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Repair Bond Strength of Self-Cure Bulk-Fill Composites: Influence of Substrate Composition, Surface Conditioning, and Repair Material Type

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ABSTRACT

Objective: This in vitro study aimed to evaluate the effects of substrate composition, surface conditioning protocol, and repair material type on the repair shear bond strength (SBS) of an aged self-cure bulk-fill resin composite.

Materials and Methods: A total of 80 specimens were fabricated using two substrate compositions of a self-cure bulk-fill composite (Stela; Automix and Capsule). After initial aging by thermocycling, specimens were repaired according to a 2×2×2 factorial design based on surface conditioning (mechanical roughening with or without 37% phosphoric acid etching) and repair material type (self-cure composite with proprietary primer or light-cure nanohybrid composite with a universal adhesive). SBS was measured using a universal testing machine. Failure modes were analyzed using a stereomicroscope. Data were analyzed using three-way ANOVA, Tukey's HSD, and Fisher's exact tests ($p < 0.05$).

Results: Substrate composition, surface conditioning protocol, and repair material type each significantly affected repair bond strength ($p < 0.001$). Capsule-based substrates showed higher SBS values than Automix substrates. Phosphoric acid etching significantly increased SBS compared with mechanical roughening alone. Repairs performed with the same self-cure composite exhibited significantly higher SBS than those repaired with a light-cure composite. Significant two-way interactions were observed between substrate composition × repair material type ($p < 0.001$) and surface conditioning × repair material type ($p = 0.015$). The highest SBS was observed in the Capsule + acid etching + self-cure repair group. Failure mode analysis revealed predominantly cohesive or mixed failures in self-cure repair groups, whereas light-cure repair groups showed a higher frequency of adhesive failures.

Conclusion: Repair bond strength of a self-cure bulk-fill composite is highly material- and protocol-dependent. Utilizing a chemically compatible self-cure material system combined with adjunctive phosphoric acid etching significantly optimizes repair longevity, especially when applied to mechanically triturated capsule-based substrates.

Clinical Significance: The selection of repair material and surface conditioning protocol significantly influences the repair bond strength of aged self-cure bulk-fill composites. When the original restorative material is known, repair with the same composite system following phosphoric acid conditioning may provide more durable bonding.

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1 | Introduction

Repair of resin composite restorations is increasingly regarded as a core component of minimally invasive dentistry, as it preserves sound tooth structure while avoiding the biological risks associated with complete restoration replacement. Clinical and educational reports highlight that repair procedures reduce operative time, limit pulpal irritation, and align with contemporary minimum-intervention strategies [1, 2]. Long-term clinical studies further demonstrate that repaired composite restorations can achieve survival rates comparable to fully replaced restorations, supporting repair as a valid long-term management option [3, 4].

Chemically cured bulk-fill resin composites have gained attention due to their ability to simplify restorative procedures by eliminating incremental placement and by reducing polymerization shrinkage stress [5, 6]. Stela (SDI, Australia) is a recently introduced self-cure bulk-fill composite designed to provide unlimited depth of cure and low polymerization contraction stress, offering favorable internal adaptation and broad clinical applicability [7, 8]. Although the Automix and Capsule formulations share a similar manufacturer-reported resin matrix chemistry, they differ substantially in filler loading, filler composition, and glass filler characteristics, all of which may influence surface morphology and repair performance [7–9].

Achieving durable adhesion between an aged composite substrate and a new repair layer requires an effective combination of micromechanical and chemical interactions. Mechanical roughening alone may be insufficient, and several studies have shown that the addition of chemical conditioning—such as phosphoric acid etching, silane application, or the use of universal adhesives—can enhance repair bond strength [10, 11]. Universal adhesives containing functional monomers such as 10-MDP have demonstrated promising results when used on aged composite substrates, although their performance is material-dependent and may vary according to the substrate's degree of conversion and surface characteristics [12–14]. Current evidence on the repair of bulk-fill composites predominantly focuses on light-cured systems, and data regarding self-cure bulk-fill materials are scarce [15–17].

A clinically relevant but underexplored factor is the choice of repair material. When the clinician knows that the failed restoration was fabricated with Stela, repairing the defect using the same composite and its proprietary primer may enhance chemical compatibility through shared monomer chemistry and compatible polymerization pathways [7–9]. Conversely, in routine clinical situations where the substrate identity is unknown, repair is commonly performed using a light-cure nanohybrid composite in combination with a universal adhesive, following contemporary composite-repair protocols [12–17]. To date, however, no study has examined whether repairing aged Stela substrates with self-cure composite yields different bond strengths compared with repair using a light-curing composite, nor whether these repair strategies interact with (1) the substrate composition and (2) the surface conditioning method.

Therefore, the present in vitro study aimed to evaluate the effects of (1) Stela substrate composition, (2) surface conditioning protocol, and (3) repair material type on the repair shear bond strength (SBS) of aged Stela substrates. The following research hypotheses were tested: substrate composition would affect the repair bond strength of the self-cure bulk-fill composite, the surface conditioning protocol would influence repair bond strength, the type of repair material would affect repair bond strength, and interactions would occur among substrate composition, surface conditioning protocol, and repair material type with respect to repair bond strength.

2 | Materials and Methods

2.1 | Study Design

This in vitro study investigated the effects of substrate composition (Automix vs. Capsule), surface conditioning protocol (with or without phosphoric acid), and repair material type (self-cure composite vs. light-cure composite) on the SBS of a self-cure bulk-fill resin composite (Stela; SDI, Australia) (Table 1). An a priori sample size calculation was performed using G*Power software (version 3.1.9.7; Heinrich Heine University, Düsseldorf, Germany) to determine the required sample size for this study. The calculation was performed using the *F*-test family and the "analysis of variance (ANOVA): fixed effects, special, main effects and interactions" procedure. Based on an effect size of $f = 0.40$, as reported in a previous repair bond strength study [13], an α error probability of 0.05 and a statistical power of 0.80, the minimum required total sample size was calculated as 52. To ensure equal allocation within the $2 \times 2 \times 2$ factorial design and increase statistical precision, 80 specimens were included, with 10 specimens assigned to each of the eight experimental groups. A schematic illustration of the experimental design and group allocation is presented in Figure 1.

2.2 | Specimen Preparation

2.2.1 | Fabrication of Substrate Specimens

Two substrate compositions of Stela—Automix and Capsule—were used as substrate materials, with 40 specimens prepared for each substrate material.

- Automix: The base and catalyst pastes were extruded through the automixing tip directly into square Teflon molds measuring 5×5 mm with a height of 4 mm.
- Capsule: The capsules were activated and triturated for 10 s in an amalgamator, and the material was dispensed into identical square Teflon molds (5×5 mm with a height of 4 mm).

A transparent Mylar strip and glass slide were positioned on the top and bottom mold surfaces during placement to obtain flat and standardized composite surfaces. All specimens were allowed to self-cure for 15 min, then stored in distilled water at 37°C for 24 h to ensure complete polymerization.

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TABLE 1 | Materials used in this study, including their manufacturer and chemical composition.

Product name	Manufacturer	Composition
Stela Capsule	SDI, Australia	Organic matrix: DUDMA (10%–25%), GDMA (5%–10%), silica amorphous, fumed (1%–10%), ytterbium fluoride (3%–7%), and 10-MDP (1%–5%). Filler content: Fluoro–alumino–silicate glass: median particle size 4.0 μm (distribution range ~2–8 μm). Filler loading: 76.8 wt% (55.4 vol%).
Stela Automix	SDI, Australia	Organic matrix: DUDMA (10%–25%), glycerol dimethacrylate (GDMA; 5%–10%), ytterbium fluoride (3%–7%), and 10-MDP (1%–5%). Filler content: Fluoro–alumino–silicate glass: mean particle size 4.0 μm (distribution range ~2–8 μm) and Barium–alumino–borosilicate glass: mean particle size 2.8 μm (distribution range ~2–5 μm). Filler loading: 61.2 wt% (36.4 vol%).
Stela Primer	SDI, Australia	Methyl ethyl ketone (10%–30%), 4-methacryloxyethyl trimellitic anhydride (10%–30%), acrylic monomer (10%–30%), 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP; 10%–30%), and diurethane dimethacrylate (DUDMA; 10%–30%)
G-Premio Bond	GC, Japan	10-MDP–4-META–dimethacrylate monomers–photoinitiators–acetone solvent–HEMA-free
G-ænial A'CHORD	GC, Japan	Bis-EMA, UDMA, TEGDMA, dimethacrylate co-monomers, silanizated barium glass (300 nm), fumed silica (16 nm), silicate glass (filler content: 41 vol%)

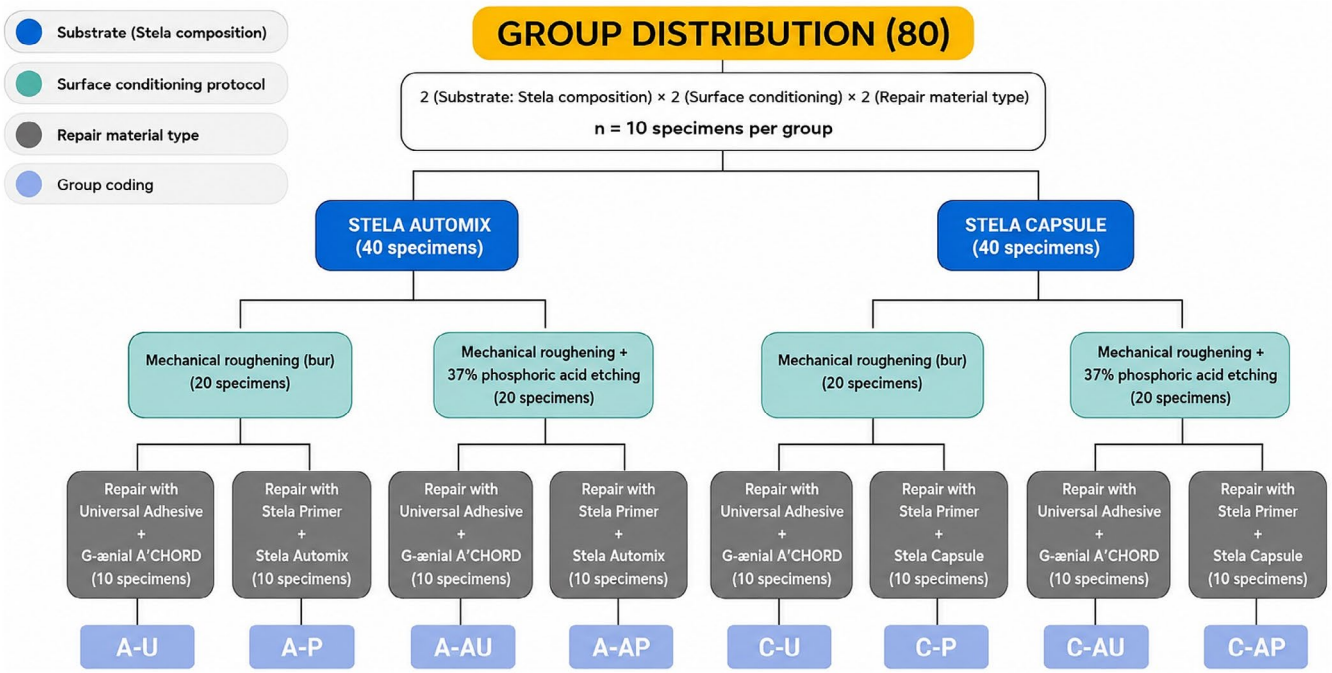


FIGURE 1 | Schematic illustration of the experimental workflow and allocation of the study groups. Specimens were divided according to substrate composition (Stela Automix or Stela Capsule), surface conditioning protocol (mechanical roughening with or without 37% phosphoric acid etching), and repair material type (universal adhesive + G-ænial A'CHORD or Stela Primer + the corresponding Stela composite), yielding eight experimental groups ($n = 10$ per group).

2.2.2 | Aging Procedure

The bonding surface was standardized by wet-polishing with 600-grit silicon carbide paper for 10 s. To simulate intraoral aging, all specimens underwent 10,000 thermocycles between 5°C and 55°C with a dwell time of 30 s and transfer time of 5 s.

Following aging, each specimen was embedded in autopolymerizing acrylic resin, leaving only one flat surface exposed for surface treatment and repair procedures. This approach was used to prevent flexural deformation of the thin substrate during SBS testing.

2.2.3 | Experimental Groups

Four Automix and four Capsule groups were created according to the surface treatment and the type of repair material ($n = 10$).

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2.3 | Surface Conditioning Protocols

2.3.1 | Mechanical Roughening (All Samples)

Mechanical roughening was performed using a fine-grit diamond bur (Komet Dental, Gebr. Brasseler GmbH, Lemgo, Germany) for 10 s under water cooling. To minimize variability, the same operator performed all surface roughening procedures, and a new bur was used after every five specimens.

2.3.2 | Phosphoric Acid Etching (Acid Groups Only)

Thirty-seven percent of phosphoric acid gel was applied for 15 s, rinsed thoroughly for 20 s, and gently air-dried.

2.3.3 | Stela Primer Application (Self-Cure Composite Repair Groups)

Stela Primer (SDI) was applied to the conditioned surface by actively scrubbing for 10 s, followed by gentle air-thinning and a waiting period of 30 s. No light-curing was performed, as the primer is chemically activated.

2.3.4 | Universal Adhesive Application (Light-Cure Composite Repair Groups)

A universal adhesive (G-Premio Bond; GC Corp.) was applied to the conditioned surface using active scrubbing for 20 s, followed by gentle air-drying for 5 s. The adhesive was then light-cured for 10 s using an LED curing unit with an output intensity greater than 1000 mW/cm^2, in accordance with the manufacturer's instructions.

2.4 | Repair Procedures

2.4.1 | Repair With Self-Cure Composite

After surface preparation, a cylindrical Teflon mold (2 mm in diameter × 2 mm in height) was positioned on the substrate surface, and fresh Stela (Automix or Capsule, matching the substrate form) was placed into the mold. Self-curing was allowed to occur for 15 min, after which the mold was carefully removed. The specimens were then stored in distilled water at 37°C for 24 h prior to testing.

2.4.2 | Repair With Light-Cure Composite

A nanohybrid light-cure composite (G-ænial A'CHORD; GC, Japan; A2 shade) was placed into an identical cylindrical Teflon mold. The composite was light-cured for 20 s from the top surface, after which the mold was carefully removed. Additional light curing was performed for 20 s from two lateral directions.

2.5 | SBS Testing

SBS was measured using a universal testing machine (Shimadzu IG-IS, Kyoto, Japan) equipped with a chisel-shaped shear testing jig at a crosshead speed of 1 mm/min until failure. The maximum load at failure was recorded, and bond strength (MPa) was calculated by dividing this load by the bonded surface area.

2.6 | Failure Mode Analysis

The fractured specimens were examined under a stereomicroscope at ×10 magnification (Olympus SZ-61, Japan) to evaluate the failure mode. Failure types were classified as adhesive failure, cohesive failure, or mixed failure.

2.7 | Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics software (Version 29.0; IBM Corp., Armonk, NY, USA). Data normality was assessed using the Shapiro–Wilk test. As the data were normally distributed, a three-way ANOVA was conducted to evaluate the main effects of substrate composition, surface conditioning protocol, and repair material type, as well as their possible interaction effects on SBS.

When statistically significant differences were detected, post hoc pairwise comparisons were performed using Tukey's honestly significant difference (HSD) test. Failure mode distributions were analyzed using Fisher's exact test. Statistical significance was set at $p < 0.05$ for all analyses.

3 | Results

Three-way ANOVA revealed that all three independent factors (substrate composition, surface treatment, and repair material type) had highly significant individual effects on SBS ($p < 0.001$). In addition, significant two-way interactions were identified between substrate composition × repair material ($p < 0.001$) and surface treatment × repair material ($p = 0.015$). However, the three-way interaction among substrate composition × surface treatment × repair material was not statistically significant ($p = 0.655$). This finding indicates that the trends observed for the combinations of surface treatment and repair material were generally consistent across both substrate compositions (Table 2).

Overall, Capsule specimens demonstrated significantly higher SBS values than Automix specimens, phosphoric acid etching resulted in significantly higher SBS than bur roughening alone, and repair with the self-cure composite yielded significantly higher SBS than repair with the light-cure composite (all $p < 0.001$).

In contrast, when the conventional light-cure composite was used as the repair material, bond strength values remained consistently lower across all combinations. The lowest SBS values were recorded in the Automix and Capsule groups that received only bur roughening before repair with the light-cure composite, with no significant difference between these two groups ($p > 0.05$). The addition of phosphoric acid etching significantly improved the performance of the light-cure composite on the Automix substrate ($p < 0.05$), whereas no statistically significant improvement was observed on the Capsule substrate ($p > 0.05$).

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Descriptive statistics for the repair SBS values of all experimental groups are presented in Table 3. The highest SBS values were obtained in the Capsule group repaired with its original material following bur roughening and phosphoric acid etching. This group exhibited significantly higher bond strength than all other experimental groups ($p < 0.05$), except for Group C-P ($p > 0.05$). A similar trend was observed in the Automix substrate groups, where phosphoric acid etching after bur roughening significantly improved bond strength when repair was performed with Stela ($p < 0.05$).

Failure mode distributions are presented in Table 4. Fisher's exact test revealed no statistically significant difference in failure mode distributions among the experimental groups ($p = 0.980$). Nevertheless, self-cure composite repair groups generally exhibited a higher proportion of cohesive and mixed failures, whereas light-cure composite repair groups showed a greater proportion of adhesive failures. The highest percentage of cohesive failures was observed in the C-AP group, which also demonstrated the highest bond strength values. Conversely, adhesive failures were most frequent in the A-U and C-U groups.

4 | Discussion

The present study evaluated the influence of substrate composition, surface conditioning protocol, and repair material type on the repair bond strength of an aged self-cure bulk-fill resin composite. The first three research hypotheses were rejected because substrate composition, surface conditioning, and repair material type each significantly affected repair SBS. The fourth hypothesis was also rejected, as significant interactions were identified between substrate composition × repair material and surface treatment × repair material, although no significant three-way interaction was observed.

The rejection of the first research hypothesis indicates that the substrate composition of Stela significantly influences repair bond strength. Specimens prepared using the Capsule formulation exhibited significantly higher repair bond strength values than those prepared with the Automix formulation. This finding may be associated with differences in filler loading, filler composition, glass filler characteristics, and the resulting microstructural properties of the two commercially

TABLE 2 | Three-way analysis of variance (ANOVA) for repair shear bond strength.

Source of variation	df	SS	MS	*F*-value	*p*
Substrate composition	1	70.835	70.835	50.315	< 0.001*
Surface treatment	1	21.611	21.611	15.351	< 0.001*
Repair material	1	744.922	744.922	529.133	< 0.001*
Substrate composition × surface treatment	1	3.555	3.555	2.525	0.116
Substrate composition × repair material	1	23.474	23.474	16.674	< 0.001*
Surface treatment × repair material	1	8.874	8.874	6.303	0.015*
Substrate composition × surface treatment × repair material	1	0.285	0.285	0.203	0.655
Error (residuals)	72	101.364	1.408	—	—
Total	79	974.920	—	—	—

Note: Statistically significant differences are indicated by an asterisk ($p < 0.05$).
Abbreviations: df = degrees of freedom; MS = mean square; SS = sum of squares.

TABLE 3 | Descriptive statistics and Tukey's post hoc comparisons of repair shear bond strength (MPa) for the experimental groups.

Group code	*n*	Mean ± SD (MPa)	Median	Minimum	Maximum	Tukey grouping
C-AP	10	23.6 ± 1.8	22.4	22.0	27.4	a
C-P	10	21.5 ± 1.2	21.8	19.5	22.7	ab
A-AP	10	19.9 ± 0.2	19.9	19.6	20.1	bc
A-P	10	18.7 ± 0.8	18.2	16.9	19.9	cd
A-AU	10	15.9 ± 1.1	15.5	14.4	17.5	de
C-AU	10	15.7 ± 0.9	15.5	14.4	17.3	e
C-U	10	13.9 ± 1.4	13.3	12.4	16.6	f
A-U	10	12.8 ± 1.1	12.8	10.4	14.9	f

Note: Groups sharing at least one common letter are not significantly different according to Tukey's HSD post hoc test ($p > 0.05$). Groups with no common letters differ significantly ($p < 0.05$).
Abbreviations: A = Automix; AP = Stela (self-cure composite) after bur roughening + phosphoric acid etching; AU = light-cure composite after bur roughening + phosphoric acid etching; C = Capsule; P = Stela (self-cure composite) after bur roughening; U = light-cure composite after bur roughening.

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TABLE 4 | Failure mode distribution (%) of repair bond strength specimens.

Group	Adhesive (%)	Cohesive in substrate (%)	Cohesive in repair (%)	Mixed (%)	*p*
A-P	60	10	10	20	0.980[a]
A-AP	40	20	10	30	
A-U	70	0	10	20	
A-AU	50	10	20	20	
C-P	40	20	10	30	
C-AP	20	30	20	30	
C-U	60	10	10	20	
C-AU	40	10	20	30	

Abbreviations: A = Automix; AP = Stela (self-cure composite) after bur roughening + phosphoric acid etching; AU = light-cure composite after bur roughening + phosphoric acid etching; C = Capsule; P = Stela (self-cure composite) after bur roughening; U = light-cure composite after bur roughening.
[a]Fisher's exact test.

available Stela formulations [7–9]. It should be emphasized that the observed differences should not be attributed solely to the delivery form. According to the manufacturer's technical information, the Automix and Capsule formulations differ not only in their dispensing systems but also in their filler characteristics. Therefore, the differences observed in this study most likely reflect the combined influence of both formulation- and delivery-related factors rather than the dispensing method alone. Higher filler loading has been associated with improved mechanical properties and reduced polymerization shrinkage, which may contribute to a more stable repair interface [5–7].

Moreover, differences in filler composition and packing density may influence surface roughness patterns after mechanical conditioning, thereby affecting micromechanical interlocking with the repair material [9, 13]. Beyond differences in filler loading, the superior repair bond strength observed in Capsule-based substrates may also be related to differences in polymerization kinetics and interfacial chemistry [5–7, 9]. Mechanical trituration of capsule-based materials has been reported to promote more homogeneous mixing, which may contribute to a higher degree of conversion and a more uniform polymer network compared with passive extrusion systems [7, 9]. These differences could potentially result in a chemically more stable and energetically favorable surface for interfacial bonding [5, 6]. However, degree of conversion, crosslink density, and polymer network characteristics were not directly evaluated in the present study; therefore, these mechanisms should be regarded as plausible explanations based on the available literature rather than experimentally confirmed findings. This interpretation is indirectly supported by the higher incidence of cohesive and mixed failures observed in the Capsule groups, suggesting that the repair interface may have exceeded the cohesive strength of the substrate composite.

Surface conditioning significantly influenced repair bond strength, leading to the rejection of the second research hypothesis. The addition of 37% phosphoric acid etching (bur + acid groups) resulted in higher bond strength values compared with mechanical roughening alone (bur groups). Although phosphoric acid does not chemically etch the inert resin matrix or barium glass fillers, its application effectively removes the smear layer and residual debris generated during diamond bur abrasion, thereby enhancing surface cleanliness and wettability [9, 17]. This cleaning mechanism facilitates better penetration and interaction of subsequent primers or adhesives with the conditioned composite surface [13, 16]. The visible shift toward increased cohesive and mixed failure modes in acid-treated groups in this study further supports the beneficial role of acid etching as an adjunctive surface conditioning step.

The strongest main effect observed in this study was associated with the type of repair material, rejecting the third research hypothesis. Repairs performed using the self-cure composite Stela demonstrated significantly higher bond strength values than those repaired with the light-cure nanohybrid composite. This finding underscores the profound importance of chemical compatibility between the aged substrate and the repair material. When the same composite system was used for both substrate and repair, the shared monomer chemistry (GDMA, DUDMA, 10-MDP) and compatible polymerization pathways facilitated seamless chemical interaction and interdiffusion across the repair interface via the chemically activated proprietary Stela Primer [7, 8].

In contrast, repairs performed with the light-cure composite relied on a universal adhesive layer (G-Premio Bond) to mediate bonding between chemically dissimilar materials. Despite the presence of functional monomers such as 10-MDP within the universal adhesive, its bonding performance in composite repair remains material-dependent and can be limited by elastic modulus mismatches and differences in polymerization kinetics (light-activated vs. chemically activated) [13, 14]. These variations create localized stress concentrations during shear testing, explaining the higher prevalence of adhesive failures and lower SBS values observed in the light-cure repair groups.

The interaction between substrate composition and repair material type indicates that the benefit of using the self-cure composite as a repair material was significantly more pronounced for Capsule substrates than for Automix substrates, where

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mechanical homogeneity and chemical compatibility synergistically optimized interfacial integrity [5, 7, 9]. Furthermore, the significant interaction between surface conditioning and repair material type demonstrates that the efficacy of phosphoric acid etching is highly material-dependent. Acid-catalyzed cleansing significantly upgraded the performance of the light-cure composite by modifying the substrate surface free energy, whereas its effect was less critical—yet still beneficial—when the inherent compatibility of the Stela system was utilized. Conversely, the lack of a three-way interaction suggests that these factors exert an additive rather than a synergistic effect under the conditions tested, behaving consistently across both substrate delivery forms [15, 16].

Failure mode analysis provided valuable insight into the mechanical integrity of the repair interface. Specimens repaired with the self-cure composite predominantly exhibited cohesive or mixed failures, indicating that the bond strength at the repair interface exceeded the cohesive strength of the material. Conversely, specimens repaired with a light-cure composite showed a higher frequency of adhesive failures, particularly in nonetched groups. This strong correlation between higher bond strength values and cohesive/mixed failure patterns has been widely reported in composite repair literature, supporting the clinical relevance of SBS testing as a reliable indicator of repair quality [13, 17].

Clinically, the results of this study suggest that when the identity of the failed restoration is known to be Stela, repairing the defect using the same self-cure bulk-fill composite and its proprietary primer provides superior bonding performance and enhances repair longevity. In daily clinical situations where the substrate material is unknown, the conventional use of a light-cure composite in combination with a universal adhesive remains a practical alternative, provided that phosphoric acid etching is incorporated into the protocol to maximize surface cleaning and wettability [11, 14].

This study has limitations inherent to its in vitro design. Thermocycling was used to simulate intraoral aging; however, this laboratory method cannot fully replicate the complex mechanical, thermal, and chemical challenges of the oral cavity. In addition, the repair material variable was inherently linked to its corresponding bonding protocol. Specifically, repair with the self-cure composite was performed using the proprietary Stela Primer, whereas repair with the light-cure composite was performed using a universal adhesive. Therefore, the individual effects of the restorative material and the bonding system could not be completely separated. Accordingly, the observed differences should be interpreted as reflecting the combined performance of two clinically relevant repair systems rather than the restorative materials alone. Future studies should evaluate the restorative materials and bonding protocols independently to better clarify their individual contributions to repair bond strength. Furthermore, long-term fatigue behavior, alternative aging protocols, and different adhesive strategies should be investigated to further elucidate the durability of repair interfaces in self-cure bulk-fill composites. Clinical studies are also required to confirm the translational relevance of these findings.

5 | Conclusion

Within the limitations of this in vitro study, repair bond strength of a self-cure bulk-fill resin composite was significantly affected by substrate composition, surface conditioning protocol, and repair material type. Capsule-based substrates and repairs performed with the same self-cure composite showed superior bond strength. Phosphoric acid etching generally improved repair performance, although its effect varied according to the repair material and substrate combination. Light-cure composite repair with a universal adhesive resulted in lower bond strength values.

Author Contributions

Esra Yildirim-Manav: writing – review and editing, writing – original draft, methodology, investigation, data curation. **Sema Yazici-Akbiyik:** writing – review and editing, validation, methodology, formal analysis, data curation, conceptualization. **Sedanur Sakalli:** writing – review and editing, validation, methodology, formal analysis, data curation, conceptualization. **Simge Canatan-Keskin:** writing – review and editing, writing – original draft, validation, investigation, data curation, conceptualization. **Sıla Nur Usta:** writing – review and editing, writing – original draft, validation, supervision, project administration, investigation, data curation, conceptualization.

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Disclosure

The authors have nothing to report.

Ethics Statement

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

1. M. Belleflamme, L. Seidel, A. Albert, A. Bolette, and A. Guéders, "Two-Year Clinical Comparison of Direct and Indirect Composite Restorations in Severely Damaged Molars: A Split-Mouth Randomized Clinical Study," *Journal of Dentistry* 165 (2026): 106785.

2. Ö. Hatipoğlu, J. F. B. Martins, M. I. Karobari, et al., "Clinical Decision-Making of Repair vs. Replacement of Defective Direct Dental Restorations: A Multinational Cross-Sectional Study With Meta-Analysis," *Journal of Esthetic and Restorative Dentistry* 37, no. 4 (2025): 977–991.

3. E. Fernández, A. C. Gil, R. Caviedes, L. Díaz, and C. Bersezio, "Clinical Longevity of Direct Dental Restorations: An Umbrella Review of Systematic Reviews," *Journal of Esthetic and Restorative Dentistry* 38, no. 2 (2026): 307–324.

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4. R. Hickel, S. Mesinger, N. Opdam, et al., "Revised FDI Criteria for Evaluating Direct and Indirect Dental Restorations—Recommendations for Its Clinical Use, Interpretation, and Reporting," *Clinical Oral Investigations* 27, no. 6 (2023): 2573–2592.

5. M. G. F. de Souza, E. E. M. Vasconcelos, C. T. Haur, et al., "Evaluation of Physical, Chemical, and Mechanical Properties of a Self-Curing Bulk-Fill Resin Composite: An In Vitro Comparative Study," *Journal of Clinical and Experimental Dentistry* 17, no. 12 (2025): e1463.

6. N. Attik, P. Colon, R. Gauthier, C. Chevalier, B. Grosgogeat, and H. Abouelleil, "Comparison of Physical and Biological Properties of a Flowable Fiber Reinforced and Bulk Filling Composites," *Dental Materials* 38, no. 2 (2022): e19–e30.

7. J. A. G. Guarneri, C. Maucoski, S. Ghaffari, B. D. MacNeil, R. B. Price, and C. A. G. Arrais, "Ability of a Novel Primer to Enhance the Polymerization of a Self-Cured Resin Composite," *Dental Materials* 41, no. 1 (2025): 42–50, https://doi.org/10.1016/j.dental.2024.10.013.

8. E. H. Albelasy, A. G. Raghip, and H. S. Ismail, "Internal Adaptation and Micromorphological Analysis of a New Self-Cure Resin Composite," *Journal of Clinical and Experimental Dentistry* 17, no. 8 (2025): e912–e919.

9. A. D. Loguercio, B. Carpio-Salvatierra, R. Ñaupari-Villasante, et al., "Clinical Evaluation of a New Chemically-Cured Bulk-Fill Composite in Posterior Restorations: 18-Month Multicenter Double-Blind Randomized Clinical Trial," *Journal of Dentistry* 162 (2025): 106031.

10. D. Bompolaki, E. B. Lubisich, and A. P. Fugolin, "Resin-Based Composites for Direct and Indirect Restorations: Clinical Applications, Recent Advances, and Future Trends," *Dental Clinics* 66, no. 4 (2022): 517–536.

11. M. D. Furtado, F. Immich, W. L. da Rosa, E. Piva, and A. F. da Silva, "Repair of Aged Restorations Made in Direct Resin Composite—A Systematic Review," *International Journal of Adhesion and Adhesives* 124 (2023): 103367, https://doi.org/10.1016/j.ijadhadh.2023.103367.

12. T. Amran, J. Esati, R. Weiger, M. B. Blatz, and F. Eggmann, "Impact of Phosphoric Acid Etching Duration on the Bonding Performance of Universal Adhesives on Enamel: A Systematic Review of Laboratory Studies," *Journal of Esthetic and Restorative Dentistry* 38, no. 4 (2026): 780–791.

13. E. E. Devrimci, H. Kemaloglu, C. Peskersoy, T. Pamir, and M. Turkun, "Shear Bond Strength and Finite Element Stress Analysis of Composite Repair Using Various Adhesive Strategies With and Without Silane Application," *Applied Sciences* 15, no. 15 (2025): 8159.

14. H. Yin, S. Kwon, S. H. Chung, and R. J. Y. Kim, "Performance of Universal Adhesives in Composite Resin Repair," *BioMed Research International* 2022 (2022): 7663490, https://doi.org/10.1155/2022/7663490.

15. A. L. R. Vilela, A. D. G. Soares, A. C. Machado, M. G. Borges, L. H. A. Raposo, and M. D. S. Menezes, "Impact of Repair Protocols on the Bond Strength to Composite Resin," *Odontology* 113, no. 2 (2025): 685–692.

16. M. Binhasan, F. Althobaiti, R. Alyami, K. Aljabri, T. Alabbas, and H. Barakah, "Effect of Surface Treatments on Repair Bond Strength of Aged Bulk-Fill Resin Composites," *Polymers* 17, no. 17 (2025): 2326, https://doi.org/10.3390/polym17172326.

17. A. Altuğ Yıldırım and M. B. Üçtaşlı, "The Role of Aging and Various Surface Preparation Methods in the Repair of Nanohybrid Composites," *BMC Oral Health* 25, no. 1 (2025): 113.

17088240, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/jerd.70243 by Esra YILDIRIM MANAV - Lokman Hekim University , Wiley Online Library on [27/07/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License