Effects of Glass Fiber Layering on the Flexural Strength of Microfill and Hybrid Composites

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ABSTRACT

Statement of the Problem: In stress-bearing cavities, low fracture resistance adversely affects the longevity of the dental resin composite restorations.

Purpose: The aim of this in vitro study was to investigate the effect of glass fiber layering on the flexural strength of microfill and hybrid composites.

Materials and Methods: Flexural test specimens ($N = 75$) were prepared according to International Organization for Standardization (ISO) 4049 specifications ($25 \times 2 \times 2$ mm) by using a standard metallic mold. Materials used and groups were as follows ($N = 15$): group 1: hybrid composite (Clearfil APX, Kuraray Co.Ltd, Osaka, Japan); group 2: microfill composite (Clearfil ST, Kuraray Co.Ltd.); group 3: hybrid + microfill composite; group 4: woven glass fiber (EverstickNet, StickTech Ltd, Turku, Finland) + hybrid composite; group 5: woven glass fiber + microfill composite. The specimens were stored in distilled water at 37°C for 7 days. Afterward, they were loaded to fracture (1 mm/min) by using a universal testing machine (AG-50 kNG Shimadzu Co., Kyoto, Japan). Flexural strengths were expressed as maximum flexural load per cross-sectional area of the specimen. The results were statistically analyzed with Kruskall–Wallis and Mann–Whitney U tests ($p < 0.01$).

Results: Significant increases in the flexural strength were found for both hybrid and microfill composites when fiber layering was used (group 1: 78 ± 7 MPa; group 4: 93 ± 4 MPa) (group 2: 42 ± 5 MPa; group 5: 64 ± 4 MPa) ($p < 0.01$). Flexural strength of fiber-reinforced hybrid composite was significantly higher than the other groups evaluated ($p < 0.01$). There were no significant differences in flexural strength between microfill/hybrid combination and fiber-reinforced microfill composite ($p > 0.01$).

Conclusions: Glass fiber layering of microfill and hybrid composites presented higher flexural strength, and veneering of hybrid composite with microfill composite increased the resistance of the restoration.

CLINICAL SIGNIFICANCE

Glass fiber reinforcement of both hybrid and microfill resin composite materials may be a clinical option in otherwise unfavorable clinical conditions, such as large cavities and/or where bruxism is in present restorative dentistry.

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INTRODUCTION

The improvements in mechanical properties of resin-based composites as well as esthetics and bonding to tooth structure physicochemically have expanded their use in both anterior and posterior teeth.[1,2] However, further improvements are needed in order to use composites in stress-bearing conditions, such as direct posterior restorations involving cusps, and inlays and onlay restorations due to relatively low fracture resistance and high brittleness.[3–5]

Many studies have reported that the filler size and volume fraction significantly affect the mechanical properties of composite as well as failure rate.[3,6–8] Microfill composites, with their lower filler volume, have been shown to have lower fracture toughness, stiffness, and strength than more heavily filled composites.[9,10] Therefore, they are proposed for restoration of anterior teeth because they have superior esthetic properties.[11,12] Hybrid composites with higher filler amount combine the fracture resistance of conventional composites with acceptable esthetic appearance and are preferred in especially large anterior restorations. On the other hand, the surface characteristics of hybrid composites are not considered to be as smooth as those of microfill composites.[11,13,14] Microfill veneering of anterior hybrid composite restorations has been proposed to improve the esthetics (polishability) while utilizing enhanced fracture resistance of the hybrid composite.[14] As in the case of a large anterior restoration (Class IV), the main body of the restoration may be built up by means of a hybrid composite, and a microfill composite may be used as a labial veneer.[14,15]

Fiber reinforcement has been proposed for resin-based composite restorations to increase resistance of materials to fracture especially in high stress-bearing cavities.[15–19] Fiber-reinforced composites (FRC) are made of a polymer matrix impregnated with fibers. The fibers allow the stresses to be distributed throughout the restoration. In light of the fact that the role of the fibers is to improve the structural properties of the material by acting as crack stoppers, the framework of FRCs provides strength and rigidity to the composite materials. The surrounding resin matrix acts to protect the fibers and fix their geometrical arrangement so that the reinforcement is supported.[15,16,18,20] Clinical application of fibers has been extended from intracoronal restorations to fixed partial dentures.[2,5,15–21]

The selection of fiber type is dependent on the strength required for reinforcement. Continuous parallel unidirectional fibers are used to reinforce the connection between pontic and crown in a fixed partial denture, and woven fibers are indicated to reinforce the crown.[16,18,20,21–23] Reinforcement of resin composite with randomly oriented short glass fibers was also used for improving the mechanical properties of the material.[24,25]

Flexural strength is often relied upon as an indicator of structural performance for brittle dental materials including composites.[13] Composite restorations are subjected to flexural stresses, especially in stress-bearing cavities (Classes I, II, and IV).[2–5,18] Flexural strength test has been used to measure mechanical properties of a composite material, namely, compression and tension, acting together and relied upon in predicting clinical performance of restorative materials (International Organization for Standardization [ISO] 4049).[13,15,26] In some previous studies, several types of fibers for dental use showing higher flexure strengths are screened.[5,17–22] In a study, it was stated that flexural strength values two or three times higher were observed by adding fibers to composites.[2] Xu and colleagues[5] reported that superior reinforcement was achieved by using fiber preforms (flexural strength of more than 300 to 400 MPa, whereas that of hybrid composite without fibers was 120 MPa) and suggested the use of fiber preforms in large restorations in areas that may experience high occlusal loads.

The mechanical properties and reinforcing capacity of FRCs applied in dentistry depend on the fiber type, fiber orientation relative to load, fiber position in the restoration, impregnation of the fiber, adhesion of the fiber to the resin matrix, and fiber volume fraction.[16,17,20,22,27–32] The highest flexural strength was achieved when the fiber framework was placed on the tensile side (base) of the composite materials.[28–30]

The woven glass fiber used (EverstickNet, StickTech Ltd, Turku, Finland) introduced in the early 2001s is preimpregnated with light-curing monomers that cross-link during polymerization of the overlying composite and forms a multiphase polymer network. Multiphase structure is called a semi-interpenetrating polymer network structure (semi-IPN). The advantages of the semi-IPN are said to be easier handling of the fiber material, high strength, reduced water sorption, high flexural strength, and improved adhesion between FRC framework and veneering composite after polymerization.[27,31,32] Several studies have been published on the successful use of woven glass fibers to reinforce composite restorations.[19,21]

In this study, it is hypothesized that, by using glass fiber layering under the composite, flexure strength of the material would be improved. Therefore, the aims of the study were to determine the effects of woven glass fiber layering on the flexural strength of hybrid and microfill composites and to investigate the veneering hybrid composite by microfill composite that increased the flexure strength of the restoration.

MATERIALS AND METHODS

The materials used in this study are listed in Table 1. The specimens were prepared ($N = 75$) by placing the composite into a standard stainless steel split mold ($25 \times 2 \times 2$ mm), according to ISO 4049 specifications. The groups ($N = 15$) were as follows: group 1: hybrid composite (Clearfil APX, Kuraray Co.Ltd, Osaka, Japan); group 2: microfill composite (Clearfil ST, Kuraray Co.Ltd); group 3: hybrid + microfill composite; group 4: woven glass fiber (EverstickNet) + hybrid composite; group 5: woven glass fiber + microfill composite. The mold was placed over a glass plate, and then the composite material or the cut-to-fit glass fiber was placed into the mold by using a plastic instrument in two increments. The resin was covered with another glass plate and gently pressed against the mold to extrude excess material. Between each glass plate and the mold, Mylar matrix strips (Hawe-Neos Dental, Bioggio, Switzerland) were positioned to avoid air entrapment. For A3 to be standardized, shade was used in all the specimens (Figure 1).

TABLE 1. MATERIALS EVALUATED IN THE STUDY.

Material	Manufacturer	Lot #	Chemical composition*
Clearfil ST (Microfill)	Kuraray Co.Ltd, Osaka, Japan	41135	Colloidal silica, borosilicate glass (0.04 µm, 81.6%), BisGMA, TEGDMA
Clearfil APX (Hybrid)	Kuraray Co.Ltd, Osaka, Japan	41113	Colloidal silica, Barium glass (3 µm, 86%), BisGMA, TEGDMA
EverstickNet (Bidirectional, woven FRC)	StickTech Ltd, Turku, Finland	2031106-EN–049	PMMA, E-glass fibers, BisGMA

FRC = fiber-reinforced composites.

*Information on the composition of composites and glass fiber was supplied by the manufacturers.

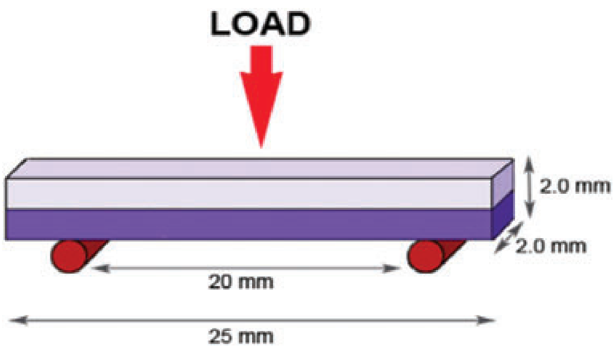

Figure 1. Schematic drawing of a three-point bending test used in the study.

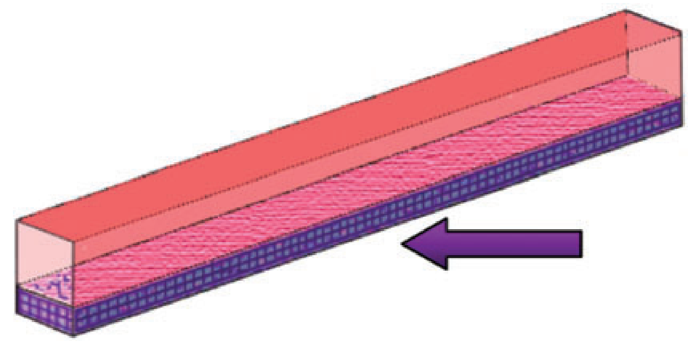

Figure 2. Schematic drawing of the specimen with the glass fiber placed in the tensile side.

Photopolymerization of the specimens was performed in each one-third of the length of the specimen from one side of the mold, by a blue light-emitting diode (Elipar Freelight, 3M ESPE, St.Paul, MN, USA), with the light intensity of 400 mW/cm^2 and the wavelength range of 440 to 480 nm. The radius of the tip of the curing light was measured as 7.96 mm.

The procedures applied in each group were as follows:

1. Group 1: Hybrid composite was placed into the mold in two increments by using plastic instrument and photopolymerized for 20 seconds in each increment and each one-third of the specimen. Total curing time was 120 seconds for each specimen.
2. Group 2: Microfill composite was placed into the mold and photopolymerized as in group 1.
3. Group 3: Hybrid composite was placed in a 1-mm increment and photopolymerized for 20 seconds. The mold's height was completed with microfill resin in one increment (1 mm) and photopolymerized as in group 1.
4. Group 4: Woven preimpregnated glass fiber (EverstickNet) (0.06 mm in thickness, 25 mm in length) was condensed with a plastic instrument to the bottom of the mold (tension side), and a layer of hybrid composite was inserted (onto the fiber), making a thickness of 1 mm. They were photopolymerized together for 20 seconds in each one-third of the specimen. Then this layer was covered with another increment of the composite in a single movement to fill the rest of the mold (Figure 2). Photopolymerization was completed as in group 1.
5. Group 5: Woven preimpregnated glass fiber combined with microfill composite was applied as in group 4.

The specimens were not polished on the surfaces before testing. All applications were performed by the same person in order to standardize laboratory procedures. After being removed from the mold, the specimens were stored at room temperature in distilled water for 7 days. After storage and prior to the loading, the thickness and width of the specimens were measured by using a digital micrometer (Digimatic, Mitutoyo Corp., Niles, IL, USA), with an accuracy of 0.01 mm at three locations along the rectangular bar samples. A three-point bending test was carried out to assess the flexural strength of the specimens. The distance between the supports was 20 mm (Figure 1). Load application was performed under room temperature by using a universal testing machine (AG-50 kNG Shimadzu Co., Kyoto, Japan). Load was applied at the

TABLE 2. MEAN FLEXURAL STRENGTH AND ±SD FOR GROUPS.

Groups (N = 15)	Mean flexural strength (±SD) MPa
Group 1; Hybrid composite	78 (7)
Group 2; Microfill composite	42 (5)
Group 3; Hybrid + microfill composite*	62 (5)
Group 4; Fiber + hybrid composite	93 (4)
Group 5; Fiber + microfill composite*	64 (4)

*Indicate mean values that are not significantly different ($p < 0.01$).

middle of the test specimens at 90° to the long axis of the specimen, with a knife-edged anvil at a cross-head speed of 1 mm/min. The specimens were loaded until the first sound of crack was detected and the load was recorded. Flexural strength was calculated by using the following equation:[3,28]

$$\textit{Flexural strength MPa} = \frac{3Fl}{2bh^2} \quad (1)$$

where F is the maximum load in Newtons exerted on the specimen, l is the distance in millimeters (20 mm) between the supports and b and h are the width and thickness (height) in millimeters of the specimen measured immediately prior to testing.

Statistical analysis was accomplished by using the SPSS (SPSS Inc., Chicago, IL, USA) statistical software program. A nonparametric analysis of Kruskal–Wallis was used to determine the differences among the groups. Comparisons between means of pairs were performed by using Mann–Whitney U test at a significance level of $p < 0.01$.

RESULTS

The mean flexural strengths of the five groups in the study are presented in Table 2. The results indicated that glass fiber layering (placement) at the tensile side improved flexural strength of both microfill and hybrid composites significantly ($p < 0.01$). Glass fiber-reinforced hybrid composite (group 4: 93 ± 4 MPa) exhibited higher mean flexural strength in than the other groups ($p > 0.01$). No significant difference was found in mean flexural strengths between microfill composite/hybrid combination (group 3: 62 ± 5 MPa) and glass fiber combined with microfill composite (group 5: 64 ± 4 MPa, $p > 0.01$).

DISCUSSION

The performance of dental restorative materials is related to mechanical properties. The flexural test (three-point bending test) has been widely used in evaluation of mechanical properties of dental restorative materials.[3,5,7,10,13,15] It is stated that ISO specifications for height and width are acceptable because the dimensions of the specimens permit effective polymerization.[10,13] However, the recommended length is advocated to be not realistic, considering the diameter of the teeth.[10,13] Also, multiple overlapping curing is necessary to polymerize the specimens because the exit window of clinical light-cure units is smaller than 25 mm.[10,13] This may lead to inhomogeneity of the specimens, as localized areas exposed to twice the curing time, which results in a higher degree of polymerization than the adjacent region. It is also said that preparing flaw-free specimens at this length is difficult.[10] Any voids or irregularities present in the materials would result in uneven stress distribution within the specimen, which may influence the observed strength.[10,13] However, many studies reported that the three-point bending test is reliable in evaluation of flexural strength of resin-based dental composites.[3,5,10,22]

The findings of the present study are in agreement with the previous studies demonstrating that microfill composite shows lower flexural strength than hybrid composite.[7,8,15]

The flexural strength of the groups evaluated in the study fulfilled the minimum requirement specified in ISO 4049 (flexural strength > 50 MPa) except for microfill composite (42 ± 5 MPa) (Table 2). In the studies, although higher flexural strength values are obtained in common, results may show dissimilarity when FRC layering was applied. Thus, direct comparison with previous studies is not always possible. Factors such as fiber volume fraction, location of the fiber in the test specimen, bending test span-length-height of the specimen ratio, polymerization conditions, and degree of water saturation of the test specimen may have an effect on the resultant flexural strength values.[2,32]

In the present study, the woven glass fiber used (EverstickNet) is preimpregnated. In a previous study, it is stated that the strength of the FRC-veneering composite structure is dependent on the adhesion between the FRC framework and veneering composite.[32] The degree of impregnation of fiber reinforcements affects properties of the FRC. In the case of incomplete impregnation, there are voids in the polymer matrix of the FRC, and the mechanical properties such as flexural strength values of the FRC may be lower. The voids caused by an incomplete impregnation also increase the water sorption of the FRCs, which affects long-term stability of FRC dental applications in an aqueous environment such as in the oral cavity.[27] The complete degree of impregnation of the FRCs can be obtained if the fiber reinforcement is preimpregnated either with polymer, monomer, or a combination of these. Preimpregnation also affects the adhesive properties of the polymerized FRC positively.[27]

FRCs were shown to have superior physical properties than unreinforced resin composites in earlier studies.[10,18,26,28,29,31] The fibers in woven designs are divided equally in the longitudinal and transverse directions, which gives composite material orthotropic mechanical properties.[16,18,19,21] Therefore, they are suitable especially in cases where multidirectional reinforcement of the restoration is needed, and the direction of load is difficult to predict.[16,18,19] The results of this study are in agreement with the previous studies where addition of woven glass fiber placed in the tension side (base) improved the flexural strength of both microfill and hybrid composites. Similarly, significantly higher flexural strength with woven glass fiber-reinforced specimens than those without woven glass fiber was found.[18,28,32,33] Lassila and colleagues[32] found that the position of the FRC layer had an effect on the flexural strength of the test specimen. According to this study, the highest flexure strength was achieved when the FRC layer was located at the tensile side of the specimens.

The finding of this study that the combination of microfill and hybrid composites exhibited higher flexural strength than microfill composite used alone is in agreement with a study by Pereira and colleagues.[15] However, the finding that hybrid composite combined with glass fiber exhibited higher flexural strength than without reinforcement is not in agreement with the findings of the same study, demonstrating that fiber-composite laminate did not increase fracture strength of reinforced hybrid composite, although unpreimpregnated polyethylene fiber was used in the above-mentioned study.

In the present study, similar results were obtained with glass fiber reinforcement and veneering of the microfill composite with hybrid composite. Therefore, both applications may be an alternative to each other in unfavorable clinical conditions such as large cavities and bruxism. However, the value of in vitro studies for investigation of restorative systems is limited and needs to be evaluated clinically.

Thus, favorable results reported when reinforcement of resin composite with randomly oriented short glass fibers was used were not confirmed in a clinical study, at 6 years, conducted by Van Dijken and colleagues.[25] The difference in durability of composites was explained by the combination of factors such as differences in resin matrix, amount and size of the glass fibers, fiber geometry within the structure, and bond between fibers and matrix as well as the influence of different adhesives used.[25,31] It is also reported that, clinically, axial forces in addition to lateral forces and fatigue loading should be considered.[2]

The results of this study showed that the reinforcement obtained by using the fiber preforms may extend the use of resin composites to large restorations in stress-bearing conditions. Woven fibers would be beneficial in these situations because they can reinforce the restoration in multiple directions. Further developments in fiber reinforcement systems and various applications such as using flowable composites under fiber-reinforced resin restorations may enhance better results in the fracture resistance of the restorations and could be examined in future studies.

CONCLUSIONS

Within the limitations of the experimental design, the following were concluded: (1) glass fiber reinforcement of the hybrid and microfill composites improves the flexural properties of the material significantly, and, therefore, FRCs may offer an alternative toward overcoming some potential problems of composite restorations in high stress-bearing areas, and (2) Microfill veneering of hybrid composites would provide higher flexural strength than microfill composite used alone.

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