

Use of Flowable Composites for Orthodontic Bracket Bonding

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ABSTRACT

Objective: To test the bonding characteristics of four flowable composites for orthodontic bracket bonding.

Materials and Methods: Metal brackets were bonded to acid-etched human enamel using four flowable composites (Grandio Flow, GF; UniFil Flow, UF; UniFil LoFlo Plus, UL; and DenFil Flow, DF), an orthodontic bonding system (Transbond XT, TX), and a restorative composite (Filtek Z250, FZ). After 24 hours of storage in water at 37°C, a shear bond strength (SBS) test was performed. After debonding, the adhesive remnant index (ARI) was assessed. In addition, the flow and flexural strength of the materials were examined.

Results: The SBS for the flowable composites ranged between 7.2 and 8.3 MPa, and TX showed a significantly higher value (mean 10.9 MPa). The flowable composites also demonstrated a significantly superior flowability, yet inferior flexural strength (except for DF) than TX and FZ. Two flowable composites (GF and UL) produced significantly higher ARI scores than TX and FZ, which represented a larger resin remnant on the enamel surfaces after debonding.

Conclusion: When considering the SBS and ARI scores obtained in this study, flowable composites with no intermediate bonding resin could be conveniently applied for orthodontic bracket bonding.

KEY WORDS: Flowable composite; Shear bond strength

INTRODUCTION

When bonding an orthodontic bracket, the bond strength should be sufficient to withstand the forces of mastication and stresses exerted by the archwires. Thus, the acid etched/composite technique has been widely adopted in contemporary orthodontic practice. However, this system still has a number of shortcomings, including the loss of enamel after acid etching,¹ potential enamel fractures during the debonding pro-

cedure,² and enamel damage caused by post-debonding cleanup procedures.²

Retief³ demonstrated enamel fractures on in vitro specimens with bond strengths even as low as 9.7 MPa. Plus, because the bond strength should allow bracket debonding without damaging the enamel surface, high bond strength of composite materials to enamel may be unfavorable to the substrate from the point of view of enamel conservation. Various studies have already suggested that the appropriate bond strength for orthodontic brackets in a clinical situation ranges from 2.8 MPa to 10 MPa.⁴⁻⁸

Recently, flowable composites have been applied for orthodontic use by many clinicians. Unlike orthodontic bonding systems such as Transbond XT (3M Unitek, Monrovia, Calif),⁸⁻¹⁰ flowable composites can be applied to acid-etched enamel without the use of intermediate bonding resins because of their low filler loading and improved flowability. By reducing the number of steps during bonding, clinicians can save time and reduce potential errors related to contamination during the bonding procedure. Thus, if flowable composites can guarantee clinically acceptable bond strength to acid-etched enamel, they would clearly be advantageous for orthodontic bracket bonding.

Along with the clinical use of flowable composites,

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there have already been several studies about their use for orthodontic bracket bonding. For example, D'Attilio et al¹¹ and Tecco et al¹² compared a flowable composite product (Denfil Flow, Vericom, Anyang, Korea) with an orthodontic bonding system (Transbond XT) and reported a clinically acceptable bond strength for both materials. However, there are still relatively few studies available on the bonding characteristics of flowable composites and the effect of these materials on the enamel surfaces during debonding.

Accordingly, the present study investigated the bonding characteristics of four flowable composites in orthodontic bracket bonding using a shear bond strength (SBS) test and adhesive remnant index (ARI) score assessment; those results were then compared with those for an orthodontic bonding system and a restorative composite. To evaluate the physico-mechanical properties of the materials, their flow and flexural strength were also measured.

MATERIALS AND METHODS

Sixty human premolars, extracted for orthodontic treatment, were collected after receiving the patients' informed consent. The teeth were stored in a 0.1% thymol solution at 4°C and were used within 6 months after extraction. The teeth were randomly divided into six groups. Each tooth was mounted in a self-cure acrylic block, and the buccal crown surface was rinsed and dried after polishing for 15 seconds with fluoride-free pumice. The enamel surface was etched using a 37% phosphoric acid gel (Etch-37, Bisco, Schaumburg, Ill) for 30 seconds, rinsed for 20 seconds, and dried with air for 20 seconds. Premolar stainless steel brackets (Gemini series, 3M-Unitek) were then bonded to the acid-etched enamel using flowable composites (GF, Grandio Flow, Voco, Cuxhaven, Germany; UF, UniFil Flow, GC, Tokyo, Japan; UL, UniFil LoFlo Plus, GC; and DF, DenFil Flow, Vericom), an orthodontic bonding system (TX, Transbond XT, 3M Unitek), and a restorative composite (FZ, Filtek Z250, 3M ESPE, St Paul, Minn). The average surface of the orthodontic bracket base was 9.1 mm². The excess material was removed from around the bracket with a scalar, and curing was performed from the mesial and distal aspects for 10 seconds each (total time = 20 seconds) using a curing light (Skylight, Dmetec Co, Ltd, Bucheon, Korea) with a light intensity of 1000 mW/cm² measured with a built-in radiometer. For TX, an intermediate bonding resin was applied to the acid-etched enamel in a thin film before applying the adhesive paste.

The bonded specimens were stored in water for 24 hours at 37°C and an SBS test was performed. The specimens were secured in a jig attached to the base

plate of a universal testing machine (3343, Instron, Canton, Mass). A chisel-edge plunger was mounted in the movable crosshead of the testing machine and positioned so that the leading edge was aimed at the enamel-composite interface before being brought into contact. A crosshead speed of 1.0 mm/min was used.

After debonding, each specimen was examined under a stereoscopic zoom microscope (SMZ800, Nikon Corporation, Tokyo, Japan) to identify the location of the bond failure. The residual composite remaining on each tooth was assessed based on an ARI score,^{12,13} where each specimen was scored according to the amount of material remaining on the enamel surface as follows: 0 = no adhesive remaining, 1 = less than 50% of the adhesive remaining, 2 = more than 50% of the adhesive remaining, and 3 = all adhesive remaining with a distinct impression of the bracket base.

Flow measurements for each material were carried out using a method similar to that of Bayne et al.¹⁴ A disposable 1-mL syringe without a needle tip was filled with the test material, and then a standard volume (0.5 mL) was extruded onto a glass plate and immediately covered by three stacked glass slides (weighing a total of 18 g). After 30 seconds, the samples were transferred to a curing unit and were cured for 60 seconds. The diameter of the resulting nearly circular disk was measured twice (along perpendicular lines). For each material, the average diameter of three disks was used as the comparative flow result.

For a flexural strength test, five sticks (25 mm × 2 mm × 2 mm) were made for each group using a stainless steel mold. Each material was covered with a transparent polyester film and slide glass and then light cured from the center of the specimen toward the edge of the mold. Specimens were separated from the mold after 15 minutes, and then stored in distilled water at 37°C. After 24 hours of storage, a three-point bending test was performed using a universal testing machine (4200, Instron, Canton, Mass) with a crosshead speed of 1 mm/min. The flexural strength σ was calculated in MPa using

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

where F is the maximum strength in N, l is the distance between the rests, and b and h are the width and height of the specimen, respectively.

When the data were normally distributed and exhibited equal variances, the means of the different groups were compared using a one-way analysis of variance (ANOVA) with Tukey's post hoc test at a significance level of .05. Otherwise, nonparametric methods (Kruskal-Wallis and Mann-Whitney tests) were adopted ($\alpha = .05$). The significance levels were adjusted using the Benjamini and Hochberg false discovery rate for a multiple testing correction. All the statistical analyses

Table 1. Means and standard deviations (SDs) of mean shear bond strength, disc diameter, and flexural strength for each material

	Shear Bond Strength in MPa (N = 10)*	Disc Diameter in mm (N = 3)**	Flexural Strength in MPa (N = 5)*
	Mean (SD)	Mean (SD)	Mean (SD)
GF (Grandio Flow)	7.2 (0.9) ^B	30.2 (1.0) ^B	85.0 (8.9) ^B
UF (UniFil Flow)	8.3 (1.0) ^B	31.1 (1.3) ^A	89.6 (11.0) ^B
UL (UniFil LoFlo)	7.3 (1.2) ^B	26.4 (0.8) ^C	81.2 (12.6) ^B
DF (DenFil Flow)	7.6 (1.4) ^B	30.6 (1.0) ^{AB}	98.2 (8.8) ^{AB}
TX (Transbond XT)	10.9 (1.7) ^A	18.4 (0.9) ^{D,a}	113.0 (14.3) ^{A,a}
FZ (Filtek Z250)	6.8 (1.2) ^B	15.2 (0.6) ^E	115.2 (13.4) ^A

^a These values were obtained when using an adhesive paste with the system.

* The same superscripts on a line are not significantly different according to Tukey's multiple comparison test at $\alpha = .05$.

** The same superscripts on a line are not significantly different according to Kruskal-Wallis and Mann-Whitney tests at $\alpha = .05$.

were performed using SPSS 12.0 for Windows (SPSS, Chicago, Ill).

RESULTS

The mean SBS values, disc diameters indicating the flowability, and flexural strengths for the six groups are presented in Table 1.

Bond strength data from the SBS test were normally distributed (Kolmogorov-Smirnov test) and exhibited equal variances (Levene test). Thus, the data were analyzed using a one-way ANOVA with Tukey's post hoc test, and post hoc comparisons revealed that TX achieved the highest bond strength (10.9 ± 1.7 MPa, $P < .001$), while the bond strengths for four flowable composites ranged between 7.2 ± 0.9 and 8.3 ± 1.0 MPa, with no significant differences in the bond strength among the groups. The SBS for FZ (6.8 ± 1.2 MPa) was also comparable to those for the flowable composite groups.

The flow results were analyzed using nonparametric methods with a multiple testing correction. The flowable composites produced a significantly larger disc diameter than TX and FZ, indicating their superior flowability, UL exhibited an inferior flowability compared with the other flowable composites, and the restorative composite FZ exhibited a more limited flowability than TX ($P = .115$).

The highest flexural strengths were exhibited by FZ and TX (115.2 ± 13.4 and 113.0 ± 14.3 MPa, respectively) with no statistical difference. Plus, a comparable flexural strength to that of the FZ and TX groups was exhibited by DF, whereas the other groups showed a significantly lower bond strength ($P < .05$).

Table 2 shows the ARI scores for the residual adhesive on the enamel surface. FZ produced the lowest ARI score among all the materials tested, and the dif-

Table 2. Adhesive remnant index (ARI) scores for residual adhesive on enamel surface (n = 10)^a

Groups	0	1	2	3	Sum of Scores*	Median Value
GF (Grandio Flow)	0	0	2	8	28 ^A	3
UF (UniFil Flow)	0	2	2	6	24 ^{AB}	3
UL (UniFil LoFlo Plus)	0	0	3	7	27 ^A	3
DF (DenFil Flow)	0	4	5	1	17 ^B	2
TX (Transbond XT)	1	5	2	2	15 ^B	1
FZ (Filtek Z250)	9	1	0	0	1 ^C	0

^a ARI scores: 0 = no adhesive left on tooth surface, 1 = less than 50% of adhesive left on tooth surface, 2 = more than 50% of adhesive left on tooth surface, and 3 = all adhesive left on tooth surface.

* The same superscripts are not significantly different according to Kruskal-Wallis and Mann-Whitney tests at $\alpha = .05$.

ference was statistically significant ($P < .05$), indicating less resin remnant on the enamel surface after the shear testing. Meanwhile, TX attained a significantly higher score than FZ ($P = .01$), yet lower than GF and UL ($P < .05$).

DISCUSSION

TX, which was developed for orthodontic use, showed the highest SBS (10.9 ± 1.7 MPa) in this study, seemingly because of the function of the intermediate bonding resin applied to the acid-etched enamel.^{15,16} However, Frankenberger et al¹⁷ previously indicated that composites with a thinner viscosity can adequately bond to enamel without the requirement of an intermediate bonding resin. The flowable composites tested in this study produced a significantly superior flow compared to TX, indicating their ability to infiltrate acid-etched enamel and form an adequately strong bond with the enamel.^{18,19}

However, the SBS achieved by the flowable composites (range = 7.2 ± 0.9 to 8.3 ± 1.0 MPa) when applied directly to acid-etched enamel was not comparable to the SBS produced by TX, which can partly be explained by the ARI scores and flexural strengths of the materials. As reflected by the ARI scores, a larger resin remnant was left on the enamel surface with the flowable composites (median value of 2 or 3) after debonding, compared with TX (median value of 1), meaning that the primary failure site for the flowable composites was within the material or at the bracket-composite interface. In addition, the flexural strengths of the flowable composites were significantly lower than that of the TX adhesive paste, except for DF, which was comparable. Therefore, it would seem that the lower SBS values for the flowable composites were not because of a weak bond with the enamel, but rather a consequence of their comparatively inferior mechanical properties.^{11,14,20}

The SBS (range = 7.2 ± 0.9 to 8.3 ± 1.0 MPa) for the flowable composites appeared to be clinically acceptable,⁴⁻⁸ although lower than that for TX, implying that flowable composites can simplify the bonding procedure by eliminating the need to apply an intermediate bonding resin without deteriorating the bond strength.

In addition, the bond failure patterns for the flowable composites were potentially favorable for enamel preservation. The enamel fractures and damage tend to increase with an ARI score of 0 or 1; in other words, the fracture occurred at the enamel-adhesive interface.¹¹ Conversely, an ARI score of 3, meaning a bonding failure at the bracket-adhesive interface, produces a low frequency of enamel fractures.²¹ Therefore, a bond failure at the bracket-adhesive interface would seem to be more desirable to minimize the enamel fractures.^{11,21}

In this study, the median value for the ARI scores for the flowable composites was 2 or 3, while that for TX was 1. In particular, two flowable materials (GF and UL) produced significantly higher ARI scores than TX. The mechanical properties of flowable composites have previously been reported to be inferior to those of restorative composites because of their comparatively lower filler loading.^{14,20} Thus, for restorative applications, this lower filler content and resultant weaker mechanical properties may limit their clinical use. Conversely, the lower mechanical properties of flowable composites may be beneficial for preserving enamel in the case of orthodontic bracket bonding, as reflected by the ARI scores in this study. Thus, although TX can provide more stable bonding between the bracket and a tooth,²⁰⁻²² it may not be optimal in terms of enamel fractures.^{11,12} Therefore, great care is required to avoid damaging the enamel surface during debonding.

As regards the bond strengths, all the materials tested were clinically acceptable, including the restorative composite FZ (6.8 ± 1.2 MPa). Nonetheless, despite the absence of any significant difference in the SBS between the flowable composite groups and FZ, FZ produced a significantly lower ARI score than the flowable composites, indicating less resin remnant on the enamel surface after debonding and primary failure site at the composite-enamel interface. Although the SBS for FZ was lower than that for TX, its flexural strength was not different from that of TX, seemingly because of its limited flowability and resultant weak bond to the acid-etched enamel. Thus, FZ may not flow and diffuse completely into acid-etched enamel without the aid of a low-viscosity material.^{15,16} Thus, when considering the bond failure pattern presented by the ARI scores, the orthodontic use of the restor-

ative composite FZ would not seem to be recommended.

Among the flowable composites tested in this study, DF showed a statistically equivalent¹¹ or significantly higher¹² SBS compared with TX. Plus, in the present ARI analysis, DF showed a different median value (2) than the other flowable composites (3), seemingly in part because of its flexural strength, which was comparable to that of TX and FZ, in contrast to the other flowable composites.^{11,12} However, this study found no significant difference between DF and the other flowable composites as regards the SBS. This inconsistency may have been attributable to the large variations in the experimental design and procedures, including the bracket base design.²²⁻²⁴

As for the two flowable composites, UF and UL, they showed no significant difference in any of the parameters, except for flow. Therefore, clinicians could conveniently select either of these two materials with different viscosities according to the needs of the case.

The clinically optimal bond strength between an orthodontic bracket and the tooth structure is based on minimizing bond failure during orthodontic treatment⁶ and obtaining an undamaged enamel surface after debonding.²⁵ Thus, when considering the SBS and ARI scores obtained in this study, the ability of the flowable composites to bond directly to the acid-etched enamel without the use of an intermediate bonding resin seemed to be sufficient for orthodontic needs.⁴⁻⁸ Therefore, although an orthodontic bonding system with an intermediate bonding resin, such as TX, should still be applied to teeth requiring a higher bond strength, a clinical combination of flowable composites and orthodontic bonding systems can save chair time, minimize enamel damage, and maintain a clinically acceptable bond strength. However, a cyclic loading test and/or aging process to the brackets can provide more reliable information about the bonding characteristics of flowable composites for orthodontic use. Plus, further clinical studies are needed to establish the proper use of flowable composites for orthodontic bracket bonding.

CONCLUSION

- When considering the SBS and ARI scores obtained in this study, flowable composites can be effectively applied to orthodontic bracket bonding.

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