



Effect of Different Conditioning Methods on Shear Bond Strength of Orthodontic Ceramic Brackets Bonded to Porcelain Ceramic Surface

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Abstract

The study aimed to investigate the shear bond strength (SBS) of orthodontic ceramic brackets bonded to porcelain ceramic surfaces that had undergone various conditioning methods. **Materials and Methods:** Forty ceramic discs were fabricated (vita vmk master®, zahnfabric, Germany) with a diameter of (4*10mm). Ceramic discs were divided into four groups (n = 10) according to ceramic surface conditioning methods, 37% phosphoric acid (PH), 9%hydrofluoric acid (HF), and surface conditioning with a fine diamond bur. Transbond XT light-cure composite was used to bond ceramic brackets. Before bonding, extra samples from each group were chosen to be examined using a scanning electron microscope (SEM) to determine the topography of the ceramic surface. The Shear Bond Strength data were evaluated using one-way analysis of variance (ANOVA) and Tukey HSD tests. Under an optical stereomicroscope, debond surfaces were examined. **Results:** Surface conditioning with a fine diamond bur + HF acid etching group produced the highest SBS (30.64 ± 7.28 MPa), and the lowest SBS was investigated in the PH acid etching group (14.75 ± 3.32 MPa). **Conclusions:** Different conditioning methods affected the porcelain ceramic surface's shear bond strength ($P < 0.05$). The highest SBS was found in the fine diamond bur_+ HF acid etching group; however, this had a deleterious effect on the ceramic surface after debonding.

Introduction:

Adults with extensive substance loss from their teeth are commonly treated with dental ceramic crowns ⁽¹⁾. As the need for orthodontic treatment has increased, bracket binding to ceramic crowns has become more prevalent. In addition, orthodontists frequently have problems bonding brackets to ceramic porcelain restorations ⁽²⁾. Because of the inert ceramic structure, several investigations have found that attaching brackets to ceramic restorative materials have insufficient shear bond strength (SBS) ^(1, 3).

To improve the binding strength of orthodontic brackets to ceramic restorations, a variety of mechanical and chemical surface conditioning treatments could be applied ⁽⁴⁻⁷⁾. One method is to utilize hydrofluoric acid etching. Due to its destructive nature, hydrofluoric acid, on the other hand, can cause stress to soft tissues and oral structures; hence, considerable caution is essential while using it ^(8, 9). Furthermore, although phosphoric acid may be used to etch ceramic surfaces, it has a considerably weaker bond than hydrofluoric acid ⁽¹⁰⁾.

On the other hand, when used to roughen the surface, diamond burs are known to compromise the integrity of the porcelain ⁽¹¹⁾. A glazed porcelain surface cannot be penetrated by an adhesive, and it cannot be accepted after debonding if the surface is roughened to offer mechanical retention.

Numerous studies have not shown a noticeably different relationship between the binding strengths of glazed and unglazed porcelains ^(12, 13). It is critical to enhance binding strength, which can be further enhanced by using a silane agent. To accomplish chemical retention, a silane coupling agent or a tribochemical silica coating can be utilized ⁽¹⁴⁻¹⁶⁾. Silanes also act as a chemical connection between dental porcelain and composite resin; the organic component of the molecule makes the porcelain surface more wettable and strengthens the micromechanical adhesion. This study aimed to investigate and compare various surface treatment processes "in vitro" to determine which might provide adequate binding strength between ceramic brackets and porcelain

without causing damage to the porcelain surface. The topography of the porcelain surface has been examined after surface conditioning treatment. The types of bond failures on the porcelain resin and resin-bracket interfaces detected after debonding were also analyzed.

The null hypothesis proposed that the method of ceramic surface conditioning has no influence on the shear bond strength of ceramic brackets when various conditioning procedures are used.

Materials And Methods

Construction of Porcelain disc:

Forty discs of porcelain (Vita VMK feldspathic porcelain; Vita Zahnfabrik H. Rauter GmbH, Bad Sackingen, Germany) were produced from vita dentine porcelain, which is available as a powder that is mixed with liquid in a ratio according to the manufacturer's instructions, with a 3mm layer applied and fired at 930C° for 15 minutes, and then repaired with 1mm layer enamel porcelain and fired at 930C° for 15 minutes. Finally, the disc was polished with a special ceramic bur and glazed with glaze liquid in a ceramic furnace (Programat® CS, Ivoclar-Vivadent, Schaan, Liechtenstein, P20, Germany) at 940°C for 20 minutes. The porcelain discs were placed in auto-polymerizing acrylic resin blocks (VERACRIL, Guarne, Antioquia, powder 500gm, liquid 250ml, Colombia) with the smooth surface exposed for surface conditioning and bonding. According to the etching procedures utilized, forty ceramic specimens were classified into four groups, with 10 discs in each group.

1-Porcelain surface conditioned with HF acid- etch+ silane coupling agent

2-Porcelain surface conditioned with PH acid-etch+ silane coupling agent

3-Porcelain surface conditioned with a fine diamond bur, HF acid- etch + silane coupling agent

4-Porcelain surface conditioned with a fine diamond bur; PH acid-etch + silane coupling agent.

Conditioning of ceramic surface:

The ceramic discs were polished with a handpiece at 12,000 rpm/min for 10 seconds using a ceramic polisher and polishing paste. All discs were ultrasonically treated using an ultrasonic scaler for 8 minutes at 27°C (Model, BST-005, Power: 120W, Frequency: 40 kHz, Shenzhen, Guangdong, China) and distilled water to eliminate all debris that interfered with adhesion and bonding. The ceramic surface of twenty discs was mechanically prepared. Using a fine diamond bur with a high-speed turbine at a speed of 35,000 rpm for 20 seconds. To condition the surface, use a fine or coarse diamond stone bur. The porcelain discs in groups (1, 3) were etched with 9% hydrofluoric acid (buffered porcelain etch; Ultradent Products, South Jordan, UT, USA) for 2 minutes and in groups (2, 4). The porcelain disc was etched for 30 seconds with 37% phosphoric acid (SDI, Victoria, Australia), then washed well to remove any remaining acid, and air-dried. Then, in all groups, a silane agent was used (ultradent Products, Inc., South Jordan, UT, USA) for 60 seconds as directed by the manufacturer and allowed to dry with an oil-free air syringe.

Bonding ceramic bracket to porcelain surface:

The labial porcelain surface was then coated with a thin layer of adhesive priming agent (Transbond XT, South Peak Road, Monrovia, CA, 3M Unitek, USA), followed by an Application of light-cure bonding adhesive (Transbond XT, 3M Unitek) to the bottom of ceramic brackets (phantom Lp Roth 0.022 U1, IOS, USA, Bracket surface base area is 11.229 mm²). The ceramic brackets were then placed on the ceramic porcelain surface. A consistent adhesive thickness was achieved by applying a standardized constant pressure to the bracket's upper surface with a pressure gauge. Using an LED device, the light-cured adhesive paste was photo polymerized for 40 seconds, 10 seconds on each side of the ceramic bracket. After the bonding procedure was complete, the bond specimens were stored in an incubator for

24 hours in distilled water at 37°C, and Thermo cycled 500 times between 5 and 55°C with a dwell length of 30 seconds to replicate the oral environment ⁽¹⁷⁾.

An Instron universal testing machine (with a crosshead speed of 1mm/min) was used to perform the SBS test ⁽¹⁸⁾. At the bracket base, the shearing wedge was precisely placed. SBS data parameters are determined in MPa. After debonding, the broken samples were examined with 10× magnification as shown in Figure 1. In addition, the adhesive remnant index (ARI) was created According to Årtun and Bergland (1984), which is scored on a scale of 0 to 3 as follows:

- 0 = no adhesive left on the tooth.
- 1 = less than 50% adhesive left on the tooth.
- 2 = more than 50% adhesive left on the tooth.
- 3 = all the adhesive is left on the tooth, with an impression of the bracket base.
- 4 = Ceramic porcelain surface fracture ⁽¹⁹⁾.

SPSS/PC Version 26 (USA) was used to perform a statistical analysis of the data. Each group's mean and standard deviation (SD) were measured. Moreover, the Shapiro-Wilk test is performed to evaluate if the data distribution is normal.

The significant influence of shear bond strength on ceramic surface treatment procedures and their interactions was evaluated using an analysis of variance (ANOVA). Post-hoc Tukey's multiple comparisons were used to assess significant differences between every two groups. The Chi-squared test was performed to see whether there were any significant differences in the ARI scores.

Results

The mean of Shear bond strength for each kind of porcelain surface treatment is shown in Table 1 and Figure 2. The highest mean shear bond strength was found in Bur roughening HF Acid (BHF) group, while the lowest mean shear bond strength was found in Control Phosphoric Acid (CPH) group. In all groups, the mean of shear bond strength was reached beyond the bond strength described by Reynolds ⁽¹⁹⁾,

which is ideal for clinical use. To see if the data distribution was normal, the Shapiro-Wilks test was utilized, as shown in Table 2. The findings show no significant differences between the groups, implying that the data were normally distributed ($P > 0.05$).

Within the four groups, the one-way ANOVA revealed a highly significant difference in the mean shear bond strength value, as shown in Table 3, and The post hoc Tukey's HSD test, as shown in Table 3, was used to evaluate the mean differences between each of the two groups, and the result revealed that there was a highly significant difference in most groups except between control HF acid group, bur-conditioning PH acid group, and between control PH acid group, bur-conditioning PH acid group which revealed the insignificant difference.

Adhesive remnant index (ARI) frequency distribution and percentages as shown in Table 4. After debonding, most of the resin residues were attached to the bracket in the control groups, and less than half of the resin remained on the porcelain surface in just a few percentages. This is referred to as a resin-to-porcelain adhesive failure. A mixed type of failure occurred in the bur-conditioning PH acid-etched group. A cohesive type of failure was found in the bur-conditioning HF acid-etched group in which more than half of the bonding resin or all stayed attached to the porcelain surface, and in score 4 (40%) of the bur-conditioning HF acid-etched group, which showed ceramic fracture upon debonding.

The Chi-square test, as shown in Table 5, demonstrated that all groups had highly significant differences in the site of the bond failure, and Yate's correction test was used, as shown in Table 6, and revealed a highly significant difference among all Groups.

SEM images of the ceramic surface before and after surface treatment to examine the topography and architecture of the ceramic surface at magnifications of X200, X400, X500, X1000, and X2000.

Untreated (control) ceramic surfaces were consistent and homogeneous, with no porosity. The glass matrix and crystal were reflected in the dark and bright sections of the untreated ceramic surface (As shown in

Figure 3A). The surface microstructure of the ceramic surface after treatment with hydrofluoric acid changed significantly. As a result of the breakdown of the glassy phase, the etched surface displayed irregularly oriented crystals and the existence of multiple micro porosities, grooves, huge cavitation, and striations, resembling a honeycomb etched pattern with the creation of a smear layer (As shown in Figure 3B). Ceramic surface treated with bur roughening exhibited irregular surface, grooves, smear layer, and crack formation, which may propagate over time and result in the eventual crack of the ceramic surface; however, the irregular surface with Bur roughening was less than that with hydrofluoric acid-treated porcelain ceramic surface (As shown in Figure 3C). Both Bur and hydrofluoric acid had a severely destructive impact on the ceramic surface, exhibited a more pronounced uneven surface, the existence of more numerous and big micro porosities, huge cavitation, extensive microcrack development, and a more exposed crystal structure (As shown in Figure 3D).

Discussion

The objectives of this study would be to examine the SBS of ceramic orthodontic brackets attached to porcelain ceramic surfaces. The null hypothesis was that there was no effect on the shear bond strength of ceramic brackets bonded to porcelain ceramic surfaces treated with different conditioning methods; the hypothesis was rejected. Reynolds states that 5.8-7.8 MPa is the physiologically appropriate bracket bond strength⁽²⁰⁾. However, the SBS of the groups was reported to be higher than 7.8 MPa in the present study. To connect orthodontic brackets to ceramic surfaces with sufficient SBS, porcelain ceramic surfaces must be prepared in various methods. These processes could be performed mechanically or chemically, using strong acids such as hydrofluoric or phosphoric acid and silane coupling agents⁽²¹⁾. The current study's findings that HFA conditioning is more effective than 37 % phosphoric acid, which is consistent with previous research⁽²²⁻²⁴⁾. For bonding to

feldspathic porcelains, HFA etching gives superior micromechanical retention^(25, 26).

HFA treatment of the feldspathic ceramic surface revealed consistently distributed holes and shallow roughness⁽⁴⁾. HF acid dissolves the glassy component of silica-based ceramics; however, HF acid has little influence on high-strength materials like zirconia and core ceramics⁽²³⁾. Another research shows that HFA, which is very toxic and promotes porcelain surface damage, was not required to obtain sufficient bond strength⁽³⁾. Karan et al. discovered that the bond strength attained by HFA etching was excellent and equivalent to the values obtained via silicization⁽⁴⁾. In previous research comparing HFA with micro etching, HFA produced considerably greater bond strength than micro etching conditioning⁽²⁶⁾; this is in line with the current study. Although HFA 9.6 per cent is superior to sandblasting for roughening the surface of porcelain, the health hazards must be addressed⁽²⁸⁾.

According to the current research, using a bonding agent like silane enhanced the adhesion capacity of orthodontic brackets to porcelain surfaces and composite restorations^(2, 27). Zhang et al.⁽²³⁾ stated that the "best approach" for achieving optimal bond strength in clinical settings on IPS Classic, a kind of feldspathic porcelain, was to be hydrofluoric acid etching followed by silane application, this finding is in line with this study, and the application of HF acid-etching with silane coupling agent provides acceptable SBS on the ceramic surface. Barbosa et al.⁽¹⁴⁾ discovered that surface roughening using a diamond bur, followed by silane application, results in biologically acceptable bond strengths; these findings are in contrast with this study. Some research found that the use of silane had no influence on binding strength and may be an unwanted extra step^(28, 29). The application of silane without mechanical removal of the glazing from the porcelain surface results in the smallest amount of porcelain damage while retaining appropriate bond strengths,⁽²⁾ this is consistent with the findings of this research. Zelos et al.⁽³⁰⁾ demonstrated that glazing preservation allowed for nearly

perfect cleaning of the porcelain surface following debonding; these findings are consistent with the current study. Surface roughening must be minimized to avoid harming the porcelain during pretreatment or debonding⁽³²⁾. Other studies discovered that traditional acid etching with 37 percent phosphoric acid resulted in poorer bond strength values^(21, 22, 25). This is consistent with the current study.

SEM analysis of the ceramic surface after hydrofluoric acid etching revealed a glassy matrix with a consistent network of crystal distribution, fissures, and many microporosities. Nonetheless, a considerable number and extent of HF-caused microporosities persisted on the ceramic surface even after debonding, leaving these faults irreversibly and comprising the original source of crack initiation on the ceramic surface and the source of bacterial deposition. In addition, the ceramic surface still had surface pits that needed to be polished using a diamond polishing paste⁽³²⁾. Bur roughening of the ceramic surface with Hydrofluoric acid application revealed a more substantial uneven surface as well as the existence of more numerous and big micro porosities, huge cavitation, extensive microcrack development, and a more exposed crystal structure, reflecting the action of both Bur and hydrofluoric acid on the ceramic surface. Thus, if bond strength is sufficient, there is no reason to increase surface roughness since porcelain roughness can diminish the strength of porcelain repairs and even flexural strength because superficial cracks can lead to failure at lower stress levels⁽³²⁾. For bonding orthodontic brackets, however, 6 to 8 MPa bond strength is clinically sufficient⁽²⁰⁾.

As a result, the application of 9% HF acid with a silane coupling agent in the current study provides adequate bond strength than bur roughening + HF acid conditioning treatment in accordance with preserving the integrity of the porcelain surface after debonding, which is consistent with previous studies^(33, 21, 30).

This study observed the adhesive type of bond failure in the glazed PH acid-etched group; the bond failure occurred at the adhesive resin-ceramic interface. In contrast, the cohesive type of bond failure

was observed in the Bur conditioning-HF acid-etched group, and the bond failure occurred at the adhesive resin-bracket interface. A mixed type of failure occurs in the glazed HF acid-etched and Bur roughening PH acid groups. More ceramic surface fractures were present in the bur conditioning-HF acid-etched group (40%); this finding is in agreement with previous studies^(1, 34, 35).

In vitro bond strength studies can help you learn about novel adhesive materials and bonding procedures, but they should be cautiously utilized. One significant limitation of *in vitro* bond strength studies is the difficulty in reproducing the complex nature of the oral environment. Temperature, stress, moisture, acidity, and plaque changes are challenging to reproduce in the laboratory. Future studies are needed to evaluate other factors which affect porcelain-bracket bonds, such as various bonding agents^(36, 37, 38), other

ceramic types, and various conditioning treatments.

Conclusions

The different porcelain ceramic surface conditioning methods had significant differences in the SBS of the orthodontic ceramic bracket bonded to the porcelain ceramic surface. Hydrofluoric acid with a silane coupling agent provides adequate bond strength than Phosphoric acid. The glazed-etching porcelain surface had sufficient bond strength than Bur roughening-etched porcelain surface and without ceramic surface fracture after debonding.

Conflict of interest: The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

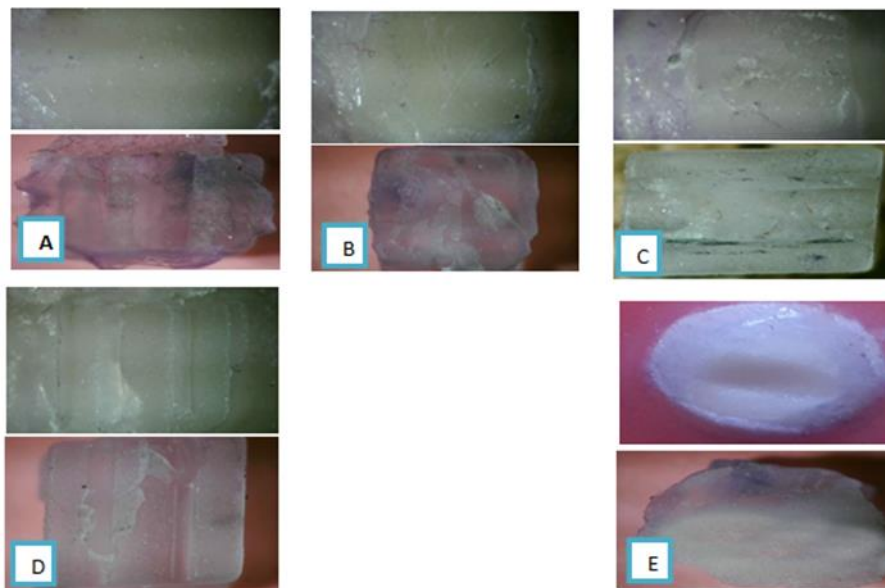


Figure 1: Adhesive remnant index. (A) Score 0, (B) Score 1, (C) Score 2, (D) Score 3, (E) Score 4 (PFI Score). and X2000 magnification

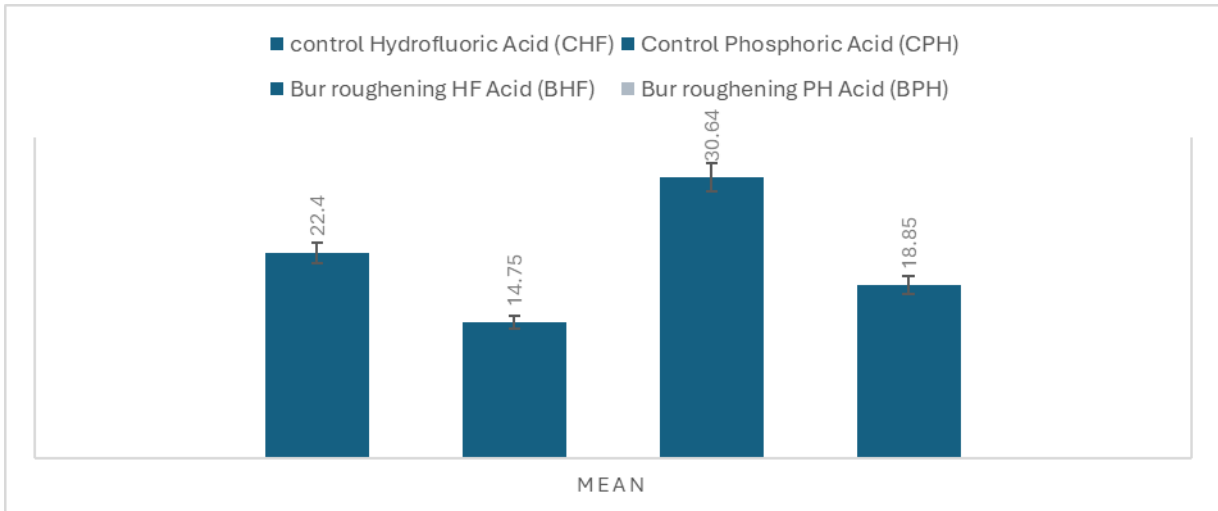


Figure 2: Mean shear bond strength values in each studied group

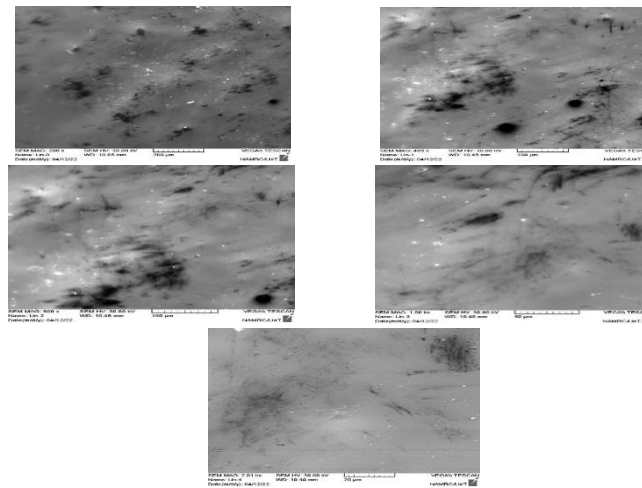


Figure 3 (A): Untreated (control) ceramic surface under X200, X400, X500, X1000, and X2000 magnification

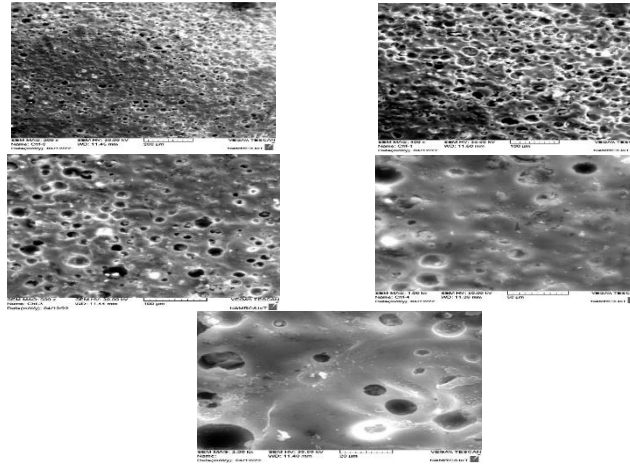


Figure 3 (B): Ceramic surface treated with Hydrofluoric acid (control hydrofluoric acid) under X200, X400, X500, X1000, and X2000 magnification

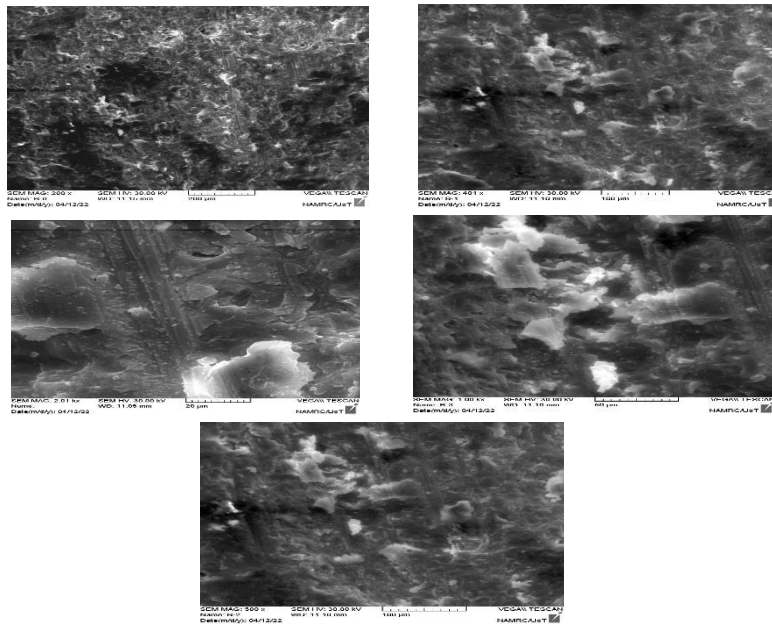


Figure 3 (C): Ceramic surface treated with Bur roughening under X200, X400, X500, X1000, and X2000 magnification

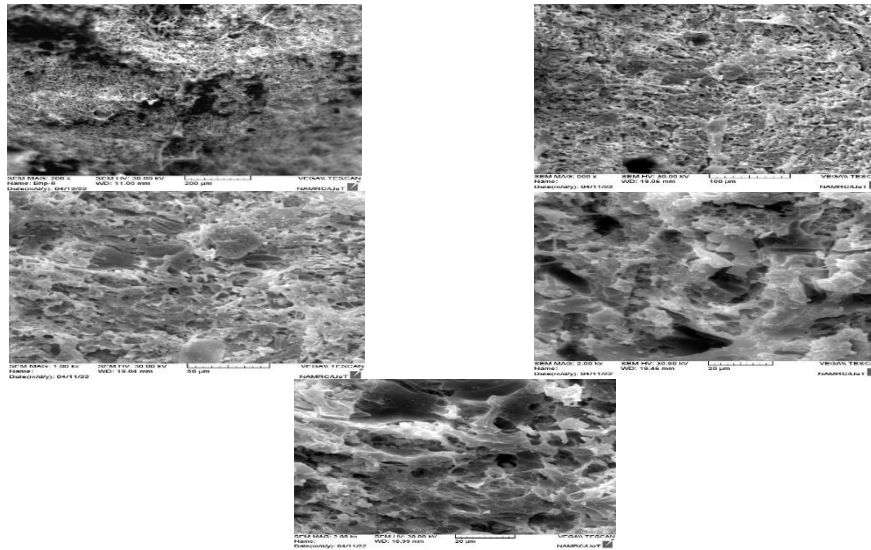


Figure 3 (D): Ceramic surface treated with bur roughening Hydrofluoric acid under X200, X400, X500, X1000,

Table 1: Descriptive statistics of the shear bond strength of different groups

Groups	No.	Mean	Standard Deviation	Standard Error	Minimum value	Maximum value
control Hydrofluoric Acid (CHF)	10	22.4	1.74	0.55	19.59	24.93
Control Phosphoric Acid (CPH)	10	14.75	3.32	1.05	10.24	19.59
Bur roughening HF Acid (BHF)	10	30.64	7.28	2.3	20.03	43.19
Bur roughening PH Acid (BPH)	10	18.85	3.08	0.97	14.69	23.71

Table 2: ShapiroWilks test

Groups	Shapiro-Wilk Test	probability-value	alpha	normal
control Hydrofluoric Acid (CHF)	0.98	0.95	0.05	yes
Control Phosphoric Acid (CPH)	0.93	0.48	0.05	yes
Bur roughening HF Acid (BHF)	0.96	0.77	0.05	yes
Bur roughening PH Acid (BPH)	0.95	0.66	0.05	yes

Table 3: One-way analysis of variance (ANOVA), post hoc Tukey's HSD test

Source of Variation	Sum of Squares	d.f	Mean Square	F-test	P-value
Between Groups	1367.98	3	455.99	23.85	0.000
Within Groups	688.18	36	19.12		
Total	2056.16	39			

treatments	Tukey HSD	Tukey HSD	Tukey HSD
pair	Q statistic	p-value	inference
CHF vs CPH	5.5323	0.0021163*	* p<0.01
CHF vs BHF	5.9576	0.0010053*	* p<0.01
CHF vs BPH	2.572	0.2816002^	^p>0.05
CPH vs BHF	11.4899	0.0010053*	* p<0.01
CPH vs BPH	2.9604	0.1748196^	^p>0.05
BHF vs BPH	8.5295	0.0010053*	* p<0.01

*=significant at p<0.05, ^=not significant at p>0.05

Table 4: Frequency distribution of adhesive remnant index (ARI) and percentages

Groups	Scores					
	0	1	2	3	4	Total
Control Hydrofluoric Acid (CHF)	5	5	0	0	0	100%
	50%	50%	0%	0%	0%	
Control Phosphoric Acid (CPH)	8	2	0	0	0	100%
	80%	20%	0%	0%	0%	
Bur roughening HF Acid (BHF)	0	0	2	4	4	100%
	0%	0%	40%	40%	40%	
Bur roughening PH Acid (BPH)	0	4	4	2	0	100%
	0%	40%	40%	20%	0%	

Table 5: The Chi-square test

	X ²	degree of freedom (d.f)	P-Value
Among all groups	46.4	12	0.000

Table 6: Yate's correction test

Groups	XYATES	d.f	*P-Value
Control HF Acid-Control PH Acid	16.000	2	0.000*
Control HF Acid-Bur roughening HF Acid	15.800	1	0.000*
Control HF Acid-Bur roughening PH Acid	13.902	4	0.008*
Control PH Acid-Bur roughening HF Acid	15.800	1	0.000*
Control PH Acid-Bur roughening PH Acid	11.502	2	0.003*
Bur roughening HF Acid-Bur roughening PH Acid	13.702	2	0.001*

*=significant at $p < 0.05$

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