# Comparative Evaluation Of Surface Conditioning Methods On The Tensile Bond Strength Between Composite And Porcelain: An In Vitro Study

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**KEYWORDS**

Tensile bond, porcelain, composite, surface conditioning

**ABSTRACT:**

**Background:** Ceramic restorations are preferred in dentistry for their esthetics, durability, and biocompatibility, but chipping and minor fractures are common. Repairing defective ceramics preserves tooth structure, reduces treatment time, and prolongs restoration longevity. Successful repair relies on strong adhesion between resin composite and porcelain, which can be enhanced through surface conditioning methods such as mechanical roughening, acid etching, salinization, or bond activators. This study aimed to compare the tensile bond strength (TBS) of resin composite to porcelain using different surface conditioning techniques. **Methods:** An in vitro comparative study was conducted on 48 standardized porcelain and composite blocks (30 mm × 3 mm × 3 mm), divided into three groups: Control (no conditioning), Silane-treated, and Porcelain Activator + Silane (PA+Silane). All specimens were bonded with dual-cure resin cement and stored in distilled water at 37 °C for 7 days. TBS was measured using a universal testing machine at 0.5 mm/min. Data were analyzed with independent t-tests and Tukey HSD post-hoc analysis ($P < 0.05$). **Results:** TBS increased progressively across the groups: Control (8.24 MPa), Silane (9.50 MPa), and PA+Silane (11.01 MPa), with all differences statistically significant. SEM images showed minimal bonding in the Control group, moderate bonding with Silane, and the strongest, well-adapted interface with micro-retentive features in the PA+Silane group, indicating enhanced micromechanical and chemical adhesion. **Conclusion:** Combined phosphoric acid etching and silane treatment provides the strongest and most reliable bond between resin composite and porcelain. This approach offers an effective repair protocol that maximizes adhesion, durability, and clinical performance of ceramic restorations.

## INTRODUCTION

Ceramic materials are widely used in restorative dentistry because they provide metal-free restorations with excellent esthetics, shade stability, biocompatibility, high wear resistance, and low thermal conductivity.[1] Despite these advantages and improvements in mechanical properties, chipping remains a common cause of failure, often necessitating replacement of the restoration. [2] When replacement is not feasible—due to the need to preserve sound tooth structure, avoid procedural trauma, or reduce treatment time—repair of the restoration is recommended if the periodontium is healthy.[3]

Repairing defective ceramic or resin composite restorations is increasingly preferred over complete replacement, as it prolongs restoration longevity, conserves tooth structure, and is a cost- and time-efficient approach. [3,4] The success of such repairs depends largely on the bond strength between the repair composite and porcelain. A strong bond interface ensures proper adhesion, prevents debonding and microleakage, and maintains both esthetics and functional integrity of the restoration. [1,5]

Initially, zirconia restorations were cemented using conventional cements such as zinc phosphate or resin-modified glass ionomer, but resin cements provide higher bond strength and effectively seal minor internal flaws. This is particularly important for CAD/CAM-milled zirconia restorations, which have minimal inherent mechanical retention. [6,7] Despite these advances, there is no standardized protocol for repairing ceramics, and bond strength outcomes reported in the literature vary widely.[8]

Surface conditioning is critical to enhance adhesion between resin composite and porcelain. Methods include mechanical roughening, acid etching, silanization, or combinations of these techniques.[3] Mechanical abrasion using aluminum oxide with air-borne particle treatment has shown high effectiveness. [9] while silane coupling agents applied after acid etching improve chemical bonding with the restorative material.[10] Additionally, porcelain bond activators efficiently condition the inner surfaces of glassy ceramics, promoting strong resin adhesion.[11]

Despite these developments, information on the long-term performance of repaired restorations remains limited. Therefore, this study aimed to comparatively evaluate the tensile bond strength of resin composite to porcelain following different surface conditioning methods and to observe the bond interface. The findings are intended to provide evidence-based guidance for clinicians in selecting effective repair protocols for defective ceramic restorations.

## MATERIALS AND METHODS:

**Study design:** This cross-sectional comparative in vitro study was conducted over a period of one year, from 1st March 2024 to 28th February 2025. The research was carried out at the Department of Prosthodontics, Faculty of Dentistry, Bangladesh Medical University (BMU), Shahbag, Dhaka, and at the Departments of Nano Ceramic Engineering and Materials & Metallurgical Engineering, BUET, Dhaka, Bangladesh.

**Study population and size**: A total of 48 porcelain and composite blocks were bonded using a resin luting agent.

**Sampling technique**: Using purposive sampling, 48 defect-free porcelain blocks of standardized dimensions were prepared for resin bond strength testing.

**Data collection tools and procedure**: Data were collected using a structured sheet. Forty-eight porcelain blocks and corresponding composite blocks were prepared, surface-conditioned (Control, Silane, PA+Silane), and bonded with dual-cure resin cement (Panavia V5). Specimens were stored in distilled water at 37 °C for 7 days. Tensile bond strength was tested using a universal testing machine at 0.5 mm/min, and TBS (MPa) was calculated as force divided by bonding surface area.

**Data analysis:** Data were entered into Excel and analyzed using SPSS v30 with independent t-tests; $P < 0.05$ was considered significant.

**Ethical consideration:** Ethical clearance was obtained from BMU IRB, with departmental permission; laboratory and testing work was conducted at BMU and BUET following standard protocols.

## OPERATIONAL DEFINITION:

**Porcelain:** Porcelain can be defined as a type of ceramic material that is made by heating materials such as clay and feldspar at high temperature. Porcelain is typically very hard and durable, and is often used in the production of dental restorations, such as crowns and bridges. Operationally, porcelain can be identified by its specific composition, manufacturing process and physical properties, including its high heat resistance, low porosity and translucency.[12]

**Composite:** A composite can be defined as a material made from two or more distinct components, each of which has properties that are significantly different from the others. The components can be different types of materials, such as polymers, metals, ceramics or fibers, or they can be different forms of the same material. The composite material is formed by combining the components in a way that produces a desirable set of properties, such as strength, stiffness, durability or resistance to corrosion.[11]

**Tensile Bond Strength:** Tensile bond strength is defined as the force needed to separate two materials (usually adhesive and substrate) that have been bonded together by pulling them apart in opposite directions, perpendicular to the plane of the bond. It is typically measured in units of force per unit area, such as pounds per square inch (psi) or megapascals (MPa). Tensile bond strength is an important property of adhesives and their ability to hold materials together under various loading conditions.[13]

**Bond Interface**: A bond interface can be defined as the boundary or region where two materials are joined together through bonding. This interface is the area where the two materials interact with each other chemically or physically and can influence the overall strength and durability of the bond. The bond interface can vary in thickness and composition, and is formed by the interaction between the adhesive material and the surfaces being bonded.[11]

## RESULTS:

In this cross-sectional comparative -in vitro study, a total of 48 samples of the tensile bond strength values between composite and porcelain varied significantly across the three surface conditioning groups: Sample without Conditioning, Sample conditioned with silane coupling agent (Porcelain Bond Activator-PBA) and Sample conditioned with Phosphoric acid (K-Etchant) combined with silane coupling agent (PBA).

**Table-1: Descriptive statistic of the tensile bond strength (MPa) of Group-1, group-2 and group-3 (N=48)**

| Group | n | Mean (MPa) | SD | Median | Minimum | Maximum |
|---|---|---|---|---|---|---|
| Group-1 | 16 | 8.24 | 1.16 | 8.195 | 5.97 | 10.16 |
| Group-2 | 16 | 9.50 | 1.00 | 9.74 | 7.75 | 11.30 |
| Group-3 | 16 | 11.01 | 0.79 | 10.98 | 9.65 | 12.56 |

Descriptive analysis was done SD = Standard Deviation MPa= Mega Pascel, N= sample size
Group-1= Sample without Conditioning
Group-2= Sample conditioned with Silane coupling agent
Group-3= Sample conditioned with Phosphoric acid combined with silane coupling agent

Table-1 shows, the descriptive statistics of a progressive increase in tensile bond strength (TBS) across the three groups. Group-1 (Control), which received no surface conditioning, exhibited the lowest mean TBS at 8.24 ± 1.16 MPa, indicating a weaker bond at the composite to porcelain interface. Group-2, treated with silane coupling (Porcelain Bond Activator-PBA) alone, showed a moderate improvement with a mean TBS of 9.50 ± 1.00 MPa, suggesting that chemical bonding through silane coupling enhances adhesion. The highest bond strength was observed in Group-3, which underwent combined phosphoric acid (K-Etchant) and silane coupling (PBA) treatment, achieving a mean TBS of 11.01 ± 0.79 MPa. This result implies that mechanical roughening via etching, followed by chemical priming, creates a synergistic effect that significantly improves the micromechanical and chemical retention of the resin composite to the porcelain substrate. The median and minimum/maximum values support the consistency and reliability of the observed trend, with Group-3 showing not only the highest mean but also the narrowest standard deviation, indicating more uniform bond strength outcomes.

**Table-2: Comparison of Tensile Bond Strength (MPa) between Group-1 and Group-2 (n=32)**

| **Groups** | **n** | **Mean (MPa) ±SD** | **Mean Difference (MPa)** | **p-value** | **95% Confidence Interval of the Difference (MPa)** |
|---|---|---|---|---|---|
| Group-1 | 16 | 8.24±1.16 | 1.26 | 0.003 | -2.04 to -0.48 |
| Group-2 | 16 | 9.50±0.99 | | | |

P-value obtained by independent t-test, P<0.05 was considered as a level of *significant Independent samples t-test was done
SD = Standard Deviation MPa= Mega Pascel
n= sample size
P= Probability value
Group-1= Sample without Conditioning
Group-2= Sample conditioned with Silane coupling agent

Table-2 shows the independent t-test was conducted to compare the tensile bond strength between the Control group and the silane coupling agent group. There was a significant difference in scores for Control (M = 8.24, SD = 1.16) and silane coupling agent (M = 9.50, SD = 0.99); t (30) = -3.30, p = 0.003. The mean difference was 1.26 MPa (95% CI: -2.04 to -0.48), indicating that the use of silane coupling agent significantly increased tensile bond strength compared to the control.

**Table-3: Comparison of Tensile Bond Strength (MPa) between Group-1 and Group-3 (n=32)**

| **Groups** | **n** | **Mean (MPa) ±SD** | **Mean Difference (MPa)** | **p-value** | **95% Confidence Interval of the Difference (MPa)** |
|---|---|---|---|---|---|
| Group-1 | 16 | 8.24±1.16 | 2.77 | 0.000 | -3.48 to -2.05 |
| Group-3 | 16 | 11.01±0.79 | | | |

P-value obtained by Independent t-test, P<0.05 was considered as a level of *significant Independent samples t-test was done
SD = Standard Deviation MPa= Mega Pascel
n= sample size
P = Probability value
Group-1= Sample without Conditioning
Group-3= Sample conditioned with Phosphoric acid combined with silane coupling agent.

Table-3 shows the independent t-test was performed to compare the tensile bond strength between the Control group and the phosphoric acid combined with silane coupling agent group. The results showed a significant difference in mean bond strength for Control (M = 8.24, SD = 1.16) and phosphoric acid combined with silane coupling agent group (M = 11.01, SD = 0.79); t(30) = -7.89, p <0 .05. The mean difference was 2.77 MPa (95% CI: -3.48 to -2.05), indicating a substantial improvement in tensile bond strength with the combined surface treatment.

**Table-4: Comparison of Tensile Bond Strength (MPa) between Group-2 and Group-3 (n=32)**

| Groups | n | Mean (MPa) ±SD | Mean Difference (MPa) | p-value | 95% Confidence Interval of the Difference (MPa) |
|---|---|---|---|---|---|
| Group-2 | 16 | 9.50±0.99 | 1.51 | 0.000 | 0.86 to 2.16 |
| Group-3 | 16 | 11.0±0.79 | | | |

P-value obtained by independent t-test, P<0.05 was considered as a level of *significant Independent samples t-test was done
SD = Standard Deviation MPa= Mega Pascel
n= sample size
P = Probability value
Group-2= Sample conditioned with Silane coupling agent
Group-3= Sample conditioned with Phosphoric acid combined with silane coupling agent.

Table-4 shows the independent t-test was conducted to compare the tensile bond strength between the silane coupling agent group and the phosphoric acid combined with silane coupling agent group. There was a significant difference in bond strength between silane coupling agent (M = 9.50, SD = 0.99) and phosphoric acid + silane coupling agent (M = 11.01, SD = 0.79); t(30) = 4.75, $p < 0.05$. The mean difference was 1.51 MPa (95% CI: 0.86 to 2.16), indicating that combining phosphoric acid with silane coupling agent significantly improved bond strength over using silane coupling agent alone.

**Table-5: Tukey HSD post hoc test comparing the tensile bond strength (MPa) among the three groups (N=48)**

| Groups | Mean Difference (MPa) | p-value | 95% CI |
|---|---|---|---|
| Group-1 vs Group-2 | 1.26 | 0.003 | 0.48 – 2.04 |
| Group-1 vs Group-3 | 2.77 | 0.000 | 2.05 – 3.48 |
| Group-3 vs Group-2 | 1.51 | 0.000 | 0.86 – 2.16 |

P-value obtained by post-hoc analysis using the Tukey HSD test, P<0.05 was considered as a level of *significant
Post-hoc analysis using the Tukey HSD test was done N= Sample size
P = Probability value
Group-1= Sample without Conditioning
Group-2= Sample conditioned with Silane coupling agent
Group-3= Sample conditioned with Phosphoric acid combined with silane coupling agent

Table-5 shows the Post hoc analysis using Tukey's Honest Significant Difference (HSD) test revealed statistically significant differences in tensile bond strength among all surface conditioning groups. The Silane Coupling Agent group exhibited a significantly higher mean bond strength than the Control group (Mean Difference = 1.26 MPa, $p = 0.003$), indicating that silanation alone enhances resin–porcelain adhesion. Furthermore, the phosphoric acid combined with silane coupling agent group demonstrated the highest bond strength, with statistically significant differences observed when compared to both the Control (Mean Difference = 2.77 MPa, $p = 0.000$) and the Silane-only group (Mean Difference = 1.51 MPa, $p = 0.000$). These findings confirm that the combined use of phosphoric acid etching and silane application produces a synergistic effect, significantly improving the tensile bond strength and providing a more reliable and effective surface treatment protocol for resin composite to porcelain bonding.

### Bond Interface Observation

In this cross-sectional Comparative -in vitro study, a total of 48 samples of the bond interface observations between composite and porcelain varied significantly across the three surface conditioning groups: Sample without conditioning, Sample conditioned with silane coupling agent and Sample conditioned with Phosphoric acid combined with silane coupling agent.

## DISCUSSION:

Porcelain surface treatments with silane or phosphoric acid plus silane significantly increased tensile bond strength, with the latter showing the highest values.

Table 1 shows that tensile bond strength (TBS) significantly increased with surface treatment. The untreated control group had the lowest TBS (8.24 ± 1.16 MPa), while silane-treated specimens showed moderate improvement (9.50 ± 1.00 MPa). The highest TBS was observed in specimens treated with phosphoric acid followed by silane (11.01 ± 0.79 MPa). These results highlight that combining chemical and micromechanical conditioning enhances resin–ceramic adhesion, improving both surface wettability and bond durability, in agreement with previous studies. [14,15,16]

Table 2 shows that Group 2, treated with silane only, had significantly higher tensile bond strength than the control (9.50 ± 0.99 vs. 8.24 ± 1.16 MPa; $p = 0.003$). The improvement is attributed to silane's chemical bonding with porcelain and resin, though bond strength remained lower than that achieved with combined mechanical and chemical surface treatments. [15,17]

Table 3 shows that Group 3 (K-etchant + silane) had significantly higher tensile bond strength than the control (11.01 ± 0.79 vs. 8.24 ± 1.16 MPa; $p < 0.001$). The improvement is attributed to microroughness created by etching and chemical bonding by silane, resulting in enhanced mechanical and chemical adhesion, consistent with previous studies. [11,15,17]

Table 4 shows that Group 3 (K-etchant + silane) had significantly higher TBS than Group 2 (11.01 ± 0.79 vs. 9.50 ± 0.99 MPa; $p < 0.001$). The combination of etching-induced microroughness and silane chemistry enhanced both mechanical interlocking and chemical adhesion, consistent with previous studies. [11,15,16,17]

Table-5 shows that tensile bond strength (TBS) increased significantly with surface conditioning. Group-2 (Porcelain Bond Activator) improved over Control (1.17 MPa, $p = 0.002$), reflecting silane's chemical bonding with porcelain and resin.[15] showed the highest TBS versus Control (2.83 MPa, $p = 0.001$) and Group-2 (1.66 MPa, $p = 0.001$), demonstrating the synergistic effect of acid etching and silanization, enhancing mechanical retention and adhesion. [15,17] These findings support dual treatment as the optimal protocol for clinical resin–porcelain bonding.

## CONCLUSION:

This study confirms that surface conditioning plays a crucial role in enhancing the tensile bond strength between composite and porcelain. While silane coupling alone significantly improves adhesion compared to unconditioned surfaces, the combination of phosphoric acid etching and silane application produces the highest tensile bond strength. This synergistic effect results from the integration of mechanical roughening, which facilitates micromechanical retention, and chemical priming, which promotes siloxane bond formation between resin and porcelain. The findings highlight that dual surface treatment not only strengthens the bond but also ensures more uniform and reliable outcomes. Clinically, adopting phosphoric acid etching followed by silanization as a standard protocol can improve the longevity and performance of restorations such as porcelain veneers, inlays and composite repairs, enhancing resistance to mechanical and thermal stresses in the oral environment. These results provide practical guidance for optimizing resin–porcelain adhesion in restorative dentistry and support evidence-based decision-making for dental practitioners.

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