Shear Bond Strength to Enamel and Flexural Strength of Different Fiber-reinforced Composites

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Purpose: To assess the shear bond strength to unground human enamel (ESBS) and flexural strength (FS) of different reinforcing fibers used in combination with a flowable composite resin.

Materials and Methods: For ESBS testing, 90 human molars were selected and randomly divided into 9 groups (n = 10) according to the reinforcing fiber to be tested: 1. RTD Quartz Splint additionally impregnated at chairside with Quartz Splint Resin (RTD); 2. RTD Quartz Splint without additional impregnation; 3. Ribbond–THM (Ribbond); 4: Ribbond Triaxial (Ribbond); 5. Connect (Kerr); 6. Construct (Kerr); 7. everStick PERIO (Stick Tech); 8. everStick C&B (Stick Tech); 9. nonreinforced composite Premise flowable (Kerr). Cylinders of flowable composite reinforced with the fibers were bonded to the intact buccal surface of the teeth. After 24 h of storage, shear loading was performed until failure occurred. FS was assessed performing three-point bending test according to ISO Standard 4049/2000. ESBS and FS data were analyzed using one-way ANOVA, followed by Tukey's HSD test for post-hoc comparisons ($p < 0.05$).

Results: The ESBS and FS, respectively, in MPa were: 1. 17.07 ± 4.52 and 472.69 ± 30.49; 2. 14.98 ± 3.92 and 441.77 ± 61.43; 3. 18.59 ± 5.67 and 186.89 ± 43.89; 4. 16.74 ± 6.27 and 314.41 ± 148.52; 5. 14.38 ± 4.14 and 223.80 ± 77.35; 6. 16.00 ± 5.55 and 287.62 ± 85.91; 7. 16.42 ± 3.67 and 285.35 ± 39.68; 8. 23.24 ± 5.81 and 370.46 ± 29.26; 9. 12.58 ± 4.76 and 87.75 ± 22.87. For most fibers, no significant difference in ESBS was found compared to the control group, except for everStick C&B, which yielded higher ESBS. Nonreinforced composite exhibited the lowest FS, while all fibers positively affected the FS.

Conclusions: Fiber reinforcement of flowable composite does not affect its ESBS. The flexural strength of FRCs is significantly influenced by fiber composition and pattern.

Keywords: fiber reinforced composite, bond strength, enamel, flexural strength.

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Fiber-reinforced composites (FRCs) are multiphase materials with a unique combination of properties achieved with a specific proportion of each phase.[32] Generally, enhanced mechanical characteristics of the material are achieved by incorporation of reinforcing fibers (discontinuous phase) into polymer matrix (continuous phase).[37] Optimal reinforcement and transfer of stresses from matrix to fibers rely on an adequate interfacial bond between the two phases.[3]

FRCs have been an object of interest of dental research since the 1960s[19] and currently represent an attractive

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choice for a variety of clinical applications, such as endodontic posts and cores,[5,13,14,21] frameworks for fixed dental prostheses (FDPs),[6,16,27,38] and implant-retained FDPs.[12] FRCs are also used in direct intra-oral applications, such as periodontal and trauma splints,[25,26,36] orthodontic retainers,[4,15,33] and chairside FDPs[27] by bonding to tooth structure with adhesives and resin composites.

Limited information is available in the literature regarding the adhesion between FRCs and tooth structure.[28,33,34] According to Tezvergil et al,[34] shear bond strength to enamel and dentin of two FRC materials did not differ from that of a nonreinforced composite. Moreover, the application of a flowable composite beneath the fibers did not influence the bond strength.[34] Another study investigated the shear bond strength of composites reinforced with nonresin pre-impregnated polyethylene fibers and resin pre-impregnated glass fibers to flattened bovine enamel.[28] The results revealed that 3 out of 4 FRC materials had bond strength values to enamel similar to those of a non-FRC-containing composite. Conversely, one nonresin pre-impregnated fiber (Connect, Kerr; Orange, CA, USA) had significantly higher shear bond strength. In addition, different fracture patterns among groups were observed. However, the clinical procedure of direct intraoral application of an FRC splint does not usually involve grinding or flattening of the enamel surface. Therefore, it seemed worth examining the adhesion of FRCs to unground enamel.

Moreover, many different types of carbon-, quartz-, aramid-, polyethylene-, and glass-fiber–reinforced composites have been utilized in the fabrication of FRCs. The adhesion between quartz or glass fibers and resin matrix is enhanced by fiber silanization, while other surface treatments, such as plasma spraying, flame, or radiation, are applied to polyethylene fibers. Moreover, the fiber orientation of FRCs may differ: they can be unidirectional, bi- or multidirectional. It has been documented that the mechanical properties of FRCs are affected by various factors, such as type and architecture of the fibers,[24,37] fibers density,[1,17,30] impregnation of fibers with the polymer matrix,[20,26] and fiber/matrix adhesion.[3,29] Additionally, while some FRCs are resin pre-impregnated during the manufacturing process, others (polyethylene fibers) should be wet with a resin agent prior to use. It has also been documented that the chemical composition of the wetting agent significantly determines the mechanical properties of the FRCs.[10] In general, the mechanical properties of FRC structures have been found to be superior to those of nonreinforced composites.[32,37]

This study was designed to investigate the influence of fiber type, pattern, and resin impregnation on the adhesive and mechanical properties of 7 different FRCs. The aim was to assess the shear bond strength to unground human enamel (ESBS) and the flexural strength (FS) of different reinforcing fibers used in combination with a flowable resin composite. The failure mode distribution of debonded specimens was also evaluated. The null hypotheses were that: 1. different reinforcing fibers do not significantly change the ESBS of flowable composite; 2. failure mode distribution is not affected by the fiber reinforcement of flowable composite; 3. different reinforcing fibers have no impact on the FS of a flowable resin composite.

MATERIALS AND METHODS

Shear Bond Strength

For shear bond strength testing, 90 freshly extracted sound human molars were selected. Teeth were cleaned and stored refrigerated (4°C) in 0.5% chloramine-T solution for no longer than 1 month until use. A dental student blinded to the objective of the study randomly placed the teeth in 9 different containers, 10 teeth per container, 1 container per group. The groups were designated according to the reinforcing fiber to be tested:

- Group 1: RTD Quartz Splint additionally impregnated at chairside with Quartz Splint Resin (RTD; St Egrève, France);
- Group 2: RTD Quartz Splint without additional impregnation (RTD);
- Group 3: Ribbond-THM (Ribbond; Seattle, WA, USA) impregnated with unfilled adhesive bonding resin (OptiBond FL Adhesive, Kerr; Orange, CA, USA);
- Group 4: Ribbond Triaxial (Ribbond) impregnated with unfilled adhesive bonding resin (OptiBond FL Adhesive);
- Group 5: Connect impregnated with Kolor+Plus Color Modifiers (Kerr);
- Group 6: Construct impregnated with Construct resin (Kerr);
- Group 7: everStick PERIO (Stick Tech; Turku, Finland);
- Group 8: everStick C&B (Stick Tech);
- Group 9 (control group): flowable composite Premise flowable (Kerr) without reinforcing fiber.

The composition and batch numbers of the materials used in the study are reported in Table 1.

Metal cylindrical molds were used to embed the teeth in chemically curing methylmethacrylate resin (Paladur, Heraeus Kulzer; NY, USA). On the buccal surface of each tooth, the enamel was etched with 37.5% phosphoric acid for 15 s, thoroughly rinsed with water, and gently air dried for 5 s. In order to ensure a standardized bonding area on the target surface, a rubber cylindrical mold with 3 mm internal diameter was used (Fig 1A). After application of OptiBond FL Primer (Kerr) using a microbrush in a light scrubbing motion for 15 s and air drying for 5 s, OptiBond FL Adhesive (Kerr) was layered, thinned with a gentle stream of air, and light cured for 20 s with a halogen curing device (VIP, Bisco; Schaumburg, IL, USA; 600 mW/cm^2). A 1-mm-thick increment of resin composite Premise flowable was placed inside the rubber mold and adapted to the bonding substrate. Then, an adequately sized segment of reinforcing fiber was positioned over the composite resin layer, and light polymerization was performed for 20 s with the above mentioned curing device. The non-pre-impregnated fibers from groups 3 to 6, as well as the additionally impregnated RTD Quartz Splint from group 1, were first wet with the proprietary resin before being placed into

Table 1 Manufacturers, chemical composition, and batch numbers of the materials used in the study

Material (manufacturer), batch number	Chemical composition
Gel Etchant (Kerr; Orange, CA, USA) 3213200	37.5% ortho-phosphoric acid, silica thickener
OptiBond FL (Kerr) Primer 3215398, Adhesive 3215399	Primer: HEMA, GPDM, PAMM, ethanol, water, photo-initiator Adhesive: TEG-DMA, UDMA, GPDM, HEMA, bis-GMA, filler, photo-initiator
Premise flowable (Kerr) 3348484	PPF, barium glass, silica filler, ethoxylated bis-DMA, TEG-DMA, light-curing initiators and stabilizers, organophosphate dispersant
RTD Quartz Splint (RTD; St Egrève, France) 10298-02	Unidirectional quartz fibers, light-curing dimethacrylate (bis-GMA, TEG-DMA) resin matrix, light initiator, silica
Quartz Splint Resin (RTD) 9119-01	TEG-DMA, bis-GMA, light-curing initiator, silica
Ribbond-THM (Ribbond; Seattle, WA, USA) 9574	Silanized, plasma treated leno-woven, ultra-high molecular weight polyethylene fibers
Ribbond Triaxial (Ribbond) T107	Silanized, plasma treated triaxial braided, ultra-high molecular weight polyethylene fibers
Connect (Kerr) 3108611	Ultra-high strength, cold gas plasma-treated silanated biaxial braided polyethylene fibers
Construct (Kerr) 3163422	
Kolor+Plus Color Modifiers (Kerr) 3006330	Fumed silica, grounded barium aluminoborosilicate, dimethacrylate resins
Construct resin (Kerr) 3016437	Fumed silica, grounded barium aluminoborosilicate, dimethacrylate resins, silane
everStick PERIO (Stick Tech; Turku, Finland) 2080519-EP-087	Silanated unidirectional glass fibres, impregnated with PMMA and bis-GMA
everStick C&B (Stick Tech) 2101011-ES-272	

Abbbreviations: HEMA (hydroxyethylmethacrylate), GPDM (glycerol dimethacrylate dihydrogen phosphate), PAMM (phthalic acid monoethyl methacrylate), TEG-DMA (triethylene glycol dimethacrylate), UDMA (urethane dimethacrylate), bis-GMA (bisphenol-glycidyl methacrylate), PPF (prepolymerized filler), bis-DMA (bis-phenol-A-dimethacrylate).

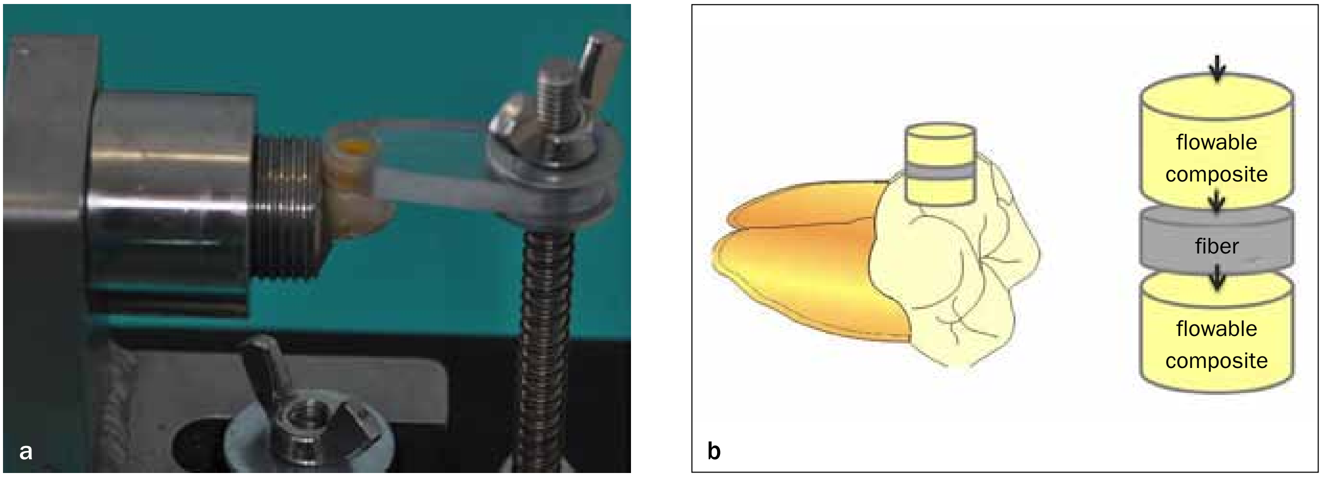


Fig 1 a. Specimen preparation for shear bond strength testing – specimen bonding on the target surface within a rubber mold. b. Schematic drawing of the specimen preparation.

the bed of flowable composite inside the mold. The fibers were then coated with another 1-mm-thick layer of resin composite and light cured for 20 s (Fig 1B).

After storing the teeth for 24 h at 37°C and 100% relative humidity in airtight containers, the shear bond strength test was performed. Shear load was applied in a direction parallel to the bonded interface using a universal testing machine (Triax Digital 50, Controls; Milan, Italy). The load speed was set at 0.5 mm/min and the loading was performed until failure occurred, as manifested by the debonding of the composite cylinder. To express the bond strength in MPa, the maximum failure load recorded in

Fig 2 Bar-shaped specimen placed in a device designed for performing three-point bending test in accordance with ISO standard 4049/2000. The specimen was loaded at its center with a cylindrical-ended striker by the universal testing machine.

Newtons (N) was divided by the area of bonded interface (mm^2). A digital caliper (Orteam; Milan, Italy) accurate to 0.01 mm was used to measure the diameter of the composite cylinders. Failure modes were separately evaluated by two operators using a stereomicroscope (Nikon SMZ645; Tokyo, Japan) at 40X magnification and were classified as: adhesive failure between enamel and composite, cohesive failure within enamel, cohesive failure within composite resin, or mixed failure if adhesive and cohesive fractures occurred simultaneously. As a measure of interexaminer reliability, the Cohen's Kappa coefficient was calculated. Cohen's Kappa coefficient was found to be 0.90, which is considered indicative of satisfactory interexaminer reliability. In the few cases of disagreement in failure mode classification, the two examiners, after re-examination of the specimens and a discussion, came to a joint definition.

Flexural Strength

To assess FS according to ISO Standard 4049/2000, 10 bar-shaped specimens were prepared for each group, using the same fibers as for ESBS testing. The specimens were obtained using vinyl polysiloxane-based molds (Elite HD+, Zhermack; Badia Polesine, Italy) that were 25 mm long, 2.1 mm high, and 2.1 mm wide. A 1-mm-thick increment of resin composite was layered in each mold, a 20-mm-long segment of fiber was placed on top, and curing was performed for 40 s using the same light used in the preparation of specimens for ESBS. Another layer of flowable composite was applied to fill up the mold and the specimen was cured for 40 s. In order to ensure complete polymerization after taking the specimens out of the mold, further light curing was carried out for an additional 40 s. All the specimens were wet-ground with 600- and 1200-grit SiC paper, until the dimensions of 2.0 ± 0.1 mm in height and 2.0 ± 0.1 mm in width were obtained. The FRC bars were then stored in 0.9% saline solution for 24 h.

A three-point bending test was performed using a device designed in accordance with the ISO Standard 4049/2000 (Fig 2). The appliance was made of two HSS/Cobalt rods (diameter 2 mm) mounted parallel with 20 mm between centers (support span 20 mm). Each specimen was loaded at its center with a cylindrical-ended striker (diameter 2 mm). A crosshead speed of 0.75 mm/min was applied by the universal testing machine (Triax Digital 50, Controls) until failure occurred. According to ISO Standard 4049/2000,[23] the flexural strength (σ) was calculated in MPa using the following equation:

$$\sigma = 3Fl/2bh^2$$

where F is the maximum load (N), l is the distance between the supports (mm), b is the specimen width (mm), and h is the specimen height (mm).

SEM Observations

The structure of each tested FRC was examined using a scanning electron microscope (JSM 6060 LV, JEOL; Tokyo, Japan). A segment of each fiber was mounted on a metallic stub and sputtered with gold-palladium (Polaron Range SC7620, Quorum Technology; Newhaven, UK). The SEM images were taken at 30X magnification.

Statistical Analysis

As ESBS data were normally distributed (Kolmogorov-Smirnov test) and group variances were homogeneous (Levene's test), one-way ANOVA was performed, followed by Tukey's HSD test for post-hoc comparisons. The same analysis was applied to flexural strength, having first verified that the data met the requirements of normal distribution and homogeneity of group variances. Tukey's test was used as a post-hoc test. In all the analyses, the level of significance was set at $\alpha = 0.05$ and calculations were done by the SPSS 18.0 software (SPSS; Chicago, IL, USA).

RESULTS

Shear Bond Strength

The results of shear bond strength are reported in Table 2. Statistically significant differences in ESBS were found among the groups ($p < 0.001$). According to the post-hoc test, everStick C&B yielded a significantly higher ESBS than Construct, Connect, RTD Quartz Splint without additional impregnation, and the control group. The distribution of failure modes is reported in Table 3.

Flexural Strength

Flexural strength data are summarized in Table 2. The type of reinforcing fiber significantly influenced the measured FS ($p < 0.001$). RTD Quartz Splint additionally impregnated with Quartz Splint Resin resulted in the highest FS. However, the difference between RTD Quartz Splint with and without additional impregnation was not statistically significant. Therefore, additional

Table 2 Shear bond strength to enamel (ESBS) and flexural strength (FS).

Group	ESBS (MPa)	FS (MPa)
1. RTD Quartz Splint additionally impregnated with Quartz Splint Resin	17.07 (4.52) ^{AB}	472.69 (30.49) ^{A}
2. RTD Quartz Splint without additional impregnation	14.98 (3.92) ^{B}	441.77 (61.43) ^{AB}
3. Ribbond-THM impregnated with OptiBond FL Adhesive	18.59 (5.67) ^{AB}	186.89 (43.89) ^{EF}
4. Ribbond Triaxial impregnated with OptiBond FL Adhesive	16.74 (6.27) ^{AB}	314.41 (148.52) ^{CD}
5. Connect impregnated with Kolor+Plus Color Modifiers	14.38 (4.14) ^{B}	223.80 (77.35) ^{DE}
6. Construct impregnated with Construct resin	16.00 (5.55) ^{B}	287.62 (85.91) ^{CDE}
7. everStick PERIO	16.42 (3.67) ^{AB}	285.35 (39.68) ^{CDE}
8. everStick C&B	23.24 (5.81) ^{A}	370.46 (29.26) ^{BC}
9. (control) without fiber	12.85 (4.76) ^{B}	87.75 (22.87) ^{F}

Numbers are means in MPa (standard deviation). Different letters indicate statistically significant differences (one-way ANOVA, Tukey's post-hoc test, $p < 0.05$).

Table 3 Failure mode distribution, number (percentage) of teeth

Group	Failure mode			
	A	CE	CC	M
1. RTD Quartz Splint additionally impregnated with Quartz Splint Resin	2 (20%)	5 (50%)	-	3 (30%)
2. RTD Quartz Splint without additional impregnation	-	1 (10%)	8 (80%)	1 (10%)
3. Ribbond-THM impregnated with OptiBond FL Adhesive	6 (60%)	-	-	4 (40%)
4. Ribbond Triaxial impregnated with OptiBond FL Adhesive	5 (50%)	-	-	5 (50%)
5. Connect impregnated with Kolor+Plus Color Modifiers	4 (40%)	-	-	6 (60%)
6. Construct impregnated with Construct resin	4 (40%)	-	-	6 (60%)
7. everStick PERIO	4 (40%)	2 (20%)	2 (20%)	2 (20%)
8. everStick C&B	3 (30%)	1 (10%)	1 (10%)	5 (50%)
9. (control) without fiber	3 (30%)	3 (30%)	2 (20%)	2 (20%)

A: adhesive failure; CE: cohesive failure within enamel; CC cohesive failure within composite; M: mixed failure.

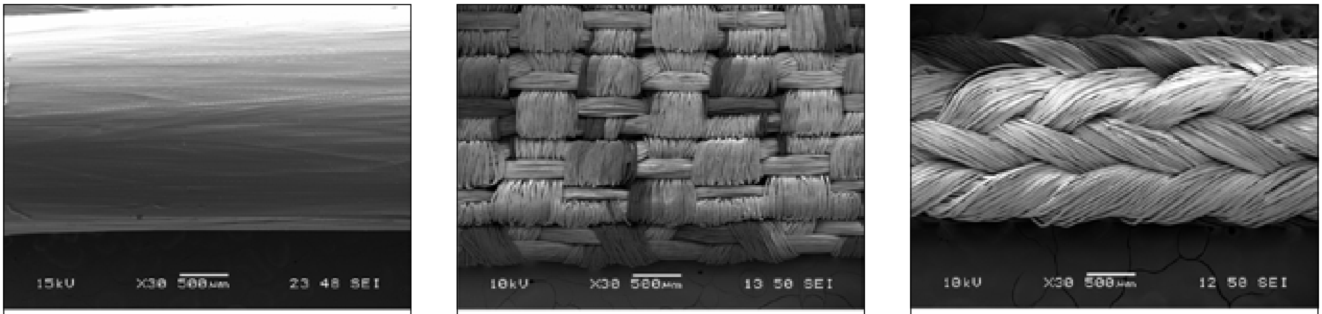
resin impregnation enhanced the FS of RTD Quartz Splint, although not statistically significantly. No statistically significant differences were observed in FS values between the following groups: Ribbond Triaxial, Construct, everStick PERIO, and Connect. The flowable composite without fiber reinforcement (control) measured the lowest FS and the difference was statistically significant.

SEM Observations

Scanning electron micrographs of the investigated fibers at 30X magnification are shown in Fig 3. RTD Quartz Splint, everStick PERIO, and everStick C&B exhibited a unidirectional fiber orientation. Ribbond-THM showed a specific crosslinked, lock-stitch, leno-woven architecture. Ribbond Triaxial featured triaxial braided fibers. Connect and Construct showed a biaxial braided fiber orientation.

DISCUSSION

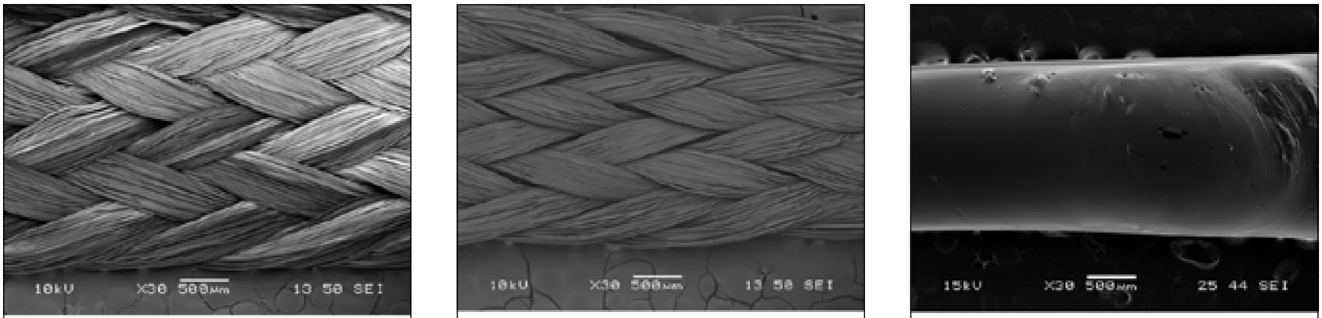
ESBS and FS differed significantly among the groups. Differences were also found in failure mode distribution.



a RTD Quatz Splint®

b Ribbond® – THM

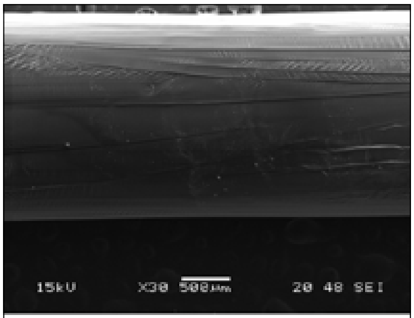
c Ribbond® Triaxial



d Connect®

e Construct®

f everStick® – PERIO



d everStick® C & B

Fig 3 Scanning electron micrographs of fibers examined (30X magnification, bar = 500 µm)

Shear Bond Strength

The statistical analysis demonstrated that for the majority of the investigated reinforcing fibers, no statistically significant differences in ESBS were found compared to the control group, in which no reinforcing fiber was used (Table 2). These results are in accordance with several previous investigations that reported no change in shear bond strength between most of reinforced composites and nonreinforced composite.[28,34,35] In the present study no difference in ESBS was observed among nonreinforced composite and composites reinforced with RTD Quartz Splint (regardless of the additional impregnation), Ribbond-THM, Ribbond Triaxial, Connect, and Construct, regardless of the different fiber types (quartz- or polyethylene fibers), nature of pre-impregnation (resin pre-impregnated or silanated, plasma treated), and fiber orientation (unidirectional or woven). In contrast with our results, one study reported that the ESBS of a composite reinforced with Connect (18.8 ± 1.5 MPa) was significantly higher than that of a nonreinforced composite (15.6 ± 2.4 MPa) and of specimens reinforced with Ribbond (15.8 ± 2.2 MPa).[28] However, in the aforementioned study, the enamel surface of bovine teeth had been flattened with sandpaper and the adhesive system and flowable composite were different from the ones used in the present study. Furthermore, the highest ESBS was recorded for everStick C&B (23.24 ± 5.81 MPa). Similarly, a higher shear bond strength to enamel was reported for composite reinforced with randomly oriented glass fibers (23 MPa), than for nonreinforced composite and bidirectional FRC.[35] EverStick PERIO (16.42 ± 3.67 MPa) yielded weaker adhesion than everStick C&B, although not to a statistically significant extent (Table 2). Both FRCs are made of unidirectionally oriented glass fibers that are silanated and pre-impregnated with PMMA and bis-GMA. It is possible that the slight difference in ESBS between the two materials is due to different fiber diameters and numbers: everStick C&B has a diameter of 1.5 mm and consists of 4000 fibers, while everStick PERIO has a diameter of 1.2 mm and consists of 2000 fibers (manufacturer's information). A significant influence of the amount of fibers (volume fraction) on the mechanical properties of FRCs has been reported in the literature.[1,17] In addition, the mechanical properties of the composite resins were found to have an effect on bond strength.[22]

Adhesive and mixed failures were the most common fracture modes. This finding suggests that the adhesion to enamel was lower than the cohesive strength of the FRCs. It is also noteworthy that when RTD Quartz Splint was not additionally impregnated with Quartz Splint Resin, 80% of the failures were cohesive within the composite (Table 3). On the contrary, when fibers were additionally impregnated with the resin prior to use, no cohesive failures within composite were observed. Therefore, it can be assumed that additional impregnation of RTD Quartz Splint with resin improved the adhesion between the flowable composite and the fiber, and could be considered beneficial in the clinical use.

Flexural Strength

Significant differences between the investigated materials were found also in flexural strength. As the lowest FS was recorded for the nonreinforced composite, it can be deduced that any reinforcing fiber contributed to an increase of the resistance to flexural load (Table 2). This finding is in line with the majority of studies that reported enhanced flexural strength with the inclusion of fiber reinforcement in composite beams.[2,9,11,18,32,37]

RTD Quartz Splint additionally impregnated with Quartz Splint Resin yielded a significantly higher FS than all the other groups, with the exception of RTD Quartz Splint without additional impregnation. From these results, it can be inferred that quartz fibers provided the most effective reinforcement of the composite specimens. FS of RTD Quartz Splint without additional impregnation was also comparable to that of everStick C&B. Both FRCs feature unidirectional fibers, and previous studies have documented a superior reinforcing effect of unidirectional fibers in comparison with woven fibers.[11,37] Nevertheless, the unidirectional everStick PERIO demonstrated relatively low FS in the present investigation. Similar to the considerations about ESBS above, the discrepancy in FS between everStick PERIO and everStick C&B may also be due to the difference in fiber content.[1,17]

With regard to the woven fibers examined in the current study, biaxial and triaxial braided polyethylene fibers (Ribbond Triaxial, Connect, and Costruct) performed similarly in terms of FS. Connect and Construct demonstrated lower FS compared with RTD Quartz Splint and everStick C&B. Moreover, in a study conducted by Ellakwa et al,[11] lower FS values were measured when a composite resin was reinforced with Connect (261.6 ± 29.0 MPa) than with unidirectional glass fibers (347.3 ± 36.8 MPa). This result may be attributed to the lower physical properties of Connect fibers or to less effective bonding between the composite and the fiber.[8] Ribbond-THM exhibited relatively low FS. This finding can be related to the leno-woven fiber architecture of Ribbond-THM, which is a unique feature of this fiber, plausibly yielding a less effective reinforcement in comparison with other fiber patterns. Additionally, the reinforcing fibers examined here differed in terms of diameter, resin matrix composition, and pretreatment. Such differences may reasonably have affected the FS of the reinforced composite.[3,31]

It should finally be pointed out that some flexural properties of FRCs are also influenced by the amount of filler loading and organic matrix composition of the composite.[8] Therefore, the same type of fiber could possibly yield a different flexural strength when used in combination with different composite resins. In order to control for this possible source of variability, in the present study, only one flowable composite was tested in combination with the different fibers.

The results of the present study show a broad range of FS values, from 186.89 ± 43.89 MPa for Ribbond-THM to 472.69 ± 30.49 MPa for RTD Quartz Splint. It should be pointed out that relatively low FS is sometimes desirable in order to allow a minimum of micromovements of splinted teeth after trauma, which contributes to the periodontal repair processes. On the other hand, when FRCs are used as prosthodontic frameworks, high flexural strength is considered beneficial for preventing the fracture of the restoration. Nonetheless, the current literature still lacks information on the clinically acceptable range of flexural strength values. Therefore, it would be of interest to assess in vivo the performance of different FRC materials to verify the effect of their mechanical properties on the clinical outcome.

It should finally be pointed out that the three-point bending test used in this experiment, although well established, has the limitation that the stress is applied in only one direction, therefore simulating just one of the many clinically possible loading conditions.[24,37] A further limitation of the present investigation is that FS and ESBS were assessed only after a 24-h storage period; the literature contains reports of the flexural strength of FRCs changing with increasing storage time.[3,7,11] Similarly, ESBS of FRCs was shown to change with aging. Opposite trends toward reduction and increase in ESBS have both been reported for thermocycled specimens in two previous studies.[34,35] Since no conclusive evidence has been provided on the adhesive and mechanical properties of aged FRCs, it would be interesting to complement the data collected in this study with ESBS and FS measurements on specimens that have been subjected to thermocycling as a method to simulate clinical service.

CONCLUSIONS

Based on the results of the present study the following conclusions can be drawn: 1. Fiber reinforcement of flowable composite does not affect its shear bond strength to unground enamel. 2. The flexural strength of FRC is significantly influenced by fiber composition and pattern.

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Clinical relevance: Based on this study's findings, the use of reinforcing fibers in combination with flowable composite doe not influece adhesion to enamel, but it is beneficial for enhanced resistance to flexural loads. Moreover, the flexural strength of fiber-reinforced composites is influenced by fiber composition and pattern.