eor.istanbul.edu.tr

Official Publication of Istanbul University Faculty of Dentistry

Eur Oral Res 2026; 60(1): 320-328

Original research

Evaluation of microtensile bond strength to dentin and adhesive layer thickness of a new generation two-bottle universal adhesive

Ahmet Özlü[1]

Gülşah Tonga[2]

Hüseyin Hatırlı[2]

Purpose

This study aimed to evaluate and compare the immediate and aged microtensile bond strengths (μTBS) and pre-aging adhesive layer thicknesses of G2-Bond Universal, a novel two-bottle universal adhesive, with those of the gold-standard two-step self-etch adhesive (Clearfil SE Bond) and one-step universal adhesive (G-Premio Bond).

Materials and Methods

Thirty extracted human molars were randomly assigned to three adhesive systems (n=10 teeth per group). After standardized dentin surface preparation, adhesives were applied according to manufacturers' protocols, followed by incremental composite build-up. Specimens were sectioned to obtain rectangular prism-shaped sticks (1 mm^2 cross-sectional area), which were allocated to immediate and 6-month water aging subgroups (n=90each). μTBS was measured using a universal testing machine. Adhesive layer thickness was assessed on 90 pre-aging sticks via scanning electron microscopy, with measurements performed using ImageJ software. Data were analyzed using two-way ANOVA for μTBS and one-way ANOVA for adhesive thickness, followed by Tukey's HSD.

Results

Aging showed no statistically significant effect on μTBS ($p>0.05$). Clearfil SE Bond exhibited the highest μTBS values, significantly outperforming G-Premio Bond ($p<0.05$), while no statistically significant difference was observed compared with G2-Bond Universal ($p>0.05$). G2-Bond demonstrated the thickest adhesive layer.

Conclusion

The thicker adhesive layer of G2-Bond may enhance its mechanical resilience and clinical durability under functional stresses.

Keywords: microtensile bond strength, adhesive layer, universal adhesive, self-etch adhesive, dental bonding

How to cite: *Özlü A, Tonga G, Hatırlı H. Evaluation of microtensile bond strength to dentin and adhesive layer thickness of a new generation two-bottle universal adhesive. Eur Oral Res 2026;60(1):320-328. DOI: 10.26650/eor.20261852732*

Authors ORCID: A.Ö. 0000-0001-7735-5502; G.T. 0000-0002-4680-6283; H.H. 0000-0002-4451-7576

[1] Dental Clinic Private practice Kocaeli Turkey

[2] Department of Restorative Dentistry Faculty of Dentistry Tokat Gaziosmanpasa University Tokat Turkey

Corresponding author: Gülşah Tonga

E-mail: gulsah.tonga@gop.edu.tr

Received: 31.12.2025

Revised: 10.02.2026

Accepted: 02.05.2026

DOI: 10.26650/eor.20261852732

Introduction

Recently, universal adhesives have been developed to simplify clinical procedures by incorporating functional acidic monomers into single-step self-etch systems. These materials offer convenient handling and multiple application options (etch-and-rinse/self-etch), enable bonding to various substrates, exhibit compatibility with resin cements, and reduce application time (1, 2). However, integrating chemically distinct components of universal adhesives into a single bottle has been associated with drawbacks such as reduced shelf life, increased water sorption and nanoleakage, and limited bond durability (1).

During the adhesive procedure, maintaining slight dentin moisture is crucial to promote monomer diffusion. For this reason, 2-hydroxyethyl methacrylate (HEMA), which acts as a wetting agent, is added to the content of universal adhesives as a monofunctional monomer. HEMA, a small molecule with a low molecular weight, is a good diffusion mediator. Thanks to its high hydrophilicity, this monomer acts as a solvent for other monomers. Additionally, HEMA helps prevent phase separation in one-step adhesive systems where hydrophobic and hydrophilic components coexist (2). Despite these benefits, the hydrophilic nature of HEMA also facilitates water uptake from dentin and the oral environment, leading to hydrolytic degradation at the adhesive interface and, consequently, a reduction in long-term bond strength (3, 4).

The thickness and quality of the adhesive layer are additional factors influencing the long-term bonding performance of universal adhesives (5, 6). During polymerization, oxygen inhibits free-radical propagation, forming a soft oxygen-inhibition layer on the adhesive surface (7, 8). This layer may facilitate water absorption from the underlying dentin and promote hydrolytic degradation (9, 10). Conversely, a thicker adhesive layer can improve bond perfor-

mance by mitigating polymerization shrinkage stress (11, 12). Typically, universal adhesives form a layer less than 10 μm thick; however, recent studies have reported thicknesses ranging from 10 to 17 μm among different products (13, 14).

Several investigations have demonstrated that the bond strength of single-bottle universal adhesives can be improved by applying an additional coat of adhesive resin or by placing a layer of flowable composite material (15, 16). Instead of these supplementary applications, newly developed two-step (two-bottle) universal adhesives can be used to achieve the desired adhesive layer thickness. One such example currently available is G2-Bond Universal (GC, Tokyo, Japan), which is designed to provide an optimal bond to both dental hard tissues and composite resin through a gradual transition from hydrophilic to hydrophobic properties. This HEMA-free universal adhesive incorporates functional monomers (4-MET, MDP, MDTP) that contribute to its broad bonding capability. According to the manufacturer, this composition reduces water sorption within the adhesive layer while improving bond strength. The manufacturer also reports an adhesive layer thickness of approximately 35 μm.

Beyond chemical composition, the thickness of the adhesive layer has been suggested to play a critical role in stress distribution and long-term bond durability. A relatively thicker adhesive layer may function as a stress-absorbing or stress-buffering layer, reducing polymerization shrinkage stress and improving interfacial integrity under functional loading (17, 18). Previous studies have demonstrated that increasing the adhesive layer thickness, either through multiple adhesive applications or the use of two-step adhesive systems, can enhance bond stability and reduce interfacial degradation over time (19, 20).

Only a limited number of publications have examined the adhesive layer dimensions and bonding capabilities of G2-Bond Universal (21, 22, 23). Tsujimoto et al. (23) reported that, following thermal cycling, G2-Bond Universal demonstrated higher dentin bonding capacity than the other adhesives tested. Tichy et al. (24) observed no statistically significant difference in the bonding effectiveness of G2-Bond Universal after prolonged water storage. In addition, the same study found that the material exhibited markedly lower water uptake than Clearfil SE Bond (Kuraray Noritake Inc., Okayama, Japan).

Accordingly, the present study aimed to assess and compare the immediate and aged microtensile bond strength as well as the pre-aging adhesive layer thickness of G2-Bond Universal with those of a universal adhesive and a two-step self-etch adhesive. The null hypotheses were that (1) adhesive type and aging would have no effect on microtensile bond strength, and (2) adhesive type would have no effect on adhesive layer thickness.

Materials and Methods

Sample size determination

The required sample size was estimated using the G*Power software (version 3.1.9.6; Franz Faul, Universität Kiel, Germany). Assuming an effect size of f = 0.3, with a statistical power $(1-\beta)$ of 95% and a confidence level $(1-\alpha)$ of 95%. The analysis indicated that a total of 30 teeth were required, with 10 teeth randomly assigned to each experimental group (25).

Sample preparation

Human mandibular molars extracted within the previous six months due to orthodontic or periodontal indications were collected for use in this in vitro research. Teeth exhibiting caries, restorations, or structural defects were excluded, and only sound specimens were retained. After thoroughly removing any residual soft and hard tissues, the teeth were immersed in distilled water containing 1 mg/L thymol and stored at 37 °C until testing. Each specimen was then embedded in acrylic resin blocks, ensuring the tooth surface was positioned approximately 3–4 mm below the cemento-enamel junction.

The occlusal one-third of each crown was cut parallel to the occlusal surface with a precision sectioning device (Micracut 152, Metkon, Turkey) to create flat dentin areas. To ensure a uniform smear layer, the dentin was polished for 60 seconds under continuous water irrigation using 180-grit silicon carbide abrasive paper on a polishing apparatus. Afterward, each specimen was examined under a stereomicroscope (Stemi C-2000; Zeiss, Oberkochen, Germany), and any sample showing pulp exposure was eliminated.

Subsequently, the teeth were randomly divided into three experimental groups (n = 10) according to the adhesive system used: two-step self-etch adhesive: Clearfil SE Bond (Kuraray Noritake, Okayama, Japan), universal adhesives: G2-Bond Universal and G-Premio Bond (GC Corp., Tokyo, Japan).

All adhesives were applied in self-etch mode following the manufacturer's guidelines. A matrix band (SuperMat Universal Dental Matrix, Kerr, Switzerland) was positioned, and a microfilled composite resin (Solare-X; GC, Tokyo, Japan) was layered in two increments of 2 mm each, reaching a total height of 4 mm. Every layer was light polymerized with an LED curing unit (Valo; Ultradent Products Inc., South Jordan, UT, USA) with a light intensity of 1000 mW/cm^2. The completed restorations were immersed in distilled water at 37 °C for 24 hours before sectioning. Comprehensive details regarding the materials and procedures are summarized in Table 1

Microtensile bonding strength test

A total of nine stick specimens (approximately 1 mm^2 cross-sectional area) were obtained from each tooth using a precision cutting device under continuous water irrigation. From each tooth, six sticks were allocated for the microtensile bond strength (μTBS) evaluation, while the remaining three were designated for measuring the adhesive layer thickness. In total, 180 sticks were prepared for μTBS analysis. The cross-sectional area of each composite resin–dentin specimen was determined with a digital caliper.

The specimens were separated into two storage subgroups: one tested after 24 h of water storage (immediate subgroup, n = 90) and the other after 6 months of storage (aged subgroup, n = 90). These sticks were equally and randomly allocated, with three sticks assigned to the immediate testing group and three sticks assigned to the aged group, ensuring that both time points were represented within each tooth. To inhibit bacterial growth, the storage solution consisted of 0.5% Chloramine-T, which was replaced every two weeks.

Each stick was fixed to the testing jig with cyanoacrylate adhesive and tested using a universal testing machine (Shimadzu Corp., Kyoto, Japan) at a crosshead speed of 1 mm/min until failure. Bond strength (MPa) was calculated by

dividing the load at failure (N) by the measured bonding area (mm^2). Testing was performed within 5 minutes of removing each stick from the water.

Evaluation of adhesive layer thickness

Thirty sticks from each adhesive group (total n = 90) were examined under scanning electron microscopy (SEM) at 10 kV. The upper surfaces were polished under water using sequential silicon carbide papers (600, 800, and 1000 grit), followed by diamond pastes (6 μm, 3 μm, and 1 μm). After ultrasonic cleaning, specimens were treated with 5% hydrochloric acid (30 s) and 5.25% sodium hypochlorite (5 min), rinsed with distilled water, sputter-coated with platinum–palladium, and observed at magnifications above $\times$2000.

Adhesive layer thickness was measured in micrometers using ImageJ software (National Institutes of Health, MD, USA) at three locations: left lateral, central, and right lateral regions. The lateral measurement points were positioned 500 μm from the specimen edges. Three readings were taken at each location, and the average value was recorded for analysis (25). (Figure 1) A schematic overview of the experimental design is presented in Figure 2.

Evaluation of fracture type

After μTBS testing, both ends of each fractured specimen were examined under a stereomicroscope (Stemi C-2000; Zeiss, Oberkochen, Germany) at $\times$10 magnification. Fractures were categorized as adhesive, cohesive within dentin, cohesive within composite, or mixed. (26) Additionally, two representative specimens per group those with bond strength values near the group mean were analyzed under SEM (Mira 3 XMU; Tescan, Brno, Czech Republic) at $\times$200 and $\times$500 magnifications to document morphological fracture characteristics.

Statistical analysis

The statistical evaluation was performed using SPSS software (version 26.0; IBM Corp., Armonk, NY, USA). The tooth was defined as the experimental unit. For each tooth, the μTBS values obtained from individual sticks were averaged to generate a single tooth-level mean value before statistical analysis. Descriptive parameters (mean $\pm$ standard deviation) were calculated for each data set. Data distribution normality and variance homogeneity were verified through the Shapiro–Wilk and Levene tests, respectively. To examine the effects and interactions of the independent factors on bond strength, a two-way ANOVA followed by Tukey's HSD post-hoc comparisons was carried out. Differences in adhesive layer thickness among the experimental groups were determined using one-way ANOVA with Tukey's HSD adjustment. The significance level for all analyses was set at $p < 0.05$.

Results

Microtensile bond strength analysis

No premature failures were detected during sample preparation or testing. The mean μTBS values and corresponding standard deviations for each group are displayed in Table 2. Statistical analysis with two-way ANOVA revealed adhesive type significantly affected μTBS values ($F = 42{,}004$, $p<0.001$).

Table 1. *Materials used in the study, their contents, and lot numbers*

MATERIALS	COMPOSITION	LOT NUMBER
Clearfil SE Bond (Kuraray, Tokyo, Japan)	Primer: HEMA, 10-MDP, initiators, water Adhesive: 2-HEMA, 10-MDP, Bis-GMA, photoinitiator	Primer: A40417 Adhesive: A40835
G2-Bond Universal (GC, Tokyo, Japan)	Primer: 4-MET, 10-MDP, MDTP, dimethacrylate monomer, acetone, water, photoinitiator, filler Adhesive: dimethacrylate monomer, Bis-GMA, filler, photoinitiator	Primer: 2210071 Adhesive: 2211011
G-Premio Bond (GC, Tokyo, Japan)	10-MDP, 4-META, 10-MDTP, methacrylate acid ester, distilled water, acetone, photoinitiators, fine powdered silica Inorganic Fillers: (77 wt%, 65 vol%) 16 μm pre-polymerized filler, 16 nm silica filler, fluoroaluminosilicate glass, lanthanoid fluoride filler: 100 nm (0.10 μm) Inorganic Silica Filler: 850 nm (0.85 μm), fumed silica 16 nm (0.016 μm)	2208091
Solare X (GC, Tokyo, Japan)	Organic Matrix Components: Camphorquinone, UDMA	1903042

10-MDP: 10-Methacryloyloxydecyl dihydrogen phosphate, 4-MET: 4-Methacryloxyethyl trimellitic acid, Bis-GMA: Bisphenol A glycidyl dimethacrylate, MDTP: Methacryloyloxydodecyl dihydrogen thiophosphate, HEMA: Hydroxyethyl methacrylate, UDMA: Urethane dimethacrylate

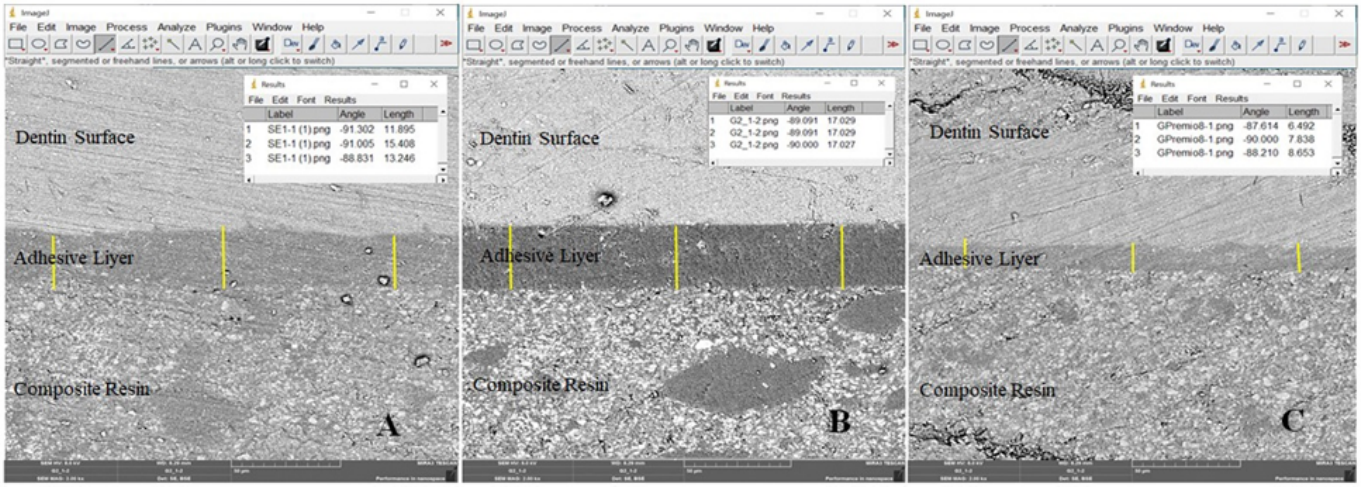


Figure 1. *Measurement of adhesive layer thickness using ImageJ program (A: Clearfil SE Bond, B: G-2 Bond, C: G-Premio Bond).*

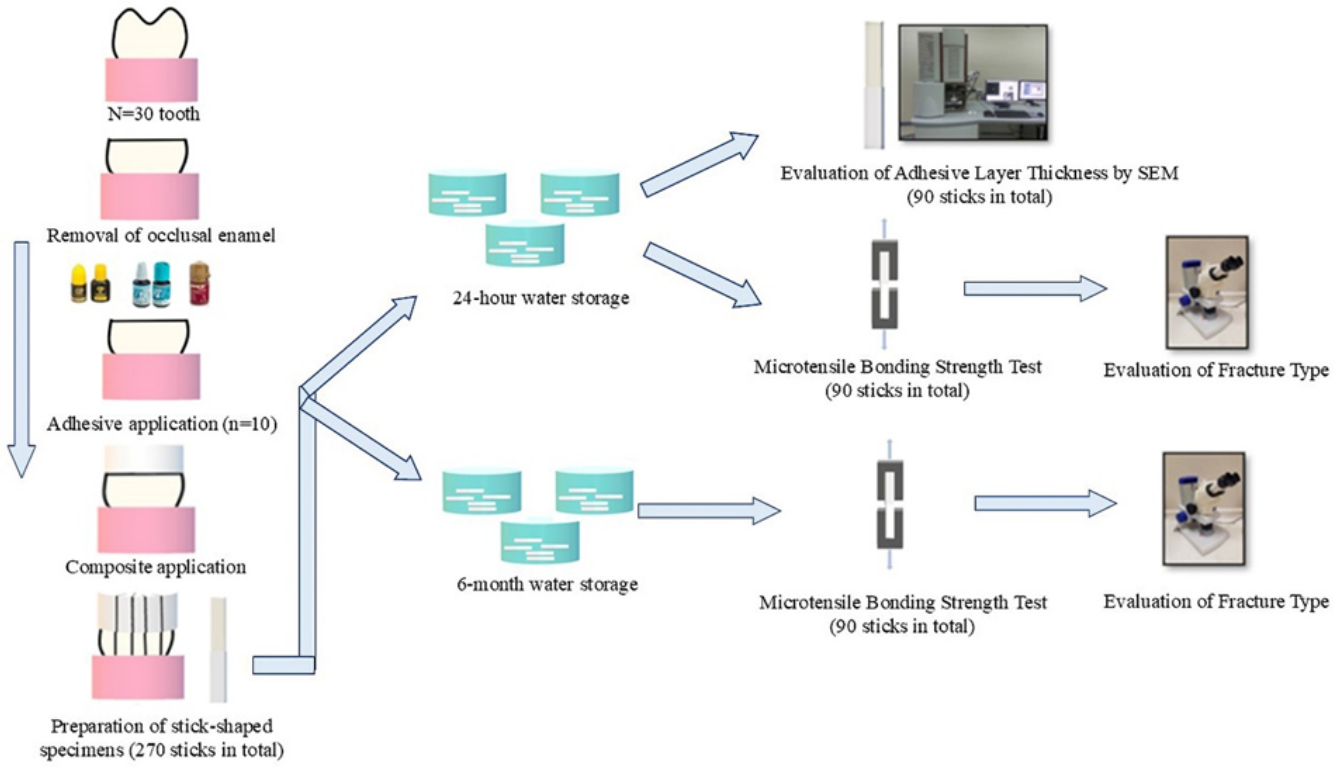


Figure 2. *Schematic view of the study groups*

Table 2. *Mean microtensile bond strength and standard deviation values of the groups.*

	Microtensile Bond Strength	
Adhesive Agent	Immediate Mean ± Standard Deviation (MPa)	After 6 Months of Water Storage Mean ± Standard Deviation (MPa)
Clearfil SE Bond	43.36 ± 10.13bA	44.28 ± 3.82bA
G2-Bond	37.99 ± 4.93bA	39.99 ± 7.81bA
G-Premio Bond	26.13 ± 4.98aA	24.38 ± 6.15aA

Superscript lowercase letters indicate significant differences between adhesive agents within the same column. Superscript uppercase letters indicate significant differences between immediate and delayed groups within the same row ($p < 0.05$).

The aging process performed by soaking adhesive agents in water increased the μTBS of Clearfil SE Bond while decreasing the μTBS of G2 Bond and G-Premio Bond. However, these effects were not significant among the adhesive agent groups ($p>0.05$).

The highest μTBS value before aging was observed in the Clearfil SE Bond group. This value was significant with G-Premio Bond ($p<0.05$) but not significant with G2 Bond Universal ($p>0.05$). The lowest μTBS value was observed in the G-Premio Bond group ($p<0.05$).

The highest μTBS value among the post-aging groups was observed in the Clearfil SE Bond group. This value was significant with G-Premio Bond ($p<0.05$) but not significant with G2 Bond Universal ($p>0.05$). The lowest μTBS value was observed in the G-Premio Bond group ($p<0.05$).

Adhesive layer thickness analysis

The mean values and standard deviations of adhesive layer thickness are presented in Table 3.

According to the one-way ANOVA, adhesive type had a statistically significant influence on the layer thickness ($p<0.05$). Thickness increased progressively from G-Premio Bond to Clearfil SE Bond, with G2-Bond Universal exhibiting the greatest mean thickness. The differences among the adhesives were statistically significant ($p<0.05$).

Fracture type analysis

The types of fractures observed in the tested groups are summarized in Figure 3. Example SEM images illustrating the different fracture modes are shown in Figure 4. Adhesive failure was identified as the predominant fracture type across all groups. Cohesive failures were noted exclusively within the composite resin, with no cohesive fractures observed in the dentin. In the G-Premio Bond group, all failures were categorized as adhesive. Mixed fracture types appeared in the 6-month Clearfil SE Bond group and both the immediate and 6-month G2-Bond Universal groups.

Discussion

According to the results of this investigation, the first null hypothesis, which proposed that there is no difference between the bond strength of different adhesive agents before and after aging, was partially rejected. Although the aging procedure did not cause a statistically significant reduction in overall bond strength, distinct variations were observed among the individual adhesive systems. The second null hypothesis, which stated that there is no difference between the adhesive layer thicknesses of different adhesive agents, was completely rejected, as the tested materials exhibited statistically significant differences in adhesive layer thickness.

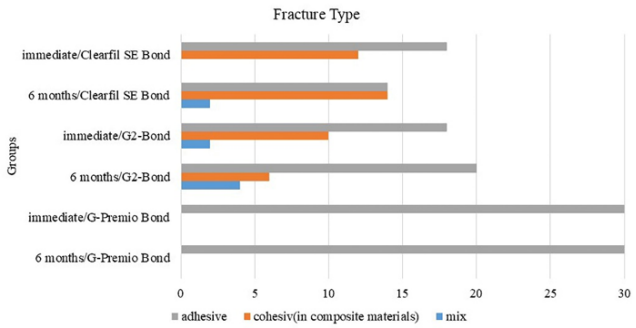


Figure 3. *Distribution of samples according to fracture types*

From the outcomes of the present work, after six months of storage in water, μTBS values for Clearfil SE Bond and G2-Bond Universal showed a slight upward trend, whereas G-Premio Bond exhibited a minor decline; these alterations were not statistically significant. This pattern could be associated with the inherent chemical composition of the adhesives and differences in their adhesive layer thickness. G-Premio Bond, as a one-step universal adhesive, contains both hydrophilic and hydrophobic monomers within a single formulation, along with solvents, which may compromise its phase stability and bonding durability over time (25). In contrast, two-step adhesives such as Clearfil SE Bond and G2-Bond require separate application of a primer containing acidic monomers and solvents, followed by a hydrophobic bonding resin (25, 27, 28). This layered configuration provides a physical shield against hydrolytic degradation, enhances monomer penetration into dentin, and facilitates the development of a thicker, more uniform adhesive layer (15, 24). Such characteristics can help maintain or even improve bonding performance over time. Conversely, in single-bottle systems like G-Premio Bond, the thinner adhesive layer and highly hydrophilic nature may lead to greater water uptake and faster breakdown of the hybrid layer during long-term moisture exposure (29, 30).

The relatively stable μTBS values of G2-Bond Universal after 6 months of water storage may be attributed to its HEMA-free chemical composition and two-bottle application approach. Unlike HEMA-containing adhesives, which are prone to increased water sorption and hydrolytic degradation over time, the absence of HEMA in G2-Bond limits water uptake within the adhesive layer. Following polymerization, the separate hydrophobic bonding resin forms a more water-resistant adhesive interface, which may reduce permeability and protect the hybrid layer from hydrolytic breakdown during long-term water exposure. This hydrophobic character of the bonding layer has been reported to enhance the durability of resin–dentin bonds by acting as a barrier against water diffusion and enzymatic degradation, thereby contributing to improved bond stability over time (24, 31).

The functional monomer 10-MDP enhances adhesive performance by chemically bonding to calcium in hydroxyapatite, forming a stable calcium-phosphate salt that contributes to long-term adhesion. Additionally, its amphiphilic

Table 3. *Mean adhesive layer thicknesses and standard deviation values of the groups*

	Clearfil SE Bond Mean ± Standard Deviation (μm)	G2-Bond Mean ± Standard Deviation (μm)	G-Premio Bond Mean ± Standard Deviation (μm)	Test Statistic	p
Adhesive Layer Thickness	8.02 ±5.31a	14.39 ± 6.76b	4.5 ± 1.64c	115,197	<0.001

Superscript lowercase letters indicate significant differences between adhesive agents in the same row (p<0.05).

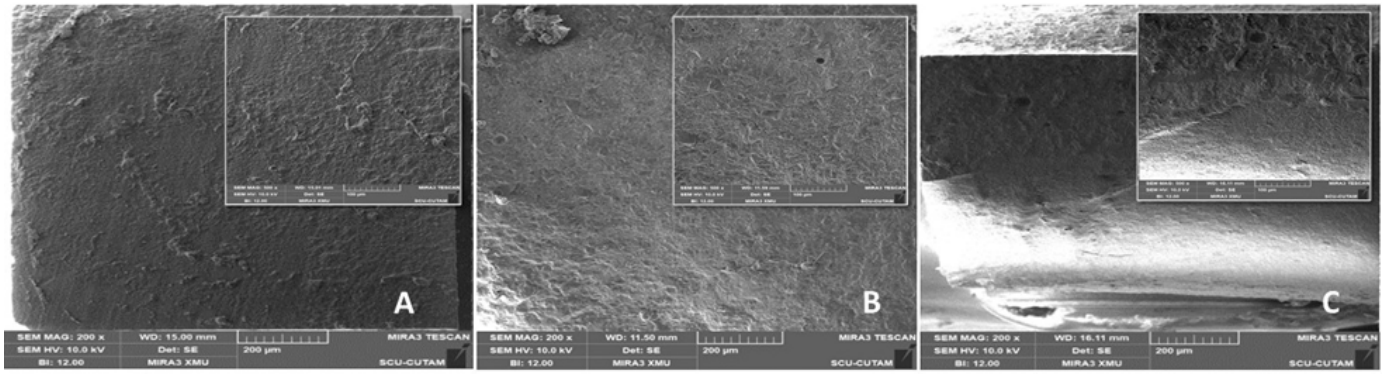


Figure 4. *SEM images of fracture types under 200x and 500x magnification (A: adhesive fracture, B: cohesive fracture, C: mixed fracture)*

molecular structure offers resistance to hydrolytic degradation at the adhesive interface (1, 32, 33). In this study, the lack of a statistically significant effect of aging on bond strength across all adhesive groups may be attributed to the presence of 10-MDP in their formulations, which likely offered some protection against hydrolytic degradation. Nevertheless, a clear hierarchy in bond strength was observed, independent of aging: Clearfil SE Bond > G2-Bond > G-Premio Bond. The significantly lower μTBS values of G-Premio Bond compared to the other two adhesives may be explained by differences in their chemical compositions and bonding strategies. In particular, the reduced MDP concentration and the simplified one-step application protocol in G-Premio Bond may have negatively affected its bonding efficiency and interfacial durability.

G-Premio Bond, which has a relatively low pH, demonstrates limited etching ability when used in self-etch mode, potentially resulting in insufficient micromechanical retention to dentin (34). Moreover, its low MDP concentration, coupled with the coexistence of solvent and monomer in a single phase, may reduce the efficiency and stability of chemical bonding (35, 36). Its highly hydrophilic nature and thin film thickness might also decrease structural strength and overall adhesion performance (22, 37). Additionally, the use of acetone as a solvent may play a role; the rapid evaporation of acetone could leave residual moisture on the dentin surface, leading to incomplete polymerization and compromised interface integrity (38, 39). On the other hand, Clearfil SE Bond and G2-Bond both two-bottle self-etch adhesives that facilitate more effective demineralization and monomer diffusion due to separate primer and bonding steps (40). The formation of a thicker, elastic adhesive layer provides better stress distribution after polymerization, enhancing the overall bonding quality. The superior bond strength of Clearfil SE Bond compared with the other adhesives may also be related to its photoinitiator system. While most adhesives, including G2-Bond, use camphorquinone (CQ) as the primary photoinitiator (41). Clearfil SE Bond incorporates both CQ and a proprietary "Integrated Photoinitiator," which reportedly improves monomer conversion, enhances the mechanical properties of the adhesive, and contributes to higher bond strength (42).

Previous research supports the findings of this study (21, 28). Daneshpooy et al. (43) compared the dentin bonding capabilities of G2-Bond and G-Premio Bond, finding that G2-Bond had significantly superior bond strength. Similarly, studies from 2021 and 2023 evaluated G2-Bond's bonding performance against Clearfil SE Bond (24, 44). Although Clearfil SE Bond exhibited slightly higher bond strength, the difference between the two systems was not statistically significant, and G2-Bond demonstrated comparable performance.

The uniformity and thickness of the adhesive layer are widely acknowledged as critical factors influencing the durability of adhesion (5, 6, 25). Nevertheless, no consensus exists regarding the ideal film thickness for adhesive systems, as multiple parameters including resin viscosity, solvent type, application pressure, air-drying duration, and operator variability affect this characteristic (45). In the present study, significant differences were detected among the tested adhesives. G2-Bond Universal showed the greatest adhesive layer thickness (14.39 ± 9.76 μm), followed by Clearfil SE Bond (8.02 ± 5.31 μm) and G-Premio Bond (4.5 ± 1.64 μm). The increased viscosity of G2-Bond, which is likely related to its HEMA-free formulation and higher content of hydrophobic UDMA monomer, may have enhanced its wettability and produced a thicker and more stable adhesive interface (46). Moreover, the use of a separate primer in two-step adhesive systems facilitates deeper monomer penetration into dentin, improving interaction with the substrate and ultimately increasing the adhesive layer thickness (2, 47). In contrast, the thinner adhesive layer observed in G-Premio Bond can be attributed to its higher solvent content and the strong air-drying process recommended by the manufacturer, which promotes solvent evaporation but reduces film build-up (30). Overall, these findings correspond with earlier observations indicating that one-step universal adhesives generally form thinner adhesive layers compared with two-step systems (25,

48, 49).

It should be noted that adhesive layer thickness is not expected to show a direct linear correlation with bond strength values. Rather contributes indirectly by modulating stress distribution, permeability, and interfacial durability, rather than acting as a direct predictor of bond strength (14, 17, 45). Therefore, in the present study, adhesive layer thickness was evaluated as a supportive structural parameter rather than as a direct predictor of bond strength.

In fracture mode analysis, adhesive failure was predominant across all groups. This finding may be associated with the characteristics of the μTBS testing method, which distributes stress uniformly across the bonding interface. The exclusive presence of adhesive fractures in the G-Premio Bond group could be attributed to its thin adhesive film and limited micromechanical retention (30). In contrast, mixed fractures observed in Clearfil SE Bond and G2-Bond groups indicate stronger and more cohesive bonding interfaces.

This study has several limitations. It was conducted under in vitro conditions, which cannot fully replicate the complexities of the intraoral environment, such as occlusal stresses and blood-saliva contamination. Therefore, clinical studies are necessary to validate these findings and better understand the actual performance of the tested materials.

Conclusion

Based on the outcomes of this in vitro investigation, Clearfil SE Bond achieved the highest μTBS values in both the immediate testing and after six months of water storage. The G-Premio Bond group showed the lowest μTBS values at both time intervals, with all failures identified as adhesive in nature. G2-Bond displayed bond performance similar to that of Clearfil SE Bond and recorded the greatest adhesive layer thickness. Across all groups, cohesive fractures were observed only within the composite resin, indicating the absence of cohesive failures within the dentin substrate.

G2-Bond may offer a buffering effect on the dentin surface due to its dual-bottle structure and thicker adhesive layer, which can be particularly advantageous in stress-bearing restorative applications. While G2-Bond appears promising for improving dentin adhesion, further long-term clinical studies are needed to confirm its durability and effectiveness in various restorative scenarios.

Ethics Committee Approval: Approval was granted by the Ethics Committee of Tokat Gaziosmanpaşa University of Medicine Clinical (07.12.2023 / 23-KAEK-288).

Informed Consent: Participants provided informed consent.

Peer Review: Externally peer-reviewed.

Author Contributions: AO, GT, HH participated in designing the study. AO, GT participated in generating the data for the study. AO, GT participated in gathering the data for the study. AO, GT, HH participated in the analysis of the data. AO, GT wrote the majority of the original draft of the paper. AO, GT, HH participated in writing the paper. AO, GT, HH has had access to all of the raw data of the study. AO, GT, HH has reviewed the pertinent raw data on which the results and conclusions of this study are based. AO, GT, HH have approved the final version of this paper. GT guarantees that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

Conflict of Interest: The authors declared that they have no conflict of interest.

Financial Disclosure: This study was supported by Tokat Gaziosmanpasa University Scientific Research Projects Coordination Unit (BAP)(project number 2023/72).

Acknowledgments: The authors would like to thank Tokat Gaziosmanpasa University Scientific Research Projects Coordination Unit for their financial support.

References

1. Van Meerbeek B, Yoshihara K, Yoshida Y, Mine A, De Munck J, Van Landuyt KL. State of the art of self-etch adhesives. Dent Mater. 2011; 27: 17-28 [CrossRef]
2. Van Meerbeek B, Yoshihara K, Van Landuyt K, Yoshida Y, Peumans M. From Buonocore's pioneering acid-etch technique to self-adhering restoratives: a status perspective of rapidly advancing dental adhesive technology. J Adhes Dent. 2020; 22: 7-34 [CrossRef]
3. Burrow M F, Tagami J, Negishi T, Nikaido T, Hosoda H. Early Tensile Bond Strengths of Several Enamel and Dentin Bonding Systems. Journal of Dental Research. 1999; 73(2): 522-528 [CrossRef]
4. Furukawa M, Shigetani Y, Finger WJ, Hoffmann M, Kanehira M, Endo T, Komatsu M. All-in-one self-etch model adhesives: HEMA-free and without phase separation. J Dent. 2008; 36: 402-408 [CrossRef]
5. Anchieta RB, Oliveira FG, Sundfeld RH, Rahal V, Machado LS, Alexandre RS, Sundefeld ML, Rocha EP. Analysis of hybrid layer thickness, resin tag length and their correlation with microtensile bond strength using a total-etch adhesive to intact dentin. Acta Odontol Latinoam. 2011; 24(3): 272-278
6. Van Meerbeek B, De Munck J, Yoshida Y, Inoue S, Vargas M, Vijay P, Van Landuyt K, Lambrechts P, Vanherle G. Adhesion to enamel and dentin: current status and future challenges. Oper Dent. 2003; 28(3): 215-235
7. Gauthier M, Stangel I, Ellis T, Zhu X. Oxygen inhibition in dental resins. J Dent Res. 2005; 84: 725-729 [CrossRef]
8. Oyama K, Tsujimoto A, Otsuka E, Shimizu Y, Shiratsuchi K, Tsubota K, Takamizawa T, Miyazaki M. Influence of oxygen inhibition on the surface free energy and enamel bond strength of self-etch adhesives. Dent Mater J. 2012; 31: 26-31 [CrossRef]
9. Perdigão J, Araujo E, Ramos RQ, Gomes G, Pizzolotto L. Adhesive dentistry: current concepts and clinical considerations. J Esthet Restor Dent. 2021; 33: 51-68 [CrossRef]
10. Cadenaro M, Antoniolli F, Sauro S, Tay FR, Di Lenarda R, Prati C, Biasotto M, Contardo L, Breschi L. Degree of conversion and permeability of dental adhesives. Eur J Oral Sci. 2005; 113(6): 525-530 [CrossRef]
11. Hirokane E, Takamizawa T, Kasahara Y, Ishii R, Tsujimoto A, Barkmeier WW, Latta MA, Miyazaki M. Effect of double-layer application on the early enamel bond strength of universal adhesives. Clin Oral Investig. 2021; 25(3): 907-921 [CrossRef]
12. Yokoyama M, Takamizawa T, Tamura T, Namura Y, Tsujimoto A, Barkmeier WW, Latta MA, Miyazaki M. Influence of different application methods on the bonding effec-

tiveness of universal adhesives to dentin in the early phase. J Adhes Dent. 2021; 23: 447-459 [CrossRef]
13. Takamizawa T, Imai A, Hirokane E, Tsujimoto A, Barkmeier WW, Erickson RL, Latta MA, Miyazaki M. SEM observation of novel characteristics of the dentin bond interfaces of universal adhesives. Dent Mater. 2019; 35(12): 1791-1804 [CrossRef]
14. Kharouf N, Ashi T, Eid A. Does adhesive layer thickness and tag length influence short-and long-term bond strength of universal adhesive systems? An in vitro study. Appl Sci. 2021; 11: 2635
15. Tang C, Ahmed MH, Yao C, Mercelis B, Yoshihara K, Peumans M, Van Meerbeek B. Experimental two-step universal adhesives bond durably in a challenging high C-factor cavity model. Dent Mater. 2023; 39: 70-85 [CrossRef]
16. Ahmed MH, Yao C, Van Landuyt K, Peumans M, Van Meerbeek B. Extra bonding layer compensates universal adhesive's thin film thickness. J Adhes Dent. 2020; 22(5): 483-501 [CrossRef]
17. Ausiello P, Apicella A, Davidson C L. Effect of adhesive layer properties on stress distribution in composite restorations: a 3D finite element analysis. Dent Mater. 2002; 18: 295-303 [CrossRef]
18. Mohammadi R, Kaplan Alkurt, Harmankaya S, Gönder A, H Y. Investigation of stress distribution and fatigue performance in restored teeth using different thicknesses of adhesive materials and different restorative materials: a 3D finite element analysis. Materials. 2025; 18(16): 3888 [CrossRef]
19. Fujiwara S, Takamizawa T, Barkmeier WW, Tsujimoto A, Imai A, Watanabe H, Erickson RL, Latta MA, Nakatsuka T, Miyazaki M. Effect of double-layer application on bond quality of adhesive systems. J Mech Behav Biomed Mater. 2018; 77: 501-509 [CrossRef]
20. Bourgi R, Kharouf N, Cuevas-Suárez CE, Lukomska-Szymańska M, Devoto W, Kassis C, Hasbini O, Mancino D, Haikel Y, Hardan L. Effect of modified triple-layer application on the bond strength of different dental adhesive systems to dentin. J Funct Biomater. 2023; 14: 522 [CrossRef]
21. Tang C, Mercelis B, Ahmed MH, Yoshihara K, Peumans M, Van Meerbeek B. Adhesive performance assessment of universal adhesives and universal adhesive/composite cement combinations. J Adhes Dent. 2023; 25: 241-256 [CrossRef]
22. Jäggi M, Karlin S, Zitzmann N U, Rohr N. Shear bond strength of universal adhesives to human enamel and dentin. J Esthet Restor Dent. 2024; 36(5): 804-812 [CrossRef]
23. Tsujimoto A, Fischer N G, Barkmeier W W, Latta M A. Bond durability of a two-step HEMA-free universal adhesive. J Funct Biomater. 2022; 13(3): 134 [CrossRef]
24. Tichy A, Hosaka K, Yang Y, Motoyama Y, Sumi Y, Nakajima M, Tagami J. Can a new HEMA-free two-step self-etch adhesive improve dentin bonding durability and marginal adaptation? J Adhes Dent. 2021; 23: 505-512 [CrossRef]
25. Chowdhury AFMA, Alam A, Yamauti M, Álvarez Lloret P, Saikaew P, Carvalho RM, Sano H. Characterization of an experimental two-step self-etch adhesive's bonding performance and resin-dentin interfacial properties. Polymers. 2021; 13(7): 1009 [CrossRef]
26. Cova A, Breschi L, Nato F, Ruggeri A, Carrilho M, Tjäderhane L, Prati C, Di Lenarda R, Tay FR, Pashley DH, Mazzoni A. Effect of UVA-activated riboflavin on dentin bonding. J Dent Res. 2011; 90: 1439-1445 [CrossRef]
27. Jafarnia S, Zeinaddini Meymand J, Zandkarimi F, Saberi S, Shahabi S, Valanezhad A, Safaee S, Nesabi M, Watanabe I. Comparative evaluation of microtensile bond strength of three adhesive systems. Front Dent. 2022; 19: 8 [CrossRef]
28. Takamizawa T, Yokoyama M, Sai K. Effect of adhesive application method on the enamel bond durability of a two-step adhesive system utilizing a universal adhesive-derived primer. Appl Sci. 2021; 11: 7675
29. Perdigão J, Reis A, Loguercio A D. Dentin adhesion and MMPs: a comprehensive review. J Esthet Restor Dent. 2013; 25: 219-241 [CrossRef]
30. Frassetto A, Breschi L, Turco G. Mechanisms of degradation of the hybrid layer in adhesive dentistry and therapeutic agents to improve bond durability: a literature review. Dent Mater. 2016; 32: e41-e53
31. Ahmed M H, Yoshihara K, Yao C. Multiparameter evaluation of acrylamide HEMA alternative monomers in two-step adhesives. Dent Mater. 2021; 37: 30-47
32. Yoshida Y, Nagakane K, Fukuda R, Nakayama Y, Okazaki M, Shintani H, Inoue S, Tagawa Y, Suzuki K, De Munck J, Van Meerbeek B. Comparative Study on Adhesive Performance of Functional Monomers. Journal of Dental Research. 2004; 83(6): 454-458 [CrossRef]
33. Van Landuyt KL, Yoshida Y, Hirata I, Snauwaert J, De Munck J, Okazaki M, Suzuki K, Lambrechts P, Van Meerbeek B. Influence of the chemical structure of functional monomers on their adhesive performance. J Dent Res. 2008; 87: 757-761 [CrossRef]
34. Perdigão Jorge. Current perspectives on dental adhesion: (1) Dentin adhesion – not there yet. Japanese Dental Science Review. 2020; 56(1): 190-207 [CrossRef]
35. Fehrenbach J, Isolan C P, Münchow E A. Is the presence of 10-MDP associated with higher bonding performance for self-etching adhesive systems? A meta-analysis of in vitro studies. Dent Mater. 2021; 37: 1463-1485
36. Fehrenbach Julia, Lacerda-Santos Rogério, Machado Lucas Silveira, Miotti Leonardo Lambertti, De Carvalho Fabíola Galbiatti, Münchow Eliseu Aldrighi. Which self-etch acidic composition may result in higher dental bonds at the long-term? A network meta-analysis review of in vitro studies. Journal of Dentistry. 2022; 126: 104283 [CrossRef]
37. Sen D, Akgüngör G. Shear bond strengths of two composite core materials after using all-in-one and single-bottle dentin adhesives. J Prosthodont. 2005; 14: 97-103 [CrossRef]
38. Saikaew P, Chowdhury AF, Fukuyama M, Kakuda S, Carvalho RM, Sano H. The effect of dentine surface preparation and reduced application time of adhesive on bonding strength. J Dent. 2016; 47: 63-70 [CrossRef]
39. Hatırlı H, Yerliyurt K. Effect of clinically relevant smear layers and pH of universal adhesives on dentin bond strength and durability. J Adhes Dent. 2022; 24: 87-94 [CrossRef]
40. Tamura T, Takamizawa T, Ishii R, Hirokane E, Tsujimoto A, Barkmeier WW, Latta MA, Miyazaki M. Influence of a primer resembling a universal adhesive on the bonding effectiveness of an experimental two-step self-etch adhesive. J Adhes Dent. 2020; 22(6): 635-646 [CrossRef]
41. Sakaguchi R, Powers J. Craig's Restorative Dental Materials. USA: Elsevier Health Sciences. 2012
42. Sato K, Hosaka K, Takahashi M. Dentin bonding durability of two-step self-etch adhesives with improved de-

gree of conversion of adhesive resins. J Adhes Dent. 2017; 19
43. Daneshpooy M, Bahari M, Tabriz Dabaghi. Effect of accelerated aging on the microtensile bond strength of a two-step adhesive containing a universal adhesive primer: an in vitro study. Open Dent J. 2025; 19
44. Takamizawa T, Hirokane E, Sai K, Ishii R, Aoki R, Barkmeier WW, Latta MA, Miyazaki M. Bond durability of a two-step adhesive with a universal-adhesive-derived primer in different etching modes under different degradation conditions. Dent Mater J. 2023; 42: 121-132 [CrossRef]
45. Tang C, Mercelis B, Yoshihara K, Peumans M, Van Meerbeek B. Does the universal adhesive's film thickness affect dentin-bonding effectiveness? Clin Oral Investig. 2024; 28(2): 150 [CrossRef]
46. Katsuki S, Takamizawa T, Yokoyama M, Sai K, Tamura T, Ishii R, Kamimoto A, Miyazaki M. Influence of bonding agent application method on the dentin bond durability of a two-step adhesive utilizing a universal-adhesive-derived primer. Eur J Oral Sci. 2022; 130: e12868 [CrossRef]
47. Nakabayashi N, Kojima K, Masuhara E. The promotion of adhesion by the infiltration of monomers into tooth substrates. J Biomed Mater Res. 1982; 16: 265-273 [CrossRef]
48. Ahmed MH, De Munck J, Van Landuyt K, Peumans M, Yoshihara K, Van Meerbeek B. Do universal adhesives benefit from an extra bonding layer? J Adhes Dent. 2019; 21(2): 117-132 [CrossRef]
49. Yao C, Ahmed MH, Li X, Nedeljkovic I, Vandooren J, Mercelis B, Zhang F, Van Landuyt KL, Huang C, Van Meerbeek B. Zinc-calcium-fluoride bioglass-based innovative multifunctional dental adhesive with thick adhesive resin film thickness. ACS Appl Mater Interfaces. 2020; 12(27): 30120-30135 [CrossRef]