BMC Oral Health

RESEARCH

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The role of aging and various surface preparation methods in the repair of nanohybrid composites

Ayşenur Altuğ Yıldırım[1*] and Mine Betül Üçtaşlı[1]

Abstract

Background Repairing composite resins is a less invasive alternative to complete restoration replacement. To achieve a successful bond between the existing and newly applied composite materials, various surface preparation methods, such as sandblasting and acid etching, have been explored. The aim of the study was to evaluate the effect of different surface treatments on the repair bond strength of a universal nanohybrid composite resin restorative material before and after thermal aging, by utilizing a micro-shear bond strength (μSBS) test.

Methods For the micro-shear bond strength test, a total of 120 cylindrical (3mmX2mm) nanohybrid resin based composite specimens were prepared. The prepared specimens were divided into three groups ($n=40$/per group) based on surface treatment methods: a non-aged group, 10,000 thermal cycle aging and 50,000 thermal cycle aging. The aged and non-aged specimens were further divided into four groups according to adhesive application modes and surface pretreatment methods: 1.universal adhesive/self-etch mode, 2.aluminum oxide sandblasting + universal adhesive/self-etch mode, 3.universal adhesive/etch-and-rinse mode, 4.aluminum oxide sandblasting + universal adhesive/etch-and-rinse mode. Subsequently, 0.8mmX2mm disc shape light cure resin based composite specimens were applied with a direct placement technique on the treated surfaces of all samples for repair. μSBS test was performed using a universal testing machine at a crosshead speed of 1 mm/min. Kruskal-Wallis and Mann-Whitney tests were performed for statistical analysis.

Results The μSBS values of the non-aged group were higher than those of the 10,000 and 50,000 thermal cycle groups, with no significant differences within the non-aged subgroup ($p>0.05$). In the aged groups, significant differences were observed between adhesive application modes and surface treatments. Specifically, the etch-and-rinse mode showed higher bond strengths than the self-etch mode after 50,000 thermal cycles ($p<0.05$). Sandblasting combined with universal adhesive (self-etch mode) improved bond strength, especially in the 10,000 thermal cycle group ($p<0.05$).

Conclusion Aging reduced the bond strength of composite resin repairs, with the etch-and-rinse mode outperforming the self-etch mode in aged specimens. Sandblasting alone did not enhance bond strength. These findings highlight the importance of considering aging and adhesive strategies to optimize repair outcomes, with further research needed on long-term durability.

Keywords Nanohybrid composite resin, Surface treatments, Microshear bond strength, Thermal cycling

*Correspondence:
Ayşenur Altuğ Yıldırım
aysenuraltug@gazi.edu.tr
Full list of author information is available at the end of the article

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Background

Composite resin materials have become the most widely preferred and continuously evolving option for conservative restorations in both anterior and posterior regions, particularly due to the increasing emphasis on minimally invasive dentistry and advancements in adhesive technologies [1, 2]. However, composite resin restorations are durable but can be susceptible to failure over time due to factors such as secondary caries, fractures, and marginal discoloration [3]. In the event of failure, two treatment options are typically considered: complete replacement of the restoration or repair [4–7]. Restoration replacement often requires enlargement of the cavity, which can heighten the risk of irreversible pulp damage [8]. In contemporary dentistry, repair is favored as it extends the clinical lifespan of restorations, minimizes unnecessary loss of dental tissue, reduces the risk of iatrogenic damage, and conserves both time and materials [9, 10].

Achieving a successful repair requires robust adhesion between the existing and newly applied composite resin materials [11]. Repair of composite resin restorations may be required either shortly after material placement and polymerization, or following extended exposure to the oral environment. Adhesion to aged composite resin presents challenges due to material degradation caused by water absorption, which leads to hydrolytic degradation of the polymer matrix and reduces the number of unsaturated double bonds available for reaction with the repair composite. This process also eliminates the oxygen inhibition layer, further complicating the bonding process [11, 12]. A range of mechanical and chemical surface preparation techniques have been explored to enhance bond strength and achieve effective adhesion between the aged and new composite materials. Commonly employed surface preparation methods include roughening with a diamond bur and etching with phosphoric acid [13, 14]. Aluminum oxide air abrasion has also demonstrated efficacy in surface conditioning [8, 15, 16]. Additionally, the use of various adhesive systems, as well as the application of silane, can significantly influence the success of composite resin repair [6, 14, 17].

One of the adhesive systems employed in the repair of composite resin materials is the universal adhesive system, which can be applied in both self-etch and etch-and-rinse modes. Universal adhesives may contain 10-methacryloyloxydecyl dihydrogen phosphate monomer (10-MDP) and silane, which enhance bonding efficacy across a variety of surfaces [18, 19]. Despite the increasing clinical success and widespread use of nanohybrid composite resin materials, there remains a scarcity of comprehensive research on how their repair potential is influenced by varying aging durations and surface treatment methods. Therefore, the objective of the in-vitro study was to assess the effect of various thermal aging periods and various surface preparation methods on the micro-shear bond strength in the repair of a contemporary nanohybrid composite resin, using different modes of a universal adhesive system. The hypothesis was that different thermal aging periods and surface preparation methods would significantly affect the micro-shear bond strength of the repaired nanohybrid composite resin.

Methods

The sample size for this study was determined based on a power analysis using G*Power 3.1.9.7 software. We aimed for a power of 0.80 and a significance level (α) of 0.05. The effect size was assumed to be medium (Cohen's f = 0.25). The materials used in the study are provided in the table. (Table 1).

Specimen preparation

In the study, 120 test specimens were prepared using A-2 shade nanohybrid composite material in dimensions of 3 × 2 mm with the aid of plexiglass molds. After placing the celluloid matrix and plexiglass molds on the glass slide, a single layer of nanohybrid composite resin

Table 1 Materials used in the study and their composition

Material	Composition	Manufacturer
Clearfil Majesty ES-2 Classic	Bis-GMA, Hydrophobic aromatic dimethacrylate, Silanized barium glass filler, Pre-polymerized organic fillers, dl-Camphorquinone	Kuraray Noritake Dental Inc., Japan LOT C80116
Clearfil S3 Bond Universal	MDP, Bis-GMA, HEMA, Hydrophilic aliphatic dimethacrylate, Colloidal silica, Silane coupling agent, dl-Camphorquinone, Ethanol, Water	Kuraray Noritake Dental Inc., Japan LOT 000041
K- Etchant Syringe	35% phosphoric acid aqueous solution, Colloidal silica	Kuraray Noritake Dental Inc., Japan LOT 420,138
Rondoflex Sand	Al_2O_3 particles; particle size 50 µm	Kavo Dental, Germany

Abbreviations: Al_2O_3 Aluminum oxide, *Bis-GMA* Bisfenol A-glisidil metakrilat, *HEMA* Hydroxyethyl methacrylate, *MDP* Methacryloyloxidecyl dihydrogen phosphate monomer

material was placed within the plexiglass molds using a dental spatula. Subsequently, the celluloid matrix and the glass slide were placed on the nanohybrid composite resin material, excess material was removed, and gentle finger pressure was applied afterwards to flatten the surface. The specimens were light polymerized using a light emitting diode (LED) (VALO Cordless, Ultradent, USA) at an irradiance of 1400 mW/cm² for 20 s. Then, each specimen was embedded into cold-cure acrylic resin blocks, leaving the upper surfaces exposed. The exposed upper surfaces of the specimens were wet-polished for 60 s with 1200, and 2000 grit silicon carbide papers under water cooling, respectively (PRESI, Mecapol, P230, France).

Aging procedures

A total of 120 composite resin specimens were prepared and randomly divided into three primary groups ($n=40$) based on the aging procedure applied:

G1: No aging procedure was applied to the specimens in this group; the repair was performed immediately after the composite resin was prepared, without any thermal or mechanical aging.
G2: The specimens in this group were subjected to 10,000 thermal cycles to simulate one year of clinical use. The thermal cycles were conducted in a standard thermal cycling device (Modental, Esetron Mechatronic, Turkey) at temperatures of 5-55 °C, with a dwell time of 20 s and a transfer time of 10 s.
G3: The specimens in this group subjected 50,000 thermal cycles to simulate five years of clinical use. The thermal cycling conditions were same as in the 10,000 thermal cycle group.

Surface treatment

Each primary group was further subdivided into four subgroups ($n=10$) based on surface treatment and adhesive application mode:

g1: In this subgroup, the surfaces of the specimens were treated with the universal adhesive Clearfil S3 Bond, according to the manufacturer's instructions, by rubbing for 10 s followed by air-drying using a gentle air stream for 5 s, and then light curing for 10 s.
g2: The surfaces of specimens in this subgroup were sandblasted using Rondoflex plus 360 sandblasting device, with aluminum oxide particles of 50 μm size, at a distance of 10 mm and an air pressure of 4 bars. The sandblasted surfaces were then washed with water for 20 s, dried with an air stream for 10 s, and treated with the universal adhesive Clearfil S3 Bond according to the manufacturer's instructions, by rubbing for 10 s, followed by air-drying using a gentle air stream for 5 s, and then light curing for 10 s.
g3: The surfaces of specimens in this subgroup were treated with 35% phosphoric acid for 15 s. After rinsing with water for 20 s, the surfaces were dried with an air stream for 10 s. The universal adhesive Clearfil S3 Bond was then applied according to the manufacturer's instructions by rubbing for 10 s, followed by air-drying using a gentle air stream for 5 s, and light curing for 10 s.
g4: The surfaces of specimens in this subgroup were sandblasted using Rondoflex plus 360 sandblasting device, with aluminum oxide particles of 50 μm size, at a distance of 10 mm and an air pressure of 4 bars. The sandblasted surfaces were then washed with water for 20 s, dried with an air stream for 10 s, and treated with 35% phosphoric acid for 15 s. After rinsing with water for 20 s, the surfaces were dried with an air stream for 10 s. The universal adhesive Clearfil S3 Bond was then applied according to the manufacturer's instructions by rubbing for 10 s, followed by air-drying using a gentle air stream for 5 s, and light curing for 10 s.

Application of repair composite resin material to test specimens

Repair composite resin material (Clearfil Majesty ES-2) in the form of disk-shaped tygon tubes measuring 0.8 × 2 mm was placed on the composite resin specimens with different surface preparation procedures. The bonding area was defined by the inner diameter of the tygon tube. The bonding area was delimited by the inner diameter of the tygon tube. After the adhesive was applied, the tygon tube was positioned and light-cured together with the adhesive for 10 s. Subsequently, the composite resin was carefully placed into the tygon tube using a blunt-tip probe and light-cured for 20 s.

Micro-shear bond strength test and failure analysis

The micro-shear bond strength (μSBS) of the specimens was conducted using a universal testing machine (Shimadzu AG-IS Autograph, Shimadzu Scientific Instruments, USA). A chisel-shaped blade was positioned perpendicular to the bonding interface between the composite resin material and the repair composite resin material. The bond strength values, expressed in Newtons (N), were obtained by applying a force at a rate of 1 mm/min until failure occurred for each specimen. Subsequently, the obtained bond strength values were divided by the surface area to record the values in Megapascals (MPa).

The fracture surfaces of the specimens subjected to the μSBS test were examined under a stereomicroscope (Leica M60, Wetzlar, Germany) (x4.0) to determine the fracture type.

Statistical analysis

The data were analyzed using the SPSS 27.0 program, and a 95% confidence level was employed. For measurement, mean (M), standard deviation (SD), minimum, maximum, and median (Mdn) statistics were provided. Data normality was assessed using the Shapiro-Wilk test, and homogeneity of variance was evaluated with Levene's test. Since each group did not have at least 30 observations (n1 = n2 = n3 = n4 = 10), non-parametric tests were used. The data were analyzed using the SPSS 27.0 program and a 95% confidence level was employed. For measurement, mean (M), standard deviation (SD), minimum, maximum, and median (Mdn) statistics were provided. Since each group did not have at least 30 observations (n1 = n2 = n3 = n4 = 10), non-parametric tests were used. In this study, the Kruskal-Wallis test was used for comparisons between groups regarding surface preparation methods and aging times, as the data did not meet the assumptions of normality and homogeneity of variance. The Mann-Whitney test was used for within-group comparisons because of the same reason. Additionally, the distribution of failure modes (adhesive, mixed, cohesive) among the groups was analyzed using the chi-square (χ^2) test).

Results

The micro-shear bond strength (μSBS) test results are shown in Fig. 1 and Table 2, while the statistical differences are provided in Tables 3 and 4. Statistical analysis revealed significant differences among groups regarding the interaction between aging durations and surface preparation methods ($p < 0.05$).

- Non-aged Group (G1)

  No significant differences were observed among subgroups in the non-aged group ($p > 0.05$).
- Aging with 10,000 Thermal Cycles (G2)
  A significant difference was found between the universal adhesive (self-etch mode) group and the sandblasting + universal adhesive (self-etch mode) group ($p < 0.05$). A significant difference was also found between the universal adhesive (etch-and-rinse mode) groups ($p < 0.05$).
- Aging with 50,000 Thermal Cycles (G3)
  A significant difference was observed between the universal adhesive (etch-and-rinse mode) group and the universal adhesive (self-etch mode) group ($p < 0.05$). Additionally, a significant difference was found between the sandblasting + universal adhesive (self-etch mode) groups ($p < 0.05$).
- Comparison of Adhesive Application Modes and Surface Preparation Methods

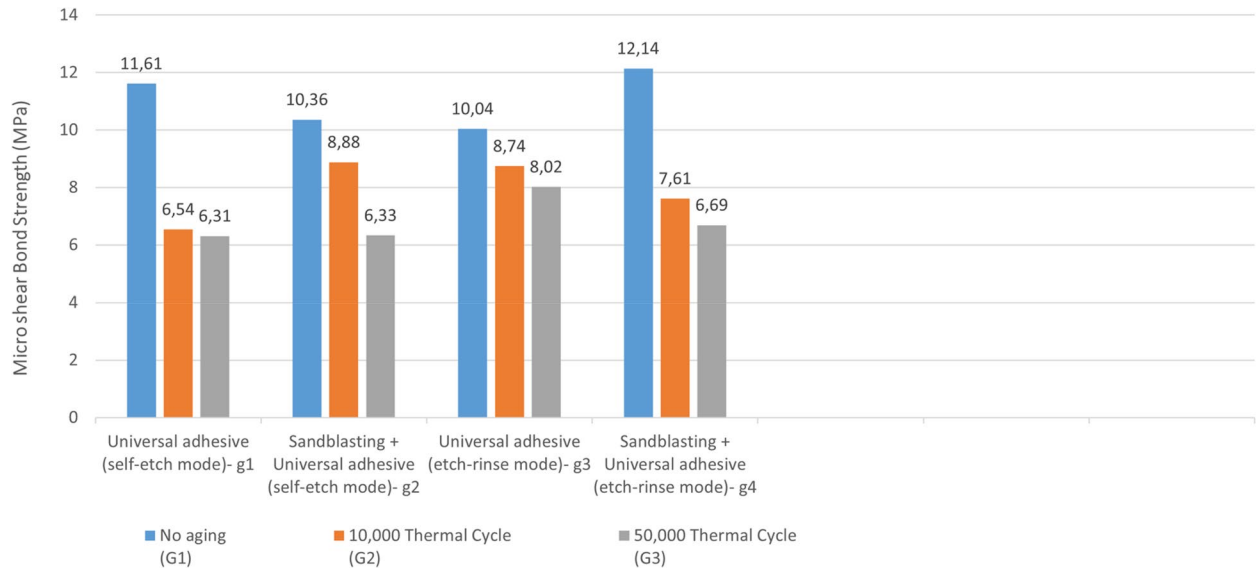


Fig. 1 μSBS (MPa) values

Table 2 μSBS (MPa) values

Micro-shear Bond Strength (MPa)	No aging (G1)		10,000 Thermal Cycle (G2)		50,000 Thermal Cycle (G3)	
	Min-Max	Mean±SD	Min-Max	Mean±SD	Min-Max	Mean±SD
Universal adhesive (self-etch mode) - **g1**	7-17 (12)	11,61±3,17	3-13 (6)	6,54±2,74	5-9 (6)	6,31±1,17
Sandblasting + Universal adhesive (self-etch mode) - **g2**	7-16 (10)	10,36±2,89	6-14 (8)	8,88±2,43	5-8 (6)	6,33±1,23
Universal adhesive (etch-rinse mode) - **g3**	6-15 (10)	10,04±2,55	6-12 (9)	8,74±2,09	5-12 (8)	8,02±1,91
Sandblasting + Universal adhesive (etch-rinse mode) - **g4**	8-17 (12)	12,14±3,1	4-12 (8)	7,61±2,9	4-11 (7)	6,69±2,15

Table 3 Comparing μSBS (MPa) measurements of aging groups according to surface preparation methods

	No aging- G1	10,000 Thermal Cycle- G2	50,000 Thermal Cycle- G3
g1-g2	0,289	0,031*	0,909
g1-g3	0,325	0,034*	0,027*
g1-g4	0,733	0,427	0,760
g2-g3	0,791	0,880	0,040*
g2-g4	0,185	0,212	0,849
g3-g4	0,173	0,226	0,159

*p<0,05; Mann Whitney Test

∘ Universal Adhesive (Self-etch Mode) (g1)

A significant difference was found between the non-aged group and the groups subjected to 10,000 and 50,000 thermal cycles (p< 0.05).

∘ Sandblasting + Universal Adhesive (Self-etch Mode) (g2)

Significant differences were observed between the group aged with 50,000 thermal cycles and the non-aged group (p < 0.05), as well as between the groups aged with 10,000 thermal cycles (p < 0.05).

∘ Universal Adhesive (Etch-and-Rinse Mode) (g3)

A significant difference was observed between the non-aged group and the group aged with 50,000 thermal cycles (p < 0.05).

∘ Sandblasting + Universal Adhesive (Etch-and-Rinse Mode) (g4)

A significant difference was found between the non-aged group and the groups subjected to 10,000 and 50,000 thermal cycles (p< 0.05).

Failure type analysis

The distribution of fracture types of the specimens after the micro shear bond strength test is presented in Fig. 2 in the study.

The distribution of failure modes (adhesive, mixed, and cohesive) among the different groups was analyzed using the chi-square (χ^2) test. The results revealed a significant difference in failure mode distribution across the tested groups ($\chi^2 = 18.0$, df = 2, $p = 0.00012$). Specifically, adhesive failures were predominantly observed in all groups, whereas mixed failures were less frequent, and no cohesive failures were detected.

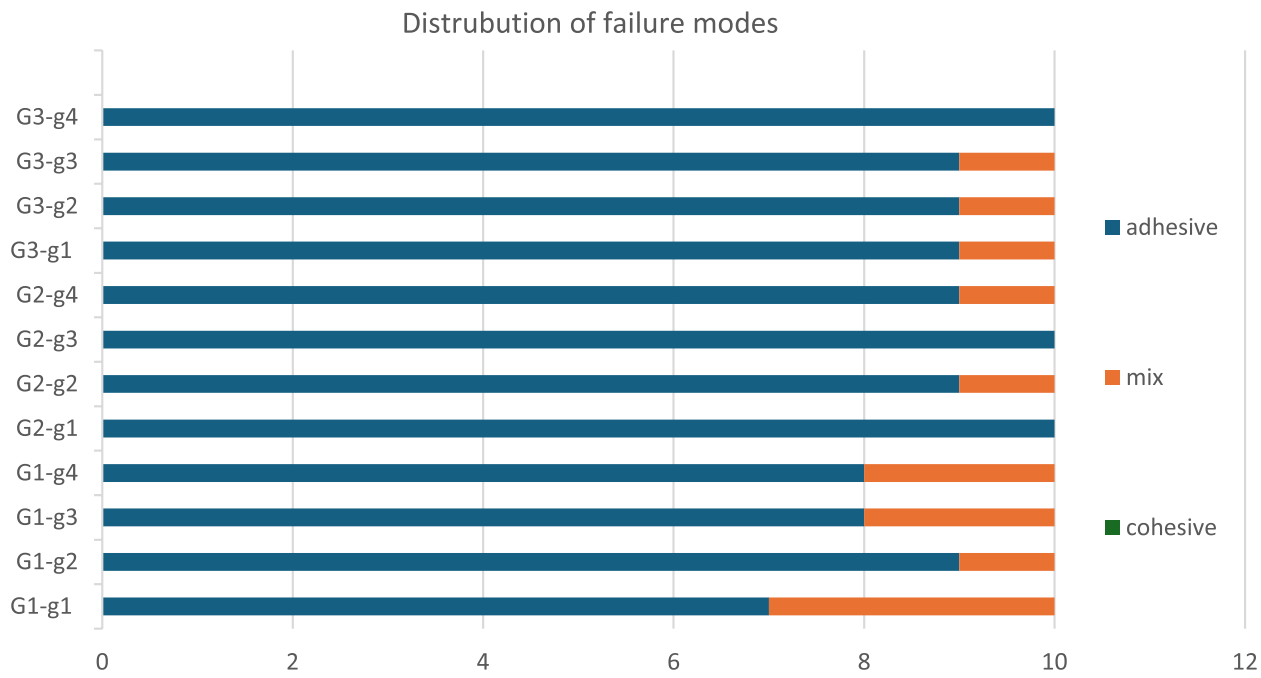
Discussion

To achieve successful repair of composites, good adhesion between old and new composite resin materials is essential [11]. Repair may be necessary shortly after the material is placed and polymerized, and it can also be required after extended use in the oral environment.

Table 4 Comparing μSBS (MPa) measurements of surface preparation method groups according to aging

	Universal adhesive (self-etch mode)- g1	Sandblasting + universal adhesive (self-etch mode)- g2	Universal adhesive (etch-and-rinse mode)- g3	Sandblasting + universal adhesive (etch-and-rinse mode)- g4
G1-G2	0,004*	0,173	0,364	0,006*
G1-G3	0,000*	0,001*	0,049*	0,001*
G2-G3	0,595	0,006*	0,288	0,448

*p<0,05; Mann Whitney Test



G1: No aging
G2: 10,000 thermal cycle
G3: 50,000 themal cycle
g1: Universal adhesive self-etch
g2: Sandblasting + Universal adhesive self-etch
g3: Universal adhesive etch-and-rinse
g4: Sandblasting + Universal adhesive etch-and-rinse

Fig. 2 Distrubution of failure modes

Overcoming these challenges involves employing different surface preparation techniques to establish macro-mechanical, micro-mechanical, and chemical bonding between old and new composite resin restorations [20]. While no consensus exists regarding the most effective method, this suggests that the issue remains open to discussion.

Nanohybrid composite resin materials with reduced filler sizes have a larger surface area, leading to a wider filler-matrix interface and an increased risk of degradation due to water exposure [21]. Nanohybrid composite resin materials have shown lower stability during water absorption compared to microhybrid resin composite materials [22]. Although numerous studies have explored the repair of nanohybrid composites, variations in material formulations, surface treatment protocols, and aging conditions still present challenges in achieving consistent and reliable repair outcomes. While mechanical surface roughening and silane application are effective for repairing microhybrid composites, these procedures may not always yield optimal results for nanohybrid composites [23]. Therefore, further evaluation is necessary to optimize repair protocols for nanohybrid composite resin materials under different clinical condition.

The success of repairs is closely related to the duration and exposure of the restoration in the oral cavity [24, 25]. Prolonged exposure of a composite resin restoration to the oral environment results in chemical deterioration such as water absorption, hygroscopic expansion, hydrolytic degradation in the polymer matrix and filler interface, and a decrease in unsaturated double bonds [11]. Artificial aging methods are employed to mimic the factors to which composite resin restorations are exposed to over time in the oral environment [26]. Thermal cycling is the most commonly used aging method [27]. It has been reported that at least 500 thermal cycles are needed to accurately reflect the aging process, and exceeding this number results in a significant decrease in bond strength [28]. The literature suggests that approximately 10,000 thermal cycles can simulate one year of real aging in the oral environment [29]. Therefore, in the current study, 10,000 thermal cycles were applied to mimic one year of aging and 50,000 thermal cycles to simulate five years of aging.

Previous studies have reported that thermal cycling negatively affects the repair bond strength of composite resin materials, with bond values decreasing as the number of cycles increases [11, 30, 31]. In line with these findings, our study demonstrated that the highest bond values were recorded in the non-aged groups, where no degradation had occurred. In contrast, the lowest bond values were observed in the groups subjected to 50,000 thermal cycles, likely due to the cumulative effects of water absorption and matrix degradation, which reduce the number of available double bonds necessary for chemical adhesion. This decline in bond strength can be primarily attributed to hydrolytic degradation, which progressively weakens the polymer matrix and filler interface, ultimately diminishing the reactive sites required for effective bonding.

Surface preparation procedures for aged composite resin generally serve two purposes: removing the superficial layer undergoing changes due to the oral environment to obtain a clean, higher- energy, wettable surface and creating surface irregularities to increase surface area. It has been noted that the highest bond strength of resin composites is attained through a combination of mechanical surface treatment techniques, including air abrasion with alumina particles, silica-coated alumina particles, or diamond burs, along with chemical surface treatments such as silane and/or adhesive systems [32]. Acid etching, sandblasting, silanization, and adhesive systems are recommended for use to achieve micromechanical bonding and chemical adhesion in repairing composite resin restorations [33, 34].

Universal adhesives are widely used in the repair of composite resin materials, with numerous studies demonstrating their effectiveness in both self-etch and etch-and-rinse modes. However, variations in bonding performance have been reported depending on factors such as the type of composite, surface pretreatment method, and aging conditions. Therefore, further investigation is needed to optimize the application of universal adhesives for consistent and reliable bond strength in composite repair under varying clinical scenarios.

Universal adhesives contain unique phosphate and carboxylate monomers with calcium ion-binding ability to hydroxyapatite, similar to their formulations resembling one-step self-etch adhesives. Universal adhesives containing 10-methacryloyloxidecyl dihydrogen phosphate monomer (10-MDP) are frequently used in clinical practice. The 10-MDP monomer can contribute to bond durability by preventing water absorption due to its hydrophobic properties [35]. In a previous study, 10-MDP was reported to be effective on the surfaces of old composite resin restorations that were to be repaired, binding the trapped C=C bonds by penetrating the cross-linked network [19].

Some universal adhesives contain silane because silanized surfaces become more reactive in the repair of composite resin materials, and silane enhances wetting, allowing the adhesive agent to penetrate micro-retentive surfaces more effectively. The silane agent in universal adhesives forms a chemical bridge that enhances the bond between the resin matrix and the glass filler in composites. Its inorganic group binds to the hydroxyl groups on the glass filler, while the organic group polymerizes with the resin matrix, thereby improving interfacial bond strength, mechanical properties, and durability. However, many reports suggest that the pH of universal adhesives containing silane is mildly acidic, which may render the silane ineffective [36, 37]. In such an acidic environment, the effectiveness and long-term stability of silane in universal adhesives become critical. Additionally, the effectiveness of silane in the repair protocol depends on the availability of silica (e.g., glass particles) on the composite surface. While previous research has shown that silane application alone can improve the bond strength of composite repairs [17], the present study aimed to assess the performance of universal adhesives containing silane, as this combination is commonly utilized in clinical practice.

In this study, the Clearfil S3 Bond universal adhesive containing 10-MDP and silane was used. Universal adhesives are suitable for both self-etch and etch-and-rinse modes; however, the effectiveness of each mode in the repair of composite resin restorations depends on the surface preparation methods and the clinical situation.

The effects of phosphoric acid on enamel and dentin have been extensively documented [38]. In previous studies, it has been reported that phosphoric acid increases surface energy and wettabilityby cleaning residues on the surface after mechanical surface treatment, thereby enhancing the repairbond strength of composite resins [33, 39]. On the contrary, there are some studies have reportedthat the application of phosphoric acid and adhesive alone is not sufficient for repair bond strength [40]. Therefore, it is crucial for clinicians to consider which mode is more appropriate for specific clinical scenarios. While the self-etch mode offers a less invasive and faster approach, the etch-and-rinse mode may be more advantageous in cases where surface contamination is present or higher bond strength is required.

Consistent with the results of a prior study by Yin et al. [41], our current study revealed that the universal adhesive, despite not having a pH as low as phosphoric acid, yielded comparable bond strength values in non-aged groups when applied in self-etch and etch-and-rinse

modes. This may be associated with the presence of an acidic monomer, such as 10-MDP, in the universal adhesive, or with the ability of the silane in the universal adhesive to chemically bond between the organic monomers of the universal adhesive and the glass filler of the composite resin. In contrast to the findings of this study, our current investigation revealed that phosphoric acid etching prior to the application of the universal adhesive enhanced the bond strengths in repairing a nanohybrid composite resin material subjected to 10,000 and 50,000 thermal cycles. It is known that nanohybrid composite resin materials have smaller filler sizes, larger surface areas, and thus a wider filler-matrix interface compared to microhybrid composite resins. The phosphoric acid etching step in the repair of aged nanohybrid composite resin materials may improve repair bond strengths by exposing the extensive filler surface of nanohybrid composite resin material, thereby increasing surface area and surface energy. Ritter et al. [19] reported that Clearfil Majesty ES-2 nanohybrid composite resin aged with 50,000 thermal cycles showed similar composite repair strengths with Scotchbond Universal adhesive containing silane and 10-MDP in self-etch or etch-and-rinse modes. However, in the current study, during the repair of the same nanohybrid composite resin aged with 50,000 thermal cycles, Clearfil S3 Bond universal adhesive containing silane and 10-MDP exhibited better bonding values in etch-and-rinse mode compared to the self-etch mode. This discrepancy could be attributed to variations in the concentrations of silane and 10-MDP within the content of the universal adhesives used in both studies, along with the diversity of other monomers.

Mechanical surface treatment methods such as diamond bur and air-particle abrasion have also been recommended to increase the repair bond strength of composite resin materials, in addition to adhesive application [42]. Among particle abrasion systems, aluminum oxide sandblasting has provided the best bond values compared to other methods because it creates micro-retentions on the composite resin material surface [43, 44]. This process removes the altered surface layer and promotes micro-retention by increasing the surface area [45]. Aluminum oxide particles enhance the mechanical interlocking ability of the new composite resin material with the old one due to the increased surface area, and these retentive surfaces support the surface wettability that provides an ideal fit for the composite resin material [25]. It has been shown that aluminum oxide sandblasting creates more micro-retentive surfaces and provides higher bond strength than diamond bur abrasion by mechanically roughening the surface [15, 46]. Previous studies investigating the repair bond capacity of composite resin materials have also reported results supporting that sandblasting with aluminum oxide enhances repair bond capacity compared to untreated surfaces [47–49]. Therefore, in this study, the effect of sandblasting the surfaces with 50 μm aluminum oxide before adhesive-processes on repair bond strength was examined.

According to a meta-analysis, in composite repair, surface treatments with air abrasion resulted in statistically higher bond values in most cases [50]. These results may indicate that mechanical roughening of aged composite resin material is necessary before adhesive systems for better bonding to the underlying structure. Contrary to these findings, in the present study, no beneficial effect of aluminum oxide sandblasting was observed in non-aged groups. This situation may indicate that the universal adhesive containing silane and 10-MDP monomers used in the repair of fresh composite resin could be sufficient, regardless of whether it is applied in self-etch or etch-and-rinse modes, and additional surface preparation before adhesive procedures may be unnecessary. In the group subjected to aging with 10,000 thermal cycles, a different situation was encountered, and sandblasting with 50 μm aluminum oxide before the application of universal adhesive in the self-etch mode positively contributed to the bond strength. The reason for this may be that micro-retentive preparation on the aged composite resin surface increases the surface area, promoting the formation of new bonds by exposing reactive C=C double bonds. However, the same beneficial effect was not observed in groups subjected to aging with 50,000 thermal cycles. This may indicate that restorations used for longer periods in the oral environment is less reactive despite surface treatments due to increased water absorption and decreased C=C double bonds. Nevertheless, a clear effect of aluminum oxide sandblasting was not observed in the current study.

The limitations of the present study include the use of only one nanohybrid composite as both the old and new material. Since it is not always possible to determine the brand or type of a composite restoration in the oral cavity, investigating the repair bond strengths of composite resins with different formulations is crucial. Additionally, incorporating a phase where silane is applied independently could provide valuable insights. Future research should investigate the effects of silane application alone, as well as its potential synergistic effects when combined with various adhesive systems. Furthermore, the samples were aged solely through thermal cycling. While thermal cycling is a widely used method for aging, clinical conditions expose restorations to both mechanical and chemical stresses. Therefore, in vitro and clinical studies that consider these factors and explore various treatment combinations are necessary.

Conclusion

Within the limitations of this study:

1. Aging significantly reduced adhesive performance, as bond strength decreased in aged specimens regardless of the application mode.
2. The etch-and-rinse mode demonstrated superior performance compared to the self-etch mode in aged specimens.
3. Sandblasting with aluminum oxide alone did not significantly enhance bond strength, highlighting the multifactorial nature of repair bond performance.

These findings emphasize the critical role of aging in determining adhesive efficacy and underscore the importance of selecting appropriate adhesive application modes and surface treatment protocols to optimize clinical outcomes. Further research is recommended to explore the combined effects of various surface treatments and adhesive systems on the long-term durability of repaired composite restorations, especially in aged restorations.

Acknowledgements
Not applicable.

Authors' contributions
A.A.Y., and M.B.Ü. wrote the main manuscript text and A.A.Y., and M.B.Ü. prepared figures. All authors reviewed the manuscript.

Funding
Gazi University Scientific Research Projects Coordination Unit, TDH-2023-8212.

Data availability
Yes, the datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Faculty of Dentistry, Department of Restorative Dentistry, Gazi University, Bişkek St. 1. St. Number: 8 Emek, Ankara, Turkey.

Received: 18 October 2024 Accepted: 17 January 2025
Published online: 22 January 2025

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