT) is reached.[12] Previously mentioned thresholds (PT, AT) with 95% confidence intervals are 1.22 (0.45-1.89) and 2.66 (1.96-3.37) respectively by CIELAB color space.[13]

This study aimed to evaluate, how thick a layer of PFC is required from an optical point of view, to conserve the aesthetic advantage of composite restoration.

Materials and methods

Three different SFRC materials (everX Flow Bulk, everX Flow Dentin, everX Posterior) (GC, Tokyo, Japan) were optically tested as substructure in bilayered composite structure. Materials were tested in three separate groups where a 4 mm high cavity was filled with SFRC substructure and PFC veneer (G-ænial Universal Injectable A3, GC, Tokyo, Japan) on top (Figures 2-3) (Table 1).

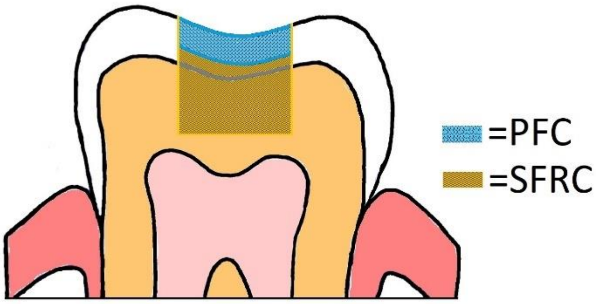

Figure 2. *Schematic drawing of the test set-up.*

Figure 3. *The tested materials front to back: Flow Dentin, everX Flow Bulk, G-ænial Universal Injectable (used as PFC on top) and everX Post (GC Corporation, Tokyo, Japan).*

Table 1. *The tested materials.*

Material	**Manufacturer**	**LOT**	**Composition**
everX Flow Bulk (eXB)	GC, Tokyo, Japan	1909181	Bis-EMA, TEGDMA, UDMA, micrometer scale glass fiber filled, Barium glass 70 wt%, 46 vol%
everX Flow Dentin (eXD)	GC, Tokyo, Japan	1907231	Bis-EMA, TEGDMA, UDMA, micrometer scale glass fiber filler, Barium glass 70 wt%, 46 vol%
everX Posterior (eXP)	GC, Tokyo, Japan	1810252	Bis-GMA, PMMA, TEGDMA, millimetre scale glass fiber filler, Barium glass 76 wt%, 57 vol%
G-ænial Universal Injectable A3	GC, Tokyo, Japan	190125B	Dimethacrylate monomers, Barium glass, silica 69 wt%

Bis-GMA, bisphenol-A-glycidyl dimethacrylate; UDMA, urethane dimethacrylate; TEGDMA, triethyleneglycol dimethacrylate; Bis-EMA, Ethoxylated bisphenol-A-dimethacrylate; PMMA, polymethyl methacrylate; wt%, weight percentage; vol%, volume percentage

Each SFRC material was tested in six different combination of material thicknesses. The selected substructure thicknesses were 3.5, 3.3, 3.0, 2.8, 2.5 and 2.0 mm and correspondingly veneering PFC thicknesses were 0.5, 0.7, 1.0, 1.2, 1.5 and 2.0 mm. A cylinder with only veneering PFC served as reference material. Cylinder shaped bilayered test samples were made in two steps. At the first step SFRC was casted in a transparent mold of the selected height. Transparent molds were made of Exaclear (GC, Tokyo, Japan) and the chosen diameter was 10 mm. Before light-curing, samples were compressed under mylar folie and microscope glass to ensure the chosen height. Samples were light-cured through mylar folie and microscope glass for 40 seconds (Elipar S10, 3M ESPE, Maplewood, USA). After removal of possible excess with silicon carbide abrasive paper (P2400, Federation of European Producers of Abrasives), the substructure layers were ready, and the thickness was measured with a digital caliper. At the second step the SFRC substructure made at the first step was placed into a transparent mold of 4.0 mm height. The mold was filled with veneering PFC (G-ænial Universal Injectable A3, GC, Tokyo, Japan) and compressed and light-cured in the same way as the substructure. Possible excess was removed and the height of the bilayered samples was measured. (Figure 4a and b, Figure 5a-g).

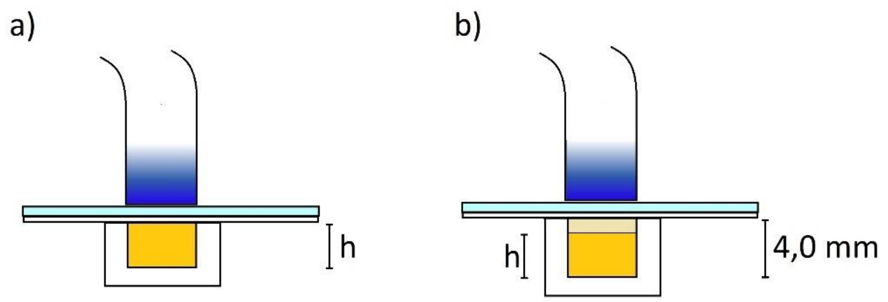

***Figure 4a and b**. Schematic drawing of the manufacturing of the test samples:*
a) step one: casting, pressing and light-curing of SFRC and b) step two: adding, pressing and light-curing PFC on top of SFRC. The total height of test samples was 4 mm where h= varying height of SFRC.

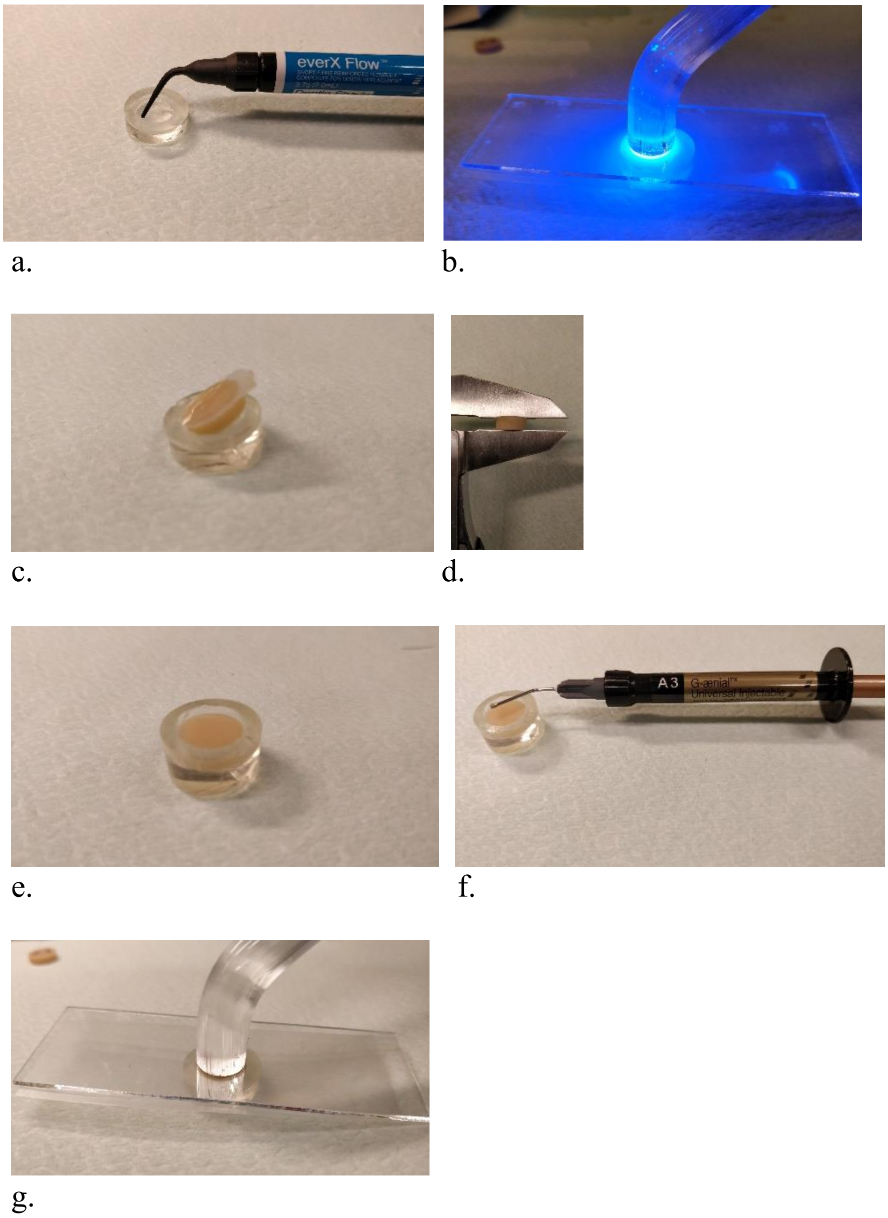

Figure 5 a-g. *Manufacturing of the bilayered test samples: a) filling the transparent mold with SFRC substructure material, b) pressing and light-curing of SFRC, c) substructure sample ready for finishing, d) measuring height of subtructure, e) SFRC substructure placed in 4 mm high mold, f) the rest of the mold is filled up with PFC and g) the 4 mm high bilayered sample is light-cured.*

The color of the bilayered samples was assessed based on the CIELAB color scale relative to the standard illuminant D65 over a black tile (CIE L* = 0, a* = 0.01 and b* = 0.03) and a white tile (CIE L* = 99.25, a* = -0.09 and b* = 0.05) on a reflection spectrophotometer (CM-700d, Konica-Minolta, Tokyo, Japan). The size of the aperture was Ø 3 mm, and the illuminating and viewing configuration was CIE diffuse/10º geometry with the specular component included (SCI) geometry. (Figure 6). The color of each sample was measured five times (n=5 /thickness /material).

Figure 6. *The Spectrophotometer used for measuring the samples optically.*

Statistical analysis

The data was statistically analysed using JMP Pro software version 16 (SAS Institute Inc., Cary, NC, USA). Assumption of equality of variances was tested with Levene's test. The results were examined by one-way analysis of variance (ANOVA) continued with Tukey method for pairwise comparisons at the $p < 0.05$ significance level.

Results

A summary of the results is shown in Figure 7 and Table 2. With all three tested SFRC materials it was observed that ΔE-values acted almost inversely proportionally to PFC thickness ($R^2 > 0.85$) (Figure 7). All three tested SFRC materials had a statistically significant difference in ΔE-values, when veneering PFC thickness was 1.0 mm ($p< 0.05$, pairwise comparisons Tukey-Kramer) with eXD showing the lowest ΔE-value.

When veneering PFC material was 2.0 mm, the flowable SFRCs (eXD, eXB) differed statistically significantly from the packable SFRC (eXP). However, when the thickness of veneering material was 2.0 mm no significant difference occurred between eXD and eXB ($p= 0.999$, pairwise comparisons Tukey-Kramer).

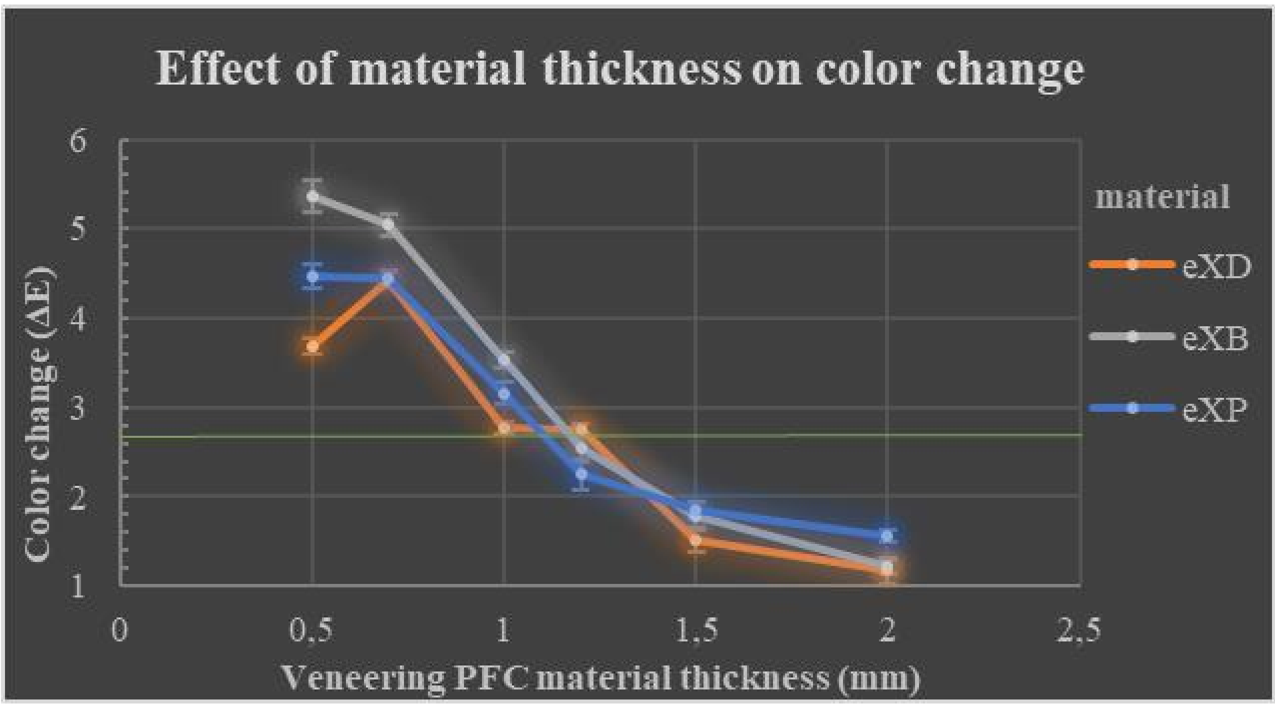

Figure 7. *The effect of PFC veneering material thickness on color change (ΔE) for the tested SFRC materials. The green line shows acceptability threshold (AT).*

Table 2 *Means of color changes (ΔE) with standard deviations (SD) with various veneering PFC thicknesses on tested SFRC materials.*

ΔE-values on various PFC thicknesses				
		PFC thickness		
		1	1,5	2
material	eXD	2.77 (0.06)[c]	1.51 (0.14)[f]	1.17 (0.14)[g]
	eXB	3.53 (0.08)[a]	1.78 (0.15)[d,e]	1.22 (0.07)[g]
	eXP	3.16 (0.12)[b]	1.86 (0.10)[d]	1.56 (0.07)[e,f]

Levels not connected by same letter are significantly different.

Discussion

In this in vitro study the optical properties by the means of color change of direct biomimetic composite restoration were evaluated. In this biomimetic restoration SFRC substructure (packable or flowable) was veneered with occlusion resistant flowable PFC. The effect of adjusting SFRC-PFC ratio was measured optically and compared to PFC without SFRC substructure. Practical application for these particular materials could be for example rehabilitation of occlusion with injectable casting technique.

According to the results the thickness of PFC showed a significant effect on the optical appearance and the color change (ΔE). The results of this study can be divided into two groups considering previously mentioned thresholds, perceptibility threshold (PT) and acceptability threshold (AT). If write off the speech professionals, we can generalize that on posterior teeth areas color change should be within AT (ΔE 2.66). Thus, in this study, thickness of PFC in the posterior area with these material combinations should be between 1.1 to 1.2 mm on aesthetic point of view (Figure 7, green line).

On highly aesthetic areas, such as anterior teeth, requirements for restorations are higher. Therefore, use of PT (ΔE 1.22) as a guideline is justified. According to our results the PT was reached at 2.0 mm thickness with both flowable SFRCs (eXD and eXB). The results also revealed that the thickness for eXP to reach PT should be more than 2.0 mm (Figure 7).

The authors want to raise that although AT and PT have been examined, the color definition is a skill that can be trained. That leads to relatively high variation in color perception which was also seen in earlier studies.[12,13] Potential source of error in this study was the small group size, where each group had only one sample which was measured from five random points. Handling with rather small sample size was also challenging in this study, but frequent measurements of sample thicknesses and the standardized molds helped to overcome that problem.

In order to be able to generalize required PFC thickness in bilayered composite structure, further research is needed. In future studies focus will be on looking into other commercial PFCs and other shades of composites. Although this study gave thumb rules about how thick a layer PFC is needed on top of the different SFRC materials, it is necessary for the clinician to analyze every case carefully and individually in order to reach the right aesthetic level needed.

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