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RESEARCH ARTICLE
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SCANNING ELECTRON MICROSCOPIC ANALYSIS OF THE BOND INTERFACE BETWEEN COMPOSITE AND PORCELAIN AFTER DIFFERENT SURFACE CONDITIONING TREATMENTS

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Abstract

Background: Ceramic materials are widely used in fixed prosthodontics and esthetic restorations due to their durability, biocompatibility, and esthetic appeal. However, they are prone to chipping or fracture, often requiring repair. Intraoral composite resin repair is a conservative and cost-effective approach, but its success depends on strong adhesion achieved through micromechanical interlocking and chemical bonding, which can be enhanced by surface conditioning methods such as acid etching and silane application. This study evaluated the effects of different surface conditioning techniques on the bond interface between composite resin and porcelain using scanning electron microscopy (SEM). ***Methods:*** This cross-sectional *in vitro* study was conducted at BMU and BUET, Dhaka, from March 2024 to February 2025. Forty-eight porcelain discs (15 mm × 3 mm × 3 mm) were divided into three groups (n = 16): Group 1—no conditioning, Group 2—silane coupling agent, and Group 3—phosphoric acid etching plus silane. Composite resin was bonded to conditioned surfaces, stored in distilled water at 37°C for 24 hours, sectioned, polished, sputter-coated, and examined under SEM at ×1500 magnification. Bond line continuity, surface roughness, micromechanical interlocking, resin penetration, and overall bond quality were qualitatively analyzed. ***Results:*** SEM revealed clear differences among groups. Unconditioned samples showed a thin, irregular bond line with minimal micromechanical interlocking. Silane-treated samples exhibited improved chemical bonding and a more continuous interface, but limited mechanical retention. The combination of phosphoric acid and silane produced a roughened porcelain surface with intimate composite adaptation, well-defined micro-retentive features, and enhanced micromechanical and chemical bonding, yielding the highest bond quality. ***Conclusion:*** Phosphoric acid etching followed by silane application provides the strongest and most durable bond between porcelain and composite resin, making it the preferred method for intraoral repairs.

Keywords: composite, porcelain, surface conditioning, scanning electron microscope, bond interface

INTRODUCTION

The use of ceramic materials, particularly silica-based porcelains, in fixed prosthodontics and esthetic restorations has increased significantly now due to their good esthetic properties, biocompatibility, and resistance to wear.[1] [Ceramic restoration are used as porcelain veneers, inlays, crowns. [2] Despite these advantages, there are some disadvantages of ceramic restorations like they are prone to chipping or fracture, particularly in posterior regions or areas subjected to high functional loads and fatigue. Such failures can compromise the structural integrity and longevity of the restoration, so it requires partial or complete replacement.[3] In case of replacing the restoration, intraoral repair with composite has become a conservative and cost-effective procedure.[4]

Previously, no standard protocol has been demonstrated for repair purposes and the obtained bond strength values vary widely in previous studies.[5] In such ceramics, acid etching does not produce significant topographic change to achieve proper micro-mechanical bonding of resin materials (Amaral, R., et al 2008). Recently, numerous surface conditioning methods are suggested in order to enhance the adhesion of resin composites to the restorative materials [6]. However, the long-term success of such repairs critically depends on achieving a strong and durable bond between the resin composite and the porcelain substrate [7] and also effective adhesion relies on both micro mechanical interlocking and chemical bonding between resin and ceramic surface [8]. To increase the bonding several surface conditioning treatments such as hydrofluoric acid etching, air abrasion, silane coupling [9]. Silane coupling improves the adhesion by foaming siloxane bonds between silica in porcelain and methacrylate groups in resin.[10]

During a study they used FE SEM (Field Emission Scanning Electron Microscopy) to evaluate the interface between porcelain and resin after surface treatments. They found a strong micromechanical interlocking of the luting resin into the pits on both acid etched porcelain and acid etched tooth surface and the etched porcelain surface was more retentive.[11] There are some dental researches in Bangladesh on bonding to dentin studies but not on the microscopic interface between porcelain and composite. The aim of this study was to evaluate and compare the effect of different surface conditioning methods on the tensile bond strength and interfacial characteristics between composite resin and porcelain using Scanning Electron Microscopic (SEM) analysis.

METHODOLOGY

Study Setting and Period:

The study was conducted at the Department of Prosthodontics, Faculty of Dentistry, Bangladesh Medical University (BMU), Shahbag, Dhaka, and the Departments of Non-Ceramic Engineering and Materials & Metallurgical Engineering, BUET, Dhaka, Bangladesh. The study was carried out over a period of one year, from 1st March 2024 to 28th February 2025.

Study Design

This was a cross-sectional, comparative *in vitro* experimental study designed to evaluate and compare the bond interface characteristics between composite resin and porcelain after different surface conditioning treatments using Scanning Electron Microscopic (SEM) analysis.

Sample Size and Grouping

A total of 48 porcelain samples were prepared and randomly divided into three groups (n = 16 per group) according to the surface conditioning treatment applied before bonding with composite resin:

- **Group 1:** No surface conditioning (control)

- **Group 2:** Surface conditioning with silane coupling agent only
- **Group 3:** Surface conditioning with phosphoric acid etching followed by silane coupling agent

Sample Preparation
Porcelain discs were fabricated using conventional dental ceramic materials commonly used for fixed prosthodontic restorations.
- Each porcelain disc measured approximately 10 mm in diameter and 3 mm in thickness.
- The porcelain samples were glazed and then cleaned ultrasonically in distilled water for 10 minutes to remove surface contaminants before surface conditioning.

Surface Conditioning Procedures
1. **Group 1 – Control (No Conditioning):**
The glazed porcelain surface was left untreated before bonding with the composite resin.
2. **Group 2 – Silane Treatment:**
The porcelain surface was cleaned with alcohol and air-dried. A uniform layer of silane coupling agent (e.g., 3-methacryloxypropyltrimethoxysilane) was applied with a microbrush, allowed to react for 60 seconds, and then air-dried.
3. **Group 3 – Phosphoric Acid + Silane Treatment:**
The porcelain surface was etched with 37% phosphoric acid for 60 seconds, rinsed thoroughly with water, and air-dried. After etching, silane coupling agent was applied as described for Group 2.

Composite Bonding Procedure
- Following surface conditioning, a bonding agent was applied to each sample and light-cured according to the manufacturer’s instructions.
- A standardized amount of nanohybrid composite resin was placed on the conditioned porcelain surface using a cylindrical mold (4 mm diameter, 3 mm height).
- Each composite build-up was light-cured for 40 seconds using an LED curing unit.

Storage Conditions
All bonded specimens were stored in distilled water at 37°C for 24 hours to simulate oral conditions before testing and SEM observation.

Specimen Sectioning for SEM Analysis
After storage, all samples were sectioned perpendicularly through the center of the bonded interface using a low-speed diamond saw under water cooling. The sectioned surfaces were polished with silicon carbide papers of increasing grit (600–1200) and cleaned ultrasonically.

Scanning Electron Microscopy (SEM) Observation
- Specimens were dried and sputter-coated with gold-palladium to provide surface conductivity.
- The interfacial characteristics between the composite and porcelain were examined using a Scanning Electron Microscope (SEM) at ×1500 magnification under 10 µm scale.
- SEM images were captured for all samples to evaluate the morphological features and bonding integrity at the composite–porcelain interface.

Outcome Measures
The following parameters were analyzed qualitatively based on SEM images:
- Continuity and thickness of the bond line
- Presence of micro-retentive features and surface roughness
- Degree of resin penetration into the porcelain surface
- Nature of micromechanical interlocking and chemical adaptation

Data Analysis

SEM micrographs were qualitatively analyzed and visually compared among the three groups to evaluate variations in surface morphology and bonding characteristics. Descriptive comparisons were performed to determine which surface conditioning method produced the most effective interfacial adaptation and bond quality. The observations focused on bond line continuity, surface roughness, micromechanical interlocking, resin penetration, and overall bond integrity.

RESULT:

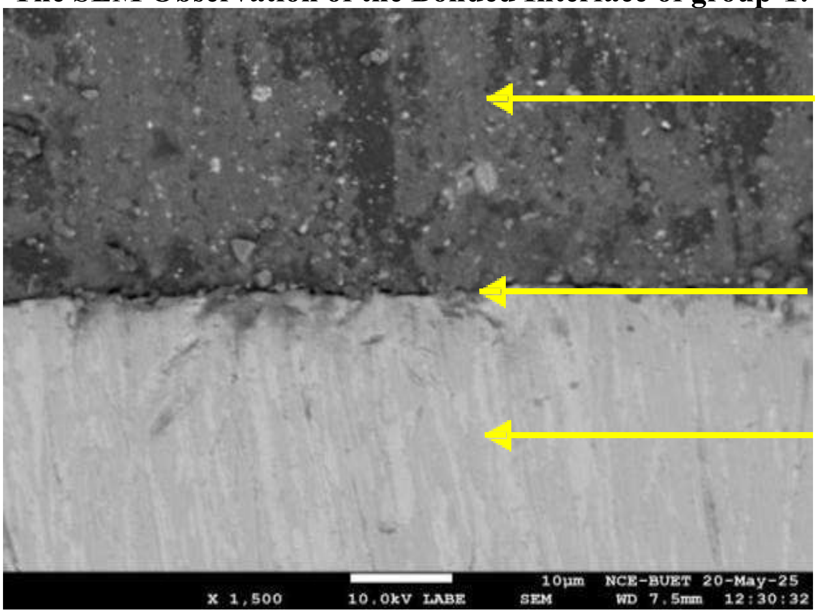
Bond Interface Observation

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 agents.

Table 1. Comparative SEM Findings of Bond Interface between Composite and Porcelain among Different Surface Conditioning Groups

Group	Surface Treatment	Bond Line Continuity	Surface Roughness	Micromechanical Interlocking	Resin Penetration / Chemical Adaptation	Overall Bond Quality
Group 1	No conditioning (Control)	Thin, irregular, partially discontinuous	Smooth surface	Minimal	Poor adhesive adaptation	Weak
Group 2	Silane coupling agent	Moderately continuous	Moderate	Limited	Improved chemical bonding	Moderate
Group 3	Phosphoric acid + silane	Thick, uniform, continuous	Roughened surface	Pronounced	Enhanced micromechanical and chemical bonding	Strong

The SEM Observation of the Bonded Interface of group-1:



Cement

Interface

Ceramic

Figure-1: SEM micrographs between the cement and porcelain interface in the group 1 on 10μm at ×1,500 magnifications.

Group-1: Sample without Conditioning

Figure-1 shows, the interface between the cement and porcelain appears relatively smooth with minimal micromechanical interlocking. The absence of surface treatment results in a thin, irregular and partially discontinuous bond line, suggesting weak adhesive adaptation and poor bond integrity.

The SEM Observation of the Bonded Interface of group-2:

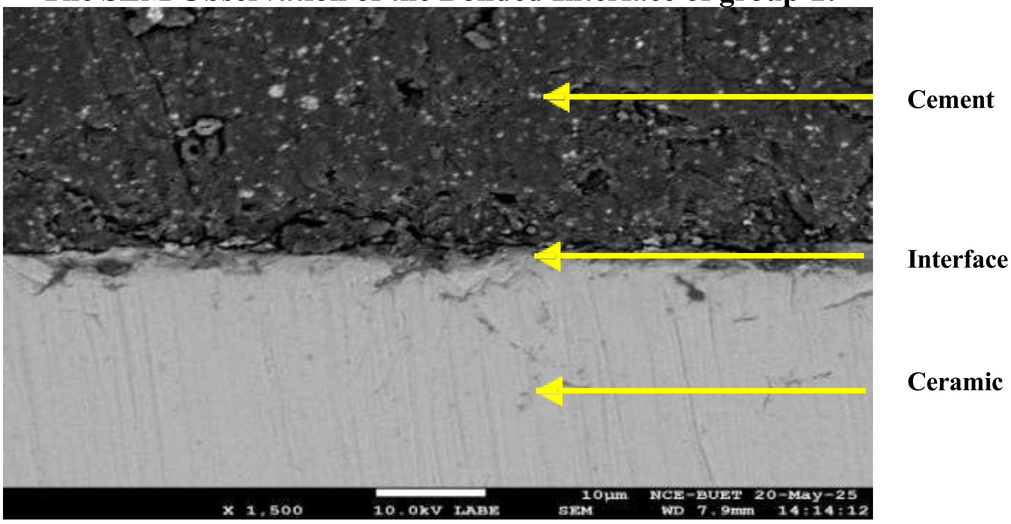


Figure-2: SEM micrographs between the cement and porcelain interface in the group-2 on 10µm at ×1,500 magnifications.

Group-2: Sample conditioned with Silane coupling agent

Figure-2 shows, the interface between cement and porcelain appears moderate surface roughness and a more continuous bonding layer are visible compared to the control. These features suggest improved chemical interaction due to the application of silane coupling agent (PBA), although micromechanical retention remains limited.

The SEM Observation of the Bonded Interface of group-3:

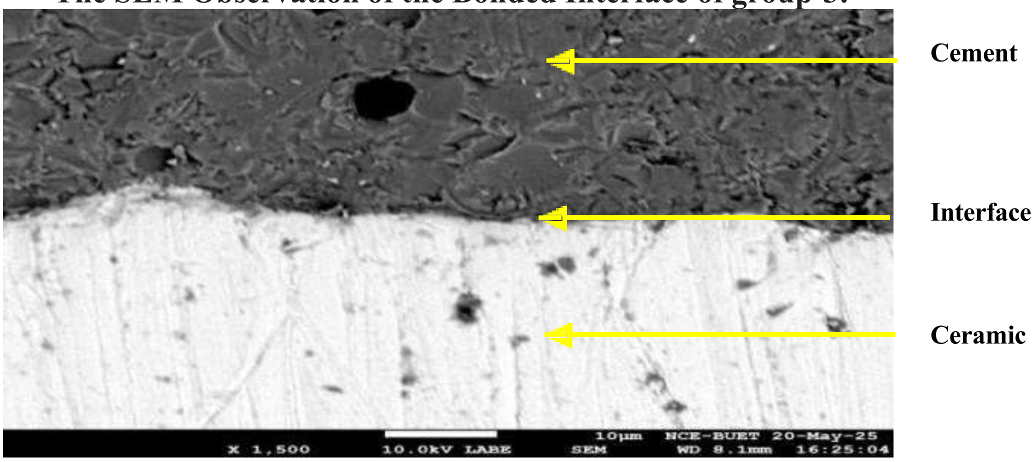


Figure-3: SEM micrographs between the cement and porcelain interface in the group-3 on 10µm at ×1,500 magnifications.

Group-3: Sample conditioned with Phosphoric acid combined with silane coupling agent.

Figure-3 shows, the interface between cement and porcelain appears a distinct, roughened porcelain surface and intimate adaptation of the composite are evident. The presence of micro-retentive features and resin penetration indicates enhanced micromechanical interlocking and chemical bonding, corresponding to the highest interface quality among the groups.

DISCUSSION:

The study showed that surface-conditioning methods significantly affect the bond interface between composite and porcelain. The dual-treatment group phosphoric acid etching followed by silane application demonstrated the highest bonding effectiveness, while the untreated control had the lowest. These results align with previous studies, highlighting that proper surface modification enhances micromechanical retention and chemical adhesion, ensuring more durable resin–ceramic bonding. [4,10]

Figure-1 shows SEM images of Group-1 (no surface conditioning), revealing a smooth, flat porcelain surface with minimal micromechanical interlocking. The thin, irregular, and partially discontinuous bond interface indicates poor resin adaptation and limited penetration, explaining the low tensile bond strength. These findings align with previous reports that untreated ceramic surfaces provide weak mechanical and chemical bonding [4,8] highlighting the importance of surface conditioning for durable resin–porcelain adhesion.

Figure-2 shows SEM images of Group-2 (silane-treated), revealing moderate surface roughness and a more continuous bonding layer compared to the untreated group. Silane improves chemical adhesion by forming siloxane bonds and enhancing wettability, but the absence of mechanical surface modification limits micromechanical interlocking. These observations correspond with the moderate increase in tensile bond strength and support previous studies indicating that silanization alone is beneficial but less effective than combined mechanical and chemical treatments. [4,8]

Figure-3 shows SEM images of Group-3 (phosphoric acid plus silane), revealing a roughened porcelain surface with intimate resin adaptation. The interface exhibits clear micro-retentive features and resin penetration, indicating strong micromechanical interlocking and chemical bonding. This combined treatment produces the most uniform and continuous bond line, consistent with the highest tensile bond strength observed, supporting previous studies on the synergistic effect of mechanical roughening and silanization in enhancing resin–ceramic adhesion. [14,15]

CONCLUSION:

The study demonstrates that surface conditioning has a significant impact on the bond interface between composite resin and porcelain. Unconditioned surfaces exhibited weak adhesion with thin, irregular, and discontinuous bond lines. Silane treatment improved chemical bonding and created a more continuous interface, though micromechanical interlocking remained limited. The combination of phosphoric acid etching and silane resulted in a roughened porcelain surface with intimate composite adaptation, well-defined micro-retentive features, and enhanced chemical and micromechanical bonding. This indicates that combined phosphoric acid and silane treatment provides the strongest and most durable bond, making it the preferred method for intraoral porcelain-composite repairs.

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