

The Effect of C-factor and Flowable Resin or Fiber Use at the Interface on Microtensile Bond Strength to Dentin

Sema Belli^a/Nazmiye Dönmez^b/Gürcan Eskitaşcıoğlu^c

Purpose: As polymerization shrinkage is compensated by flow of the composite, several attempts have been performed for relief of the contraction stresses. The aim of this *in vitro* study was to evaluate the effect of flowable composite or fiber use under composite restorations on microtensile bond strength of composite to dentin in Class I cavities or flat dentin surfaces.

Materials and Methods: Twenty-four sound extracted human first or second mandibular molars were randomly assigned to two groups (Class I cavities with a high c-factor or flattened dentin surfaces with a low c-factor). The dentin surfaces were treated with adhesive resin and restored with resin composite using four different techniques (bulk; with flowable composite; with a glass fiber (everStick NET); with a polyethylene fiber [Ribbond]). After 24 h storage at 37°C in water, the specimens were thermocycled 600 times between 5 and 55°C. Microtensile test specimens with a 0.9 x 0.9 (\pm 0.1) mm² cross-sectional area were produced, and bond strength tests were carried out at a crosshead speed of 1 mm/min. Mean bond strengths were analyzed using two-way ANOVA and Bonferroni's test at a 95% significance level.

Results: Flowable composite decreased dentin bond strength in cavities with a high c-factor ($p < 0.05$). The group restored with everStick NET showed stable bond strengths regardless of the effect of c-factor. Ribbond THM used under composite restorations increased dentin bond strength in cavities with a high c-factor ($p < 0.05$).

Conclusion: Flowable composite decreased dentin bond strength in cavities with a high c-factor; however, using a glass fiber in combination with flowable resin, stable bond strengths can be achieved in cavities with a high c-factor. Polyethylene fiber in combination with flowable resin increases the microtensile bond strength to the dentin floor in cavities with a high c-factor.

Keywords: c-factor, glass fiber, polyethylene fiber, flowable composites, microtensile bond strengths.

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Contraction of composite materials during polymerization can cause gap formation between the restoration and the tooth structure; therefore it is one of the factors effecting the success of a direct composite restoration. As the polymerization shrinkage is compensated by flow of the composite,⁷ a rigid bond between composite resin and tooth

structures generates contraction stresses at the bonding interfaces.¹⁰ These stresses can be reduced by several methods. Performance of the dentin bonding agents is assumed to resist the contraction forces by forming a continuous hybrid layer between the restoration and tooth structure.³¹ One of the suggested methods for reducing debonding during polymerization shrinkage is the application of a low viscosity, low *e*-modulus resin between the bonding agent and restorative resin to act as an "elastic buffer" or "stress breaker" that can relieve contraction stresses and improve marginal integrity.^{15,30} However, flowable composite did not produce gap-free resin margins in Black Class II slot cavities,³ and the use of flowable composite did not guarantee gap-free restorations or improved bond strength of resin to dentin in bulk-filled restorations.²⁰

The development of fiber-reinforced composite (FRC) technology has resulted in extensive use of composite resin materials. FRC has been used in the laboratory for fabrication of single crowns, full- and partial-coverage fixed partial

^a Professor and Chair, Department of Endodontics, Selçuk University, Faculty of Dentistry, Konya, Turkey.

^b Specialist, Oral Health Hospital, Selçuk, Konya, Turkey.

^c Professor, Department of Prosthodontics, Gazi University, Faculty of Dentistry, Ankara, Turkey.

Reprint requests: Dr. Sema Belli, Selçuk University, Faculty of Dentistry, Department of Endodontics, 42079, Campus, Konya, Türkiye. Tel: +90-332-223-1234, Fax: +90-332-241-0062. e-mail: sbelli@selcuk.edu.tr.

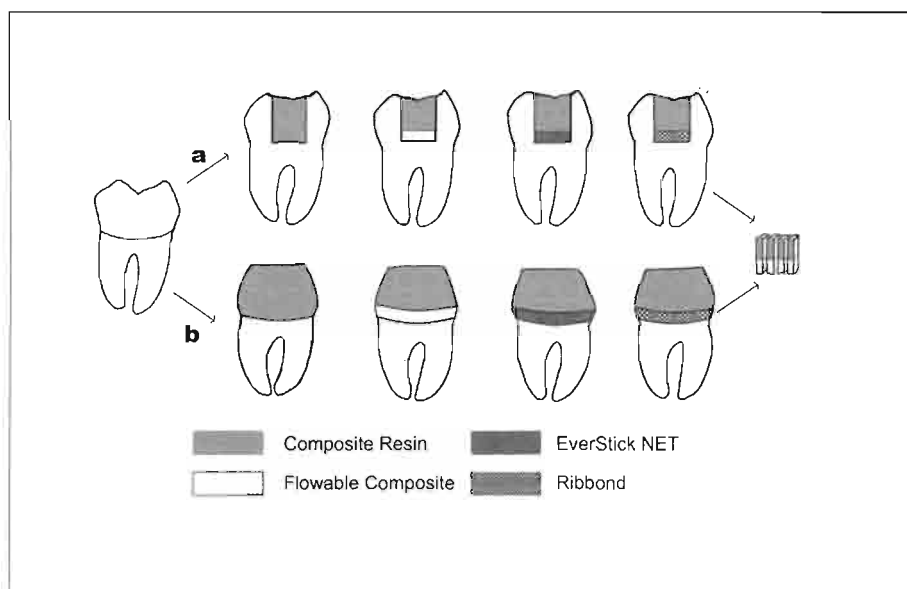


Fig 1 Schematic overview of specimen preparation with high c-factor (upper half) and low c-factor (lower half).

dentures,^{8,27} fabrication of periodontal splints, and chair-side fixed partial dentures.^{4,17,18} FRC has been shown to possess adequate flexure modulus and flexural strength to function successfully in the mouth.^{12,29} A finite-element stress analysis study reported that a FRC post-and-core system provided better restoration results by protecting the remaining tooth tissue with its elastic modulus close to that of dentin.⁹

In a previous study by Belli et al,¹ polyethylene fiber insertion under composite restorations in endodontically restored molars with MOD prepared cavities was found to increase fracture strength. With the idea that the presence of the glass or polyethylene network would create a change in stress dynamics at the enamel/composite/adhesive interface, Meiers et al¹⁹ tested shear bond strength of composite to flat bovine enamel surfaces, and concluded that the higher modulus of elasticity and lower flexural modulus of the polyethylene fiber have a modifying effect on how the interfacial stresses are developed along the etched enamel/resin boundary. There are many studies about the use of FRC in the literature; however, the effect of fiber use as a stress breaker within an extensive composite restoration in cavities with a high c-factor needs to be evaluated.

The null hypothesis of the present study was that adding a layer of FRC under the composite restoration using a polyethylene or glass fiber and/or flowable composite would increase the microtensile bond strength to dentin in cavities with a high c-factor.

MATERIALS AND METHODS

Twenty-four intact, noncarious, nonrestored human mandibular molars extracted for periodontal reasons were selected that had been stored in water at 4°C for less than two months. They were subsequently debrided and exam-

ined to ensure that they were free of defects. The teeth were randomly assigned into two main groups: a high c-factor group with Class I cavities, and a low c-factor group with flattened dentin surfaces.

For high c-factor groups, standardized Class I occlusal preparations (length: 5 mm; width 4 mm; depth 3 mm; ± 0.01 mm) were made in each tooth using BR-41 and SF-21 diamond burs (Mani, Tochigi, Japan) under profuse water cooling. Inner angles of the cavities were prepared rectangularly. The cavity bases were then polished with a piece of 600-grit sandpaper. For low c-factor groups, the occlusal enamel was removed with a low-speed diamond saw (Iso-met, Buehler, Lake Bluff, IL, USA) under water cooling, and the exposed dentin surfaces were then polished with 600-grit sandpaper.

Each group was then randomly divided into 4 subgroups according to the restoration techniques. Details of the materials investigated are listed in Table 1.

Restoration of the high c-factor group (Class I cavities) was as follows (Fig 1a):

1. The adhesive surfaces were treated with a self-etching adhesive system (Clearfil SE Bond, Kuraray, Osaka, Japan) according to the manufacturer's instructions, restored with a hybrid resin composite (Clearfil AP-X, Kuraray) in bulk, and light cured for 40 s with a halogen light curing unit (Lunar, Benlio lu Dental, Istanbul, Turkey) at an intensity of 620 mW/cm².
2. After applying the adhesive system (Clearfil SE Bond), a flowable composite resin (Protect Liner F, Kuraray) was applied as a liner over the pulpal floors using a syringe tip. When an even layer was achieved at the bottom of the floor, the excess material was thinned with a clean brush, keeping the thickness to a maximum of 0.5 mm. Light curing was performed for 20 s. The cavities were then restored with resin composite in bulk and light cured for 40 s.

Table 1 Description of products

Products	Type	Manufacturer	Composition	Batch
Clearfil SE Bond 00433 A	Self-etching adhesive system	Kuraray, Tokyo, Japan	Primer: MDP, HEMA; hydrophilic dimethacrylate, N,N-diethanol p-toluidine, water. Adhesive resin: MDP, bis-GMA, HEMA, hydrophobic dimethacrylate, CQ, N,N-diethanol p-toluidine, silanated colloidal silica.	Adhesive 00593 A Primer
Clearfil AP-X	Hybrid resin composite	Kuraray	silanated barium glass, silanated silica, silanated colloidal silica, bisphenol-a diglycidylmethacrylate, triethylene glycol dimethacrylate, d,l-camphorquinone	41124
Protect Liner	Flowable composite	Kuraray	silanated silica, silanated organic filler, bisphenol-a diglycidylmethacrylate, triethyleneglycol dimethacrylate, mma-methacryloyl fluoride copolymer, d,l-camphorquinone	0025
everStick NET	Glass fiber	Stick Tech, Turku, Finland	E-glass (electric glass, silanated); bis-GMA and PMMA	20400122 EN-061
Ribbon THM	Polyethylene fiber Seattle WA, USA	Ribbon, polyethylene	ultra-high molecular weight	9532

- Alternatively, after treatment with Clearfil SE Bond, flowable composite was applied on the cavity floor, and a 5-mm-long x 4-mm-wide (± 0.01 mm) glass fiber (everStick NET, Stick Tech, Turku, Finland) preimpregnated with adhesive resin was cut and placed into the bed of uncured flowable resin. This combination was then cured for 20 s. As in step 2, the cavities were bulk filled with resin composite and cured for 40 s.
- Alternatively, after treatment with Clearfil SE Bond, flowable composite was lined on the cavity floor, and a 5-mm-long x 4-mm-wide (± 0.01 mm) ultra-high molecular weight polyethylene (UHMWP) fiber (Ribbon THM [thinner higher modulus], Ribbon, Seattle, WA, USA) was first impregnated with adhesive resin (Clearfil SE Bond), and excess was removed with a hand instrument. Impregnated fibers were then placed into the bed of uncured flowable composite resin. This combination was cured for 20 s. As in step 2, the cavities were bulk filled with resin composite and cured for 40 s.

Restoration of the low c-factor group (teeth with flattened dentin surfaces) was as follows (Fig 1b):

- After treatment with the self-etching adhesive system as in the high c-factor group, the crowns of the teeth were reconstructed with 3-mm-thick (± 0.01 mm) resin composite in bulk and cured for 40 s.
- Alternatively, after treatment with the self-etching adhesive system, dentin surfaces were lined with flowable resin composite (< 0.5 mm thick) and cured for 20 s before bulk composite reconstruction.

- Alternatively, a 5-mm-long x 4-mm-wide (± 0.01 mm) section of everStick NET was placed into the bed of flowable resin before bulk composite reconstruction as described in Group 3 above.
- A 6.5-mm-long x 4-mm-wide (± 0.01 mm) piece of Ribbon THM was placed into the bed of flowable resin before bulk composite reconstruction as described in Group 4.

After 24 h storage at 37°C in water, the specimens were thermocycled 600 times between 5 and 55°C. The peripheral areas of the reconstructed or filled teeth were removed. The remaining tooth was then sectioned with a low-speed saw (Isomet, Buehler) under water cooling, and multiple beams with a 0.9 x 0.9 (± 0.1) mm² cross-sectional area were formed using the nontrimming version of the microtensile bond strength test (μ TBS).²³ Beams were examined under a stereomicroscope to exclude those obtained from cavity or composite reconstruction corners. From the resulting central sticks of each group, 20 sticks were randomly selected. These sticks had to have a remaining dentin thickness over the pulp of 2 ± 0.5 mm. No premature failures were observed during sectioning.

The sticks were mounted in a jaw device with a special cyanoacrylate glue (Zapit, Dental Ventures of America, Corona, CA, USA) and μ TBS was performed using a universal testing machine (Testometric 500, Lancashire, UK) at a cross-head speed of 1 mm/min until failure. The cross-sectional area at the site of failure was measured to the nearest 0.01 mm with a digital caliper (Model CD-6BS; Mitutoyo, Tokyo, Japan), from which μ TBS was calculated and expressed in MPa.

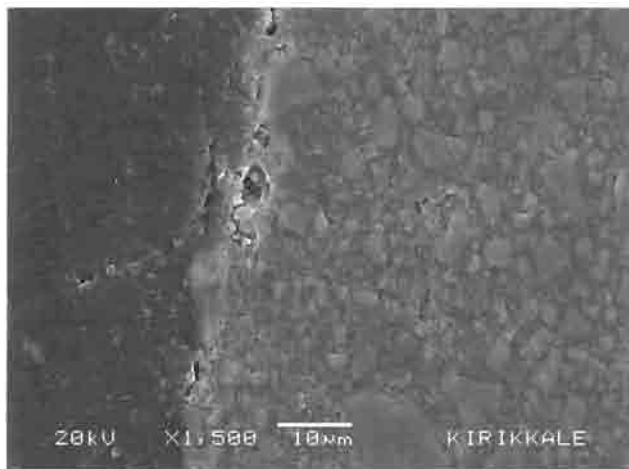


Fig 2 Adhesive interface of a specimen restored with flowable resin and hybrid composite before failure. Gap formation is observed between the flowable resin and hybrid composite.

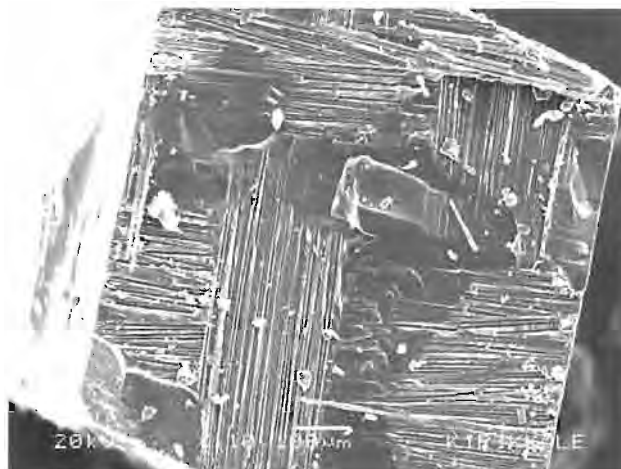


Fig 3 Composite side of a debonded specimen in which mixed failure occurred within the fiber and flowable resin. Specimen was restored with everStick NET.

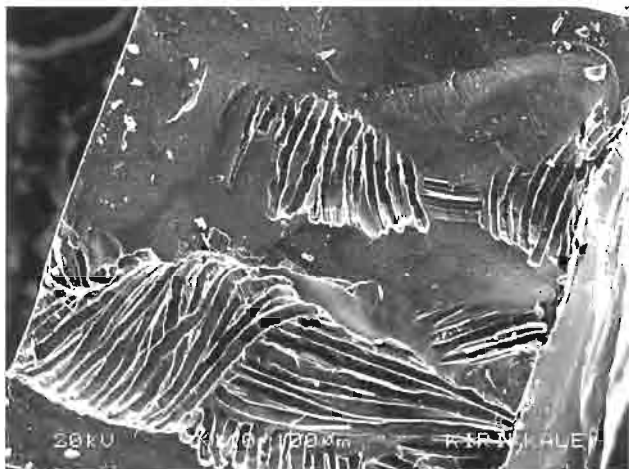


Fig 4 Dentin side of a debonded specimen in which mixed failure occurred within the fiber and flowable resin. Specimen was restored with Ribbon.



Fig 5 Composite side of a debonded specimen in the high c-factor group in which mixed failure occurred. Specimen was restored with everStick NET. The structure of the fiber material was destroyed during the specimen preparation.

Statistical Analysis

The data was analyzed using two-way ANOVA and Bonferoni's test at a 95% significance level. Failure modes were evaluated at 30X magnification with the stereoscopic microscope and classified as adhesive, cohesive within the resin composite, dentin, fiber, flowable composite, or mixed failure.

RESULTS

An overview of the results is shown in Table 2. Mean bond strength to cavity floor (high c-factor) was 6.80 MPa for the flowable composite-lined group; this value was significantly lower than the other high c-factor groups ($p < 0.05$). Flowable

resin lining decreased μ TBS to dentin on flat dentin surfaces when compared to the bulk-filled group ($p < 0.05$).

EverStick NET placement did not affect μ TBS to cavity floors, but it decreased bond strength to flat dentin surfaces when compared to the bulk-filled group ($p < 0.05$).

Insertion of Ribbon THM in combination with flowable resin at the interface had a positive effect on μ TBS to dentin in cavities with a high c-factor when compared to the other groups ($p < 0.05$), although it had no effect on μ TBS to flat dentin surfaces when compared to the bulk-filled group ($p > 0.05$).

The c-factor had negative effect on bond strength to dentin in bulk-filled or flowable composite-lined groups ($p < 0.05$). The everStick NET group showed similar μ TBS on cavity floors and on flat dentin surfaces ($p > 0.05$).

Table 2 Results of microtensile bond strength to dentin on cavity floors (high c-factor) and on flat surfaces (low c-factor)

Restoration technique	Bulk filled with CR	Flowable composite resin lined before CR	everStick NET in combination with flowable resin lined before CR	Ribbon THM in combination with flowable resin lined before CR
High c-factor (n=12)	10.67 ± 1.95 ^{a *}	6.80 ± 1.70 ^{b *}	11.41 ± 1.70 ^{a *}	13.80 ± 2.06 ^{c *}
Low c-factor (n=12)	18.22 ± 4.58 ^{a †}	13.34 ± 4.42 ^{ab †}	11.57 ± 2.01 ^{b *}	15.05 ± 1.70 ^{a *}

Values are means ± standard deviation. Subgroups with the same letter on the same line and same superscripts in the same column indicate no statistical difference ($p < 0.05$) (CR= composite resin).

Table 3 Fractures modes

	High c-factor	Low c-factor
Bulk restored	60 % adhesive 35 % mixed 5 % cohesive in composite	92 % adhesive 8 % mixed
Flowable composite lined	65 % adhesive (flowable composite/hybrid composite interface) 35 % adhesive (location: adhesive/dentin interface) hybrid	60 % adhesive (flowable composite/composite interface) 25 % mixed 10 % adhesive (location: adhesive/dentin interface)
everStick NET	65 % mixed 20 % adhesive (adhesive/dentin interface) 15 % cohesive (within FRC)	45 % adhesive (adhesive/dentin interface) 45 % cohesive (within FRC) 10 % mixed
Ribbon THM	65 % mixed 30 % cohesive (within FRC) 5 % adhesive	55 % mixed 40 % cohesive (within FRC) 5 % adhesive (adhesive/dentin interface)

Fracture modes are reported in Table 3. The results indicated that flowable composite-lined groups showed mostly adhesive failure between the flowable composite and hybrid composite resin, or failure within the flowable resin regardless the effect of c-factor. SEM observations indicated gap formation between the flowable composite and hybrid composite resin (Fig 2).

In high c-factor groups, both fiber systems showed mostly mixed failure (65%) (Figs 3 and 4), but in low c-factor groups, this percentage was reduced (10% for everStick NET and 55% for Ribbon).

When failure surfaces of fiber groups were evaluated, dislocation of the fibers was observed in both fiber systems (Figs 4 and 5).

DISCUSSION

A high c-factor is a risk factor for bonding because polymerization stresses may be amplified. The thicker layers of an adhesive providing a low modulus of elasticity are capable of reducing the interfacially acting polymerization stress of resin composites.⁵ The hybrid layer has a stress absorbing property, creating a low elastic modulus area between the restoration and dentin.² Flowable resin composites have been previously used to provide stress relief at the adhesive interface;⁶ however, Miguez et al²⁰ reported that use of a flowable composite did not guarantee gap-free restorations or improved bond strength of resin to dentin. They also reported gap formation between bulk hybrid composite and flowable resin in Class I cavities. It has been speculated that

the interaction between the flowable resin and the adhesive was stronger than that between the flowable and filled composite resin. Confirming their findings, in the present study, SEM observations demonstrated gap formation between the flowable resin and hybrid composite resin (Fig 2). The μ TBS values were also low in flowable composite lined groups (Table 2). These results demonstrate that there is a weak interaction between the flowable resin and hybrid composite resin, and use of a flowable resin under composite restorations is not an effective method to reduce contraction stresses or to increase μ TBS to dentin in cavities with a high c-factor.

Stress relief might be more important when placing the resin composite in bulk rather than in increments. In a study by Nikolaenka et al,²¹ it was reported that flowable composite used as a lining was not beneficial for bond strengths in the groups restored with a horizontal layering technique, but that bond strength was increased when a vertical layering technique was used. Bulk application may not allow sufficient light polymerization of the solely light curing materials. Therefore, layering concepts have been described as mandatory. Nevertheless, the present study employed the bulk technique to eliminate the effect of restoration technique on bond strength. Incomplete curing of the hybrid composite due to the bulk restoration technique might also have an effect on bond strength. The results might have been different if incremental technique had been used.

Meiers et al¹⁹ tested shear bond strength of fiber-reinforced composite resin (FRC) to flat bovine enamel surfaces and concluded that 3 of 4 fiber FRC materials (except Connect [Kerr; Orange, CA, USA]) did not create a significant improvement of composite to enamel shear bond strengths when compared to the non-FRC containing composite. They claimed that the polyethylene fiber Connect has a stress modifying effect along the etched enamel/resin boundary. Confirming their findings, the present study found that neither fiber material had a positive effect on bond strength to flat dentin surfaces. On the other hand, the null hypothesis that adding a FRC under composite restorations has a stress modifying effect along the interface could only be accepted for the Ribbond THM group, because this group showed higher μ TBS to dentin in cavities with a high c-factor when compared to the bulk filled group. The everStick NET group showed similar bond strength values to the bulk-filled group ($p > 0.05$).

In the present study, the effect of FRC at the interface was evaluated. Ribbond THM has a thickness of 0.18 mm and everStick NET a thickness of 0.6 mm. Both fiber materials were embedded in the layer of flowable resin with a thickness less than 0.5 mm, and a possible effect of the difference between the thicknesses of the fibers on μ TBS was disregarded.

The method utilized for bond strength testing was the microtensile bond test, which allows investigation of interfacial bond strengths on areas less than 1 mm².²² In the present study, the nontrimming technique introduced by Shono et al²³ was used. Because bonding to flat dentin surfaces exhibits differences at variable distances from the pulp, only the central areas of the exposed dentin were used for testing, and the distance from the pulp was

measured as 2 ± 0.5 mm for each sample. However, during the preparation of samples for the μ TBS test, the diamond saw had difficulty cutting the fibers. When the bonding surfaces of the specimens were evaluated with SEM after failure, damage to the fibers of both systems was observed: they had been moved from their original and intended positions (Figs 4 and 5). One of the limitations of this study was that the μ TBS test was done after producing beams and after damaging the fibers. Therefore, it can be speculated that by using a test method which does not destroy the fiber structure, higher bond strength values could be achieved. In fact, Tezvergil et al²⁶ obtained higher bond strength values to dentin with everStick NET using the shear bond strength test (15.0 MPa) compared to the results of this study (11.57 MPa).

Tezvergil et al²⁵ compared in vitro bond strength of a particulate filler composite and two brands of fiber-reinforced composite with or without the addition of flowable resin composite, reporting that bond strength of FRC did not differ from that of particulate filler composite, and that the addition of flowable composite did not improve bond strength values. Meiers et al¹⁹ found no differences in the shear bond strength of 3 of 4 FRCs compared to composite without FRC, with the exception of Connect. In the present study, all the materials used as "stress breakers" (except Ribbond) significantly decreased the μ TBS to flat dentin surfaces when compared to the bulk filled group ($p < 0.05$). Variations of the bond strength values with FRC can be explained by the differences in thermal coefficients and their influence on stress formation at the interface during thermocycling.²⁴

Although they had significantly different bond strength values, everStick NET and Ribbond THM groups exhibited the same type of failure patterns (40% to 45% cohesive failure) within the fiber. Fennis et al¹¹ reported that glass FRCs have a beneficial effect on the failure mode, and that woven continuous glass FRC provides more consistent results than unidirectional continuous glass FRC. Mechanical properties of fiber composites depend on the direction of the fibers in the polymer matrix. Unidirectional fibers are anisotropic, in contrast to woven fibers, which reinforce the polymer in two directions.²⁸ In the present study, both fiber materials had a woven structure. Ribbond THM showed a statistically significant effect on μ TBS in cavities with a high c-factor. Ribbond has a 3-dimensional structure thanks to "leno weave". Furthermore, it is designed with a lock-stitch feature. This provides mechanical interlocking of the resin and composite resin on different planes. The tensile modulus of elasticity of polyethylene fiber is higher, but the flexural modulus and flexural strength are lower than for unidirectional glass fibers.¹² The higher modulus of elasticity and the lower flexural modulus of the polyethylene fiber seem to have a modifying effect on the interfacial stresses developed along the dentin/resin boundary, as proposed by Meiers et al.¹⁹

Although the low stiffness of flowable composites may compensate the polymerization contraction of the higher modulus restorative composites,¹⁴ they also shrink more because of their reduced filler content.¹⁶ In the present study, when flowable resin was used without a fiber reinforcement, μ TBS to dentin decreased in cavities with a high c-factor. On

the other hand, when a fiber was inserted into the bed of flowable resin, μ TBS to cavity dentin surfaces was increased compared to the flowable resin lined group. There were excesses of unfilled resin between the fibers in the Ribbond group. The polymerization shrinkage of everStick NET was expected to be lower because of existing fillers of PMMA. However, everStick NET showed stable bond strength, and Ribbond THM showed an increased μ TBS to dentin compared to the bulk-filled group in cavities with a high c-factor. Karbhari and Rudo¹³ reported that Ribbond's dense concentration of fixed nodal intersections inhibits and isolates the microcracking that commonly occurs within the resin during the process of polymerization.

From the perspective of clinical dentistry, these results show that when restoring cavities with a high c-factor, using a polyethylene fiber in combination with flowable resin under composite restorations is an effective method for reducing the negative effects of polymerization shrinkage stress.

CONCLUSIONS

The results of this study show that: (1) μ TBS to dentin was lower in cavities with a high c-factor than on the flat dentin surfaces. (2) Flowable resin lining decreased μ TBS to dentin surfaces regardless of the effect of c-factor. (3) Glass fiber in combination with flowable resin provided stable μ TBS values in cavities with a high c-factor. (4) Using a polyethylene woven fiber in combination with flowable resin under a composite restoration, higher microtensile bond strengths were achieved in cavities with a high c-factor.

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Clinical relevance: From the perspective of clinical dentistry, these results show that when restoring cavities with a high c-factor, using a polyethylene fiber in combination with flowable resin under composite restorations is an effective method to reduce negative effects of polymerization shrinkage stresses.