The Effect of Fluoride Acid Etching Times on the Adhesive Behaviours of Porcelain Restorative Materials on the Cohesive Fractures of Porcelain Fused to Metal Restoration

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Abstract

Porcelain fused to metal (PFM) is commonly used in dental restorations but is prone to fractures. Packable resin composites, influenced by various surface treatments like hydrofluoric acid, serve as alternatives. The acid treatment's specifics affect the porcelain's microstructure. Recently, ceromer resin composites have been introduced for indirect restorations.

The purpose of this study is to determine the differences in packageable resin composites and ceromers as dental restorative materials. Cylindrical dental feldspathic porcelain was used, while the hydrofluoric acid was applied on the surface of the dental porcelain. The adhesive behaviours were measured, and the determination of the relationship between the timing effects and resin composites was carried out via statistical analysis.

The atomic force microscopy (AFM) characterizations were performed to determine the surface roughness of restorative technique. The results showed that there were differences in packable resin composites and ceromers, in which every treatment times showed relationship to the adhesive behaviours on the cohesive fractures. The average value of adhesive strengths of packageable resin composites and ceromers respectively accounted for 2.73±1.69 MPa and 4.43±2.43 MPa. Statistical results showed that the highest adhesive strength was found in the 4-minutes of etching time due to more and deeper pores in accordance with AFM results, indicating easier penetration of silane as coupling agents and repairing materials.

The conclusion of this study is that as the time of etching of hydrofluoric acid in porcelain increases, the value of the adhesive strength of the restorative material increases with a higher ceromer value than packable.

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Introduction

In dental porcelain restorative techniques, the porcelain fused metal (PFM) technique remains frequently applied due to its applicability in cohesive fractures. Given that the porcelain layer (feldspathic) has brittle characteristics, easier fractures have been clinically observed in both the static and cohesive layers, as well as in the metal (adhesive) parts[1]. A systematic review involving 1,192 dentures reported fractures in the porcelain layers within the PFM techniques, with the fractures often occurring in maxillary teeth, particularly on the labial surface, accounting for 75% of cases [2–4]. Porcelain fracture treatments can be performed using intraoral restorative techniques with composite resin materials, which also serve as an alternative for patients to restore functional and aesthetic features. While this treatment is not a permanent option, a study conducted by Ozcan and Niedermeier in 2002 demonstrated that PFM restorative techniques can serve as a long-term temporary treatment, with an average duration of 34.6 months among 289 restorations [5].

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Intraoral restorative procedures typically involve dental insulation, surface modification, and treatments, the application of silane as a coupling agent, and concluding with the application of repairing materials, finishing, and polishing. Among these steps, surface treatment is of utmost importance as it aims to enhance mechanical retention and achieve acceptable adhesion between the repairing material and the porcelain surface, thereby establishing adhesive strength [6]. Studies have recommended that the most effective surface treatment is etching with hydrofluoric acid (HF) compared to other chemical compounds or water abrasion. However, it is crucial to note that the use of acid in certain concentrations and exposure times can pose hazards[7,8]. Furthermore, the concentration and duration of acid etching can impact the size and shape of microstructural features, as evidenced by changes in the morphological characteristics of porcelain, thereby influencing adhesive strength [9]. Based on various studies focusing on concentration and etching time, some reports suggest etching porcelain with a low concentration, typically around 5%, for a period of 2-3 minutes. These parameters seem sufficient to selectively dissolve the glassy phase, creating a porous surface that facilitates resin composite penetration while also reducing the toxicological effects of HF. Due to the higher reaction of HF, etching time under two minutes should be considered insufficient to provide acceptable adhesive interaction between porcelain and resin composites, and by contrast, above 4-minutes of etching time may weaken the physical properties of porcelain [10]. Thus, it is important to consider that an etching time of fewer than two minutes may be insufficient to establish an acceptable adhesive interaction between porcelain and resin composites, whereas etching times exceeding four minutes may weaken the physical properties of porcelain.

In addition to surface treatment, the adhesiveness is also influenced by the volume of resin composite fillers. Two commonly used types of resin composites for restoratives are packable and flowable composites. Increasing the volume of composite fillers enhances the mechanical and physical properties of the composite, consequently contributing to improved adhesive strength. A study has shown that packable composites exhibit higher adhesive strength compared to flowable composites [11]. With the advancement of ceromer technology, which is primarily used for indirect restoration techniques, this material has now become applicable for porcelain restoratives. Ceromer materials possess superior mechanical properties when compared to other resin composites[12]. However, there is a limited studies regarding on the sue of ceromer as a restorative technique especially in terms of its adhesive characteristics.

Based on the previous explanations, this present work was carried out to determine the differences of packable resin composites and ceromer as restoration materials in porcelain restorative techniques. The etching time of 5% HF was also carried out in various times (2; 2.5; 3; 3.5 and 4 minutes) to investigate the influence of surface treatment on the adhesive strengths within the cohesive fracture of both resin composites in PFM restoration techniques.

Materials and methods

Materials

This study used 60 pieces of feldsphatic porcelain materials (Vita VMK Master, Sackingen) with cylindrical shape with 7 mm of diameter and 3 mm of width. HF acid gel with 5% of concentration was purchased from Ivoclar vivadent, Liechtenstein, while silane was purchased from Cerasesin, Japan. The composite materials were packable resin composites with high density (Filtek Z250, 3M ESP) and ceromer resin composites with super high density (Ceramage, Japan). All the chemical reagents were in analytical grades.

Preparation of Samples

Procedure of porcelain block

The preparation of ceramic block was carried out by following the standard guidelines provided by the manufacturer, and by preparing a cylindrical block (7 mm of diameter, and 3 mm of width) by pouring some mixed porcelain and liquid. The first step was to prepare by manually stirring until it reached acceptable consistencies. Then, the prepared porcelain mixture was then poured onto the metal matrix with cylindrical shapes, and this mixture was allowed to stand for 2 minutes in room temperature. After being laid out, the block was placed into an oven porcelain for sintering process at 600°C for 6 minutes. Afterward, the temperature was heated up at 930°C with heating rate of 38 $°C.min^{-1}$. Next, the block was allowed to stand to reach room temperature, and the surface was polished with sandpaper with 600-grid via micromotor. Finally, the blocks were transferred onto the block contained with swapolymerization acrylic (2.5

mm of diameter and 27 mm of height) as it is shown in Fig. 1. The specimens were prepared for 60 items.

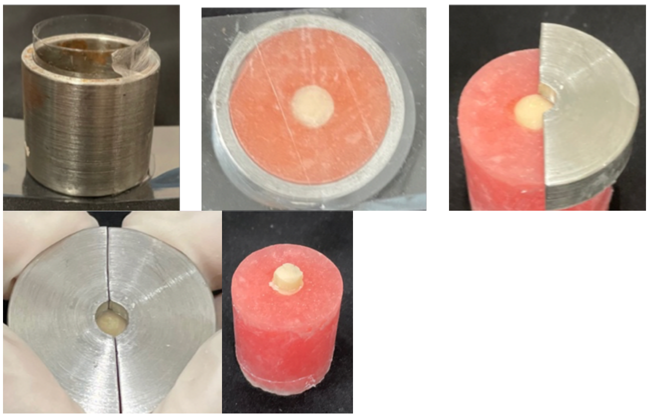

Figure 1. Self-curing acrylic moulds were made of cylindrical tubular stainless-steel metal, the result of planting samples with a porcelain surface of a plot with an acrylic surface, metal matrix moulds composite resin, double-sided merging, and the final result of specimen unification (left-to-right).

Procedure of surface treatment with HF

The surface treatment via 5% of HF was carried out experimentally. In the beginning step, the unified specimen was cleansed with distilled water for 20 seconds and dried in an open air for 20 seconds. Then, 12 items were etched with 5% of HF via brush-tip for 2 minutes. Finally, the specimen surface was washed with distilled water and dried in open air for 20 seconds, respectively. Similar steps were applied for the other specimens with different etching time which were 2.5, 3, 3.5, and 4 minutes.

Procedure or Silane Application

Each specimen that has been etched was then prepared for silane application. Firstly, the silane was prepared by mixing it with 3-MPS. The mixture was then applied by brushing via hand layout method on the surface of porcelain surface. Then, the surface was allowed to stand for 10 seconds which was followed by laying out acetone, and the specimen was again allowed to stand for 10 seconds. Finally, the specimens were radiated by light cure for 10 seconds.

Procedure of Resin Composite Application on Porcelain Block

The steps for applying the resin composites were carried out via metal-matrix mould (diameter of 5 mm and thickness of 3 mm) on the porcelain block. After the mould being placed on centre part of the specimen, packable resin mixture that has been prepared previously was poured into the mould with two times of pouring steps. The layers were then pressed with light pressure via plastic instrument, and 30 specimens were prepared for the packable specimen. Similar procedure was also applied to the other 30 specimens, but with different resin composites, which was ceromer resin. After being applied, both specimens were radiated via light cure with 5 mm of distance. The radiation took place in three different steps, i.e., the first step employed 40 seconds directly on the surface of the specimen with the mould, followed by 20 seconds before the mould being removed, and lastly 20 seconds after the mould being removed. All samples were then stored within distilled water for 24 hours at 37°C in accordance with ISO TR 11405 standard guidelines.

Characterisations

The determination of morphological features of samples were carried out via Scanning Electron Microscope (SEM) instruments with 30, 100, and 500x of magnification followed by ImageJ analysis software to measure numbers of failures, and the surface roughness was confirmed via Atomic Force Microscope (AFM) instruments (Nanosurf easyScan 2 Controller.,Ltd.,Japan). The characterization of surface roughness was carried out after the porcelain block being etched with HF. The observation of failures was carried out via stereomicroscope with 20x magnification. The mechanical properties of the samples were measured via Universal Testing Machines (INSIZE) UTM-H300B and recorded in MPa; and all data were analysed statistically.

Results

AFM Analysis

The analysis of HF etching patterns in all samples that have been etched for 2; 2,5; 3; 3,5; 4 minutes was carried out via AFM instrument. In the treatment group with a time of 2-minutes, small number of pores with features of surface roughness were observed, as it is seen in Fig. 2.

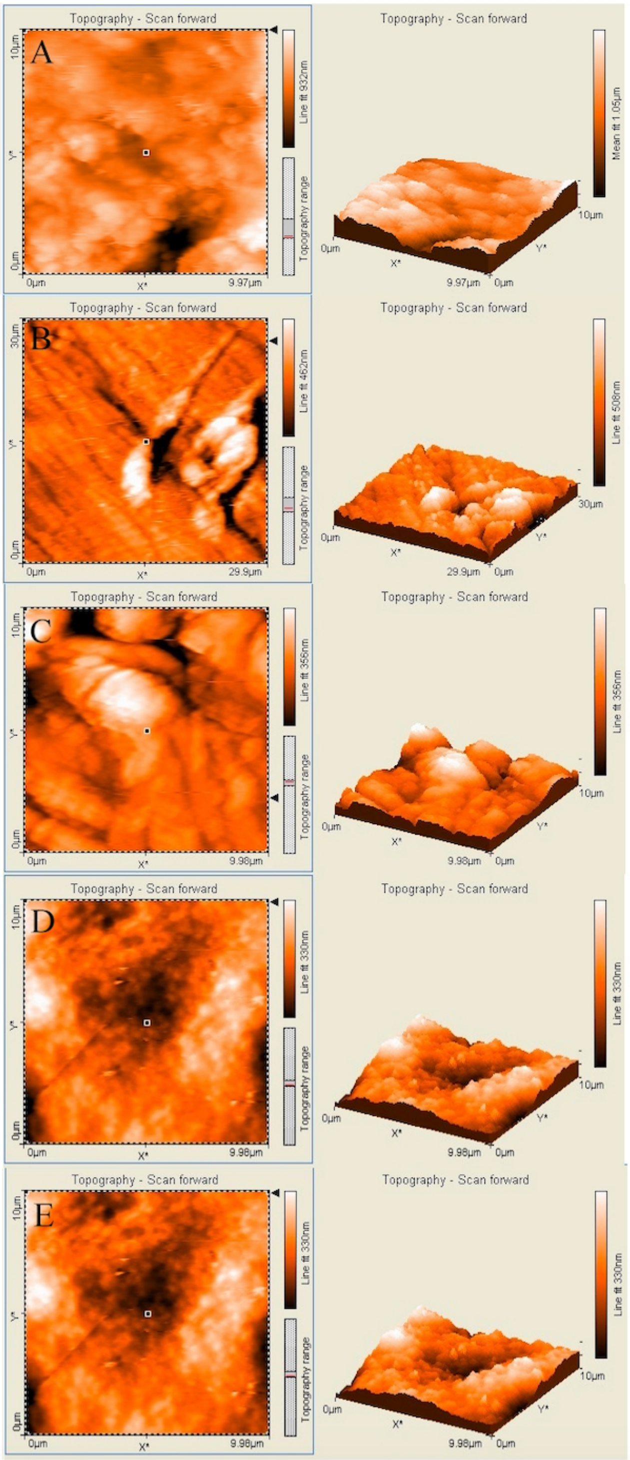

Figure 2. AFM overview of porcelain etched with HF for (A) 2-minutes, (B) 2.5-minutes, (C) 3-minutes, (D) 3.5 minutes, and (E) 4-minutes.

Based on Fig. 2, the small number of pores in 2-minutes (2A) showed shallow types compared to the other groups. Likewise, the treatment group with two higher etching-times, 3.5 and 4 minutes showed a rougher surface, indicated by the presence of more pores and deeper appearances. However, slight topographical changes were found for the treatment group in these two etching times.

Adhesive Strength Analysis

By performing the mechanical testing, the average value of shear-bond strength was obtained as it is seen the following Table 1, and Fig. 3 shows the comparison for each sample.Table 1. Average Value of Shear-Bond Strength Based on Etching-Time and Resin Composites.

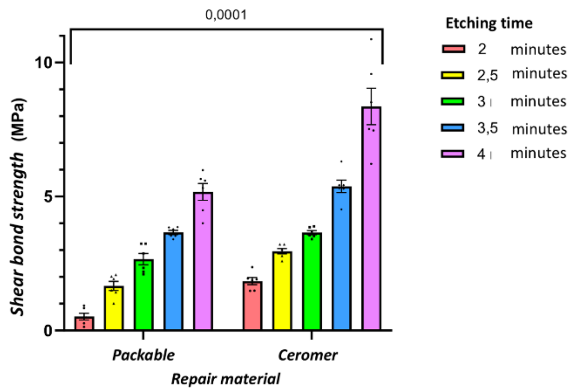

Figure 3. The Comparison of Average Shear-Bond Strength Based on Etching Time and Types of Resin Composites.

Normality test in this study employed Saphiro-Wilk that is done due to limited observation. As every variable showed not significant p-value ($p>0.05$), data is distributed normal, thus; statistical analysis can be proceeded. Table 2 shows normality data test via Shapiro-Wilk. After passing the test, it can only be continued with T- and ANOVA-test analysis.

No.	Etching Time (Minutes)	p
1.	2	0,477
2.	2,5	0,727
3.	3	0,146
4.	3,5	0,104
5.	4	0,528

Table 2. Data Distribution Normality Test (Shapiro-Wilk Test).

The average value of adhesive strength based on the resin composite repairing materials is shown in Table 3. The average value in the ceromer group was higher than that in the packable group. From these results, it can be implied that there was a difference in the repairing material of the packable resin and ceromer composites to the adhesive strength.

No.	*Restorative* Materials	Adhesive Strength (MPa)	p
		X̄±SD	
1.	*Packable*	2.73±1.69	0,003*
2.	*Ceromer*	4.43±2.43	

Table 3. Average Value of Shear-Bond Strength Based on Resin Composites. * Significant.

ONEWAY ANOVA test results showed the average of shear-bond strength depends on the etching time of resin application, particularly in the packable resin composites as it is seen in Table 4. The highest average value was found in the treatment group with etching time of 4-minutes, while the lowest average value was found in 2-minutes of etching. These results imply the influence on the etching time of HF with 5% concentration to the adhesive behaviours of the packable resin composites during PFM restoration within cohesive fractures. Similarly, etching time of 4-minutes demonstrated the highest adhesive behaviour on ceromer resin composites (Table 5).

No.	Etching Time (Minutes)	Adhesive Strength (MPa)	p
		X̄ ±SD	
1.	2	0.51 ± 0.30	0,00001*
2.	2,5	1.66 ± 0.44	
3.	3	2.66 ± 0.52	
4.	3,5	3.66 ± 0.19	
5.	4	5.17 ± 0.76	

Table 4. ONEWAY ANOVA Test Results of Etching Time on Packable Resin *significant

No.	Etching Time (Minutes)	Adhesive Strength (MPa)	p
		X̄ ±SD	
1.	2	1.84 ± 0.32	0,0001*
2.	2,5	2.95 ± 0.24	
3.	3	3.65 ± 0.19	
4.	3,5	5.38 ± 0.57	
5.	4	8.36 ± 1.66	

Table 5. ONEWAY ANOVA Test Results of Etching Time on Ceromer Resin.*significant.

SEM Evaluation

In every sample that has been tested in its shear-bond behaviours, evaluations via stereomicroscope with 20x of magnification was carried out to observe the types of failures, as it is seen in in Fig. 4. Morphological characteristics were also evaluated via SEM with 30, 100 and 500x of magnification which can be seen in Fig. 5 and Fig. 6. Types of failures are divided into three categories, i.e., adhesive behaviours that occur in the interface of porcelain/ silane, cohesive failures that occurs in composites or porcelain, and the combination failures which were interface and both materials.

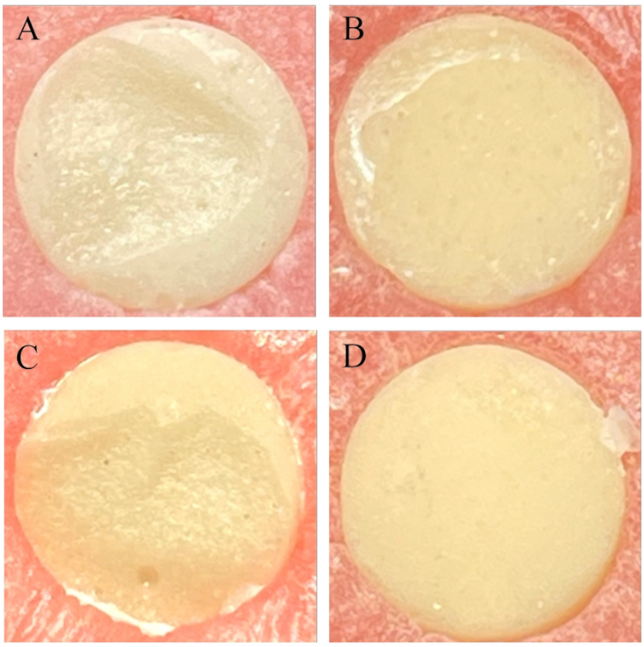

Figure 4. Failure type with picture under 20 x magnification microscope with *packable* resin composite *restorative* material: A. Cohesive failure on *porcelain* substrate, B. Adhesive failure and with ceromer *restorative* material: C. Cohesive failure on *porcelain* substrate, D. Adhesive failure

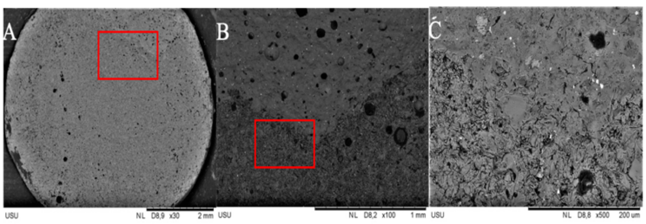

Figure 5. Cohesive failure type with packable resin composite restorative material in SEM picture with A. magnification 30 times, B. 100 times and C, 500 times, with red-boxes showed

failures.

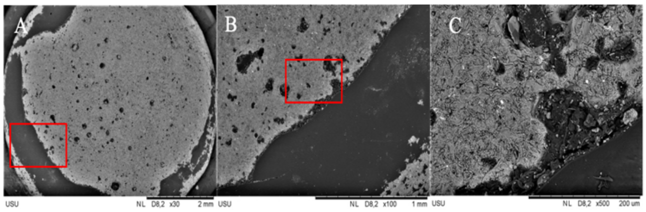

Figure 6. Adhesive failure type with *ceromer* resin composite *restorative* material in SEM picture with A. magnification 30 times, B. 100 times and C, 500 times with red-boxes showed failures.

Based on micrographic images, the type of failure that has been observed in this study is cohesive types. This type of failure is more than those observed as adhesive types. The percentages of failures were determined via ImageJ processing software that can be seen in the following Table 6.

Etching Time	*Restorative* Materials	Failure Type			
		Cohesive		Adhesive	
		n	%	n	%
2 minutes	*Packable*	4	66,67	2	33,33
	Ceromer	4	66,67	2	33,33
2.5 minutes	*Packable*	5	83,33	1	16,7
	Ceromer	3	50*	3	50**
3 minutes	*Packable*	5	83,33	1	16,7
	Ceromer	4	66,67	2	33,33
3.5 minutes	*Packable*	5	83,33	1	16,7
	Ceromer	3	50*	3	50**
4 minutes	*Packable*	6	100**	0	0*
	Ceromer	5	83,33	1	16,7

Table 6. Percentages of Failure Types Based on Etching Time and Resin Composites.

Discussion

Treatments on cohesive fractures in PFM restoration could be replacement and restoration. The replacement is selected to the case which loses more teeth structures. Meanwhile, the restoration is carried out to clinical fracture that spreads to the functional area or periapical lesions via radiographical observation. The replacement technique appears to have drawbacks, such as; trauma that occurs in restorative teeth, difficulties in removing the restoration, sacrificing healthy dental tissue, reducing the possibility of sustained pulp vitality due to greater restoration, and an increased risk of failure. Therefore, restoration appears to be more promising which is also more reliable in term of clinical condition of the fracture [13,14]. In addition to these problems, there are also problems on the patient side including high cost of treatment, demands for postponing the fractures, and preferring to restoration treatment. The most effective restorative techniques as well as timesaving is intraoral restoration with the use of resin composite restoration materials via dental insulation, surface modification and treatment, silane coupling agent application, restorative material application, finishing and polishing steps in order. In this present work, all samples were treated with surface modification via HF due to its effectiveness in forming micro-gaps that will be filled by restoration materials which lead to improvement of micromechanical retention[14].

As various studies have suggested that etching time should be longer than two minutes due to the strong reaction of HF, effective bonding between porcelain and resin composites remain unclear. Moreover, an etching time exceeding four minutes would also negatively impact the physical properties of porcelain. On the other hand, the use of a low concentration of HF (5%) is recommended as it reduces the toxic effects of the acid and can be clinically prevented by the use of rubber dam insulation. This concentration ensures the isolation at the gingival margin, careful use of triple air-water syringe, removal excess acids and high-volume aspirators [6,15,16]. Thus, investigating the etching-time limit in between 2 to 4 minutes is necessary. Every 12 sample were etched for 2; 2.5; 3; 3.5 and 4 minutes which is sufficient to selectively dissolve the glassy phase, allowing the penetration of resin composites into the pores[9]. An analysis of the etching pattern of HF with AFM determines the microporous formation and cracks that occurred due to exposure and dissolution of matrix glass[17].

The use of resin composite as restoration materials was in the form of packable resin composites since this type is the most used materials and ceromer resin composites due to its usage for indirect restoration techniques for porcelain restoration. The selection of these two restoration materials is based on their filling densities that can affect the mechanical and physical properties of the restorative tooth via improvement in adhesive behaviours [10,18]. Before shear-bond test, all samples were stored in an incubator, immersed with distilled water at temperature of 37°C for 24 hours (in accordance with ISO TR 11405) as a form of simulation of short-term oral cavity conditions. This condition is normally sufficient to distinguish the ability to resisting and non-resisting material against we environments. In this study, evaluation on the adhesive behaviours between packable and ceromer resin composites to the porcelain restoration and feldspathic porcelain respectively indicates the shear-bond strength. This is due to easier preparation and testing protocol with affordable features [19,20]. For other reasons, the use of shear adhesion force simulates an oral clinical setting with more efficiently than other tests due since most of the forces exert on the anterior restoration of the buccal region, especially in centrist motion that leads to shear movement behaviours [21–23].

The average adhesive strength values based on types of resin composites in term of packable was accounted for 2.73 MPa, whereas the ceromer group showed 4.43 MPa. This implies to the shear-bond strength of porcelain restoration varies from 3 to 37.4 MPa due to several factors including surface-treatment techniques and types of restorative materials[24]. Meanwhile, the average values of shear-bond strength of resin composites on porcelain feldspathic were in between 6-29.9 MPa depending on the types of composites, porcelains and surface-treatment techniques. In this study, the average adhesive strengths were in below due to the differences in types of materials and standard protocol. As it is reported by Moura et al., (2020), average adhesive strength was accounted for 10.68 MPa by using 5% of HF under 1 and 2 minutes of etching-time, followed by H_3PO_4 as additive surface-treatment technique[9]. Another possibility in term of these differences may have been found in different types of restorative kit, in which within the material, there have been chemicals for surface treatment, silane coupling agent. A study has reported that average adhesive strength was accounted for 12.54 MPa which used restorative kit [24].

The average adhesive strength values of ceromer composite as restoration materials showed higher values than those in packable resins. This is due to the differences in the filing densities of ceromer which is higher than those in packable resins, thereby; it increases the physical and mechanical properties, especially in polymerization shrinkage, linear expansion coefficient, and reduction in water absorption [24]. In addition, the ceromer resin composites contain porcelain particles such as glass ceramics filled with silica, hence; they are referred as prosthetic composites which have better mechanical and physical properties compared to those in conventional composite resins [12]. Our finding also showed that the greater the amount of filler contents within the restorative material increased the value of shear-bond strength as it is shown in our statistical results. Significant differences between packable resin and ceromers were found particularly in the adhesive strength within the porcelain restoration. Higher adhesive strength within the cohesive fracture during PFM restoration occur due to the differences in amounts of filing materials which was accounted for more than 70%, as a result; this improves the physical and mechanical properties of the restorative-material. A study has reported that low volume of filler (25-51%) had the lowest strength in hardness property, fracture toughness, and flexural strength; in contrast, high filler content (59-60%) was associated with higher hardness value, fracture toughness, and bending strength [25]. Similarly, another study has also shown that the filler content had significant influence among 72 restorative materials which was indicated from the feasibility of mechanical properties [26].

The etching via HF followed by the application of silane as coupling agent is an important protocol for surface treatment for repairing cohesive fractures during PFM restoration. Despite the advantages of this adhesive procedure with silane, the timing of HF can change the energy on the porcelain surfaces, affecting the size and shape of micro-retention as well as the adhesion strength and restoration lifetime[9]. When HF is applied to the surface of porcelain, it will react to the silica matrix to produce silicon tetrafluoride (SiF_4), while at the same time water molecules would be removed from the matrix. This SiF_4 will react with other molecules of HF to form hexafluoro-silicate which is dissolved complex ion. Then, hydrogen ions will react with this complex ion to form washable fluorosilic acid. By dissolving and removing the surface layer of the glassy matrix that contains silica (SiO_2), silicate (SiO_4^{-4}), and leucite crystal ($K_2O.Al_2O_3.4SiO_2$), the surface becomes porous with a hole size of 3-4 μm[27]. The HF also will react to silicon dioxide (SiO_2) from glass phase ceramic, creating surface micropores as well as resulting in the formation of mechanical interlocks with the repairment materials[12,15]. The results of the reaction can be seen from the AFM images which showed the formation of micropores that occur due to the exposure and dissolution of matrix glasses. Longer etching times result in coarser surface roughness due to deeper and clearer pores, as shown in Fig. 2. These results indicate a significant change in the microstructure of the porcelain surface with an increase in the time of etching, the longer the etching time, greater the number of pores with deeper conditions. Similar results found a clearer pattern of etching after being etched from 20 to 120 seconds, and a prolong etching up to 90 and 120 seconds caused changes in surface micromorphology that looked more porous and deeper[28]. Another study also found that etching time with 5% HF in feldspathic porcelain for 20, 40, 80 and 160 seconds resulted in an increase in the number and width of the pores, in which these pores increased at a faster rate than their depth. The presence of increased surface roughness of porcelain will be useful for increasing the surface areas as micromechanical bonding [10].

In this study, 5% of HF with various times of etching have changed the surface condition of the porcelain. The 4-minutes showed the largest adhesive strength value, while the 2-minutes of etching time showed the lowest strength value. These results also showed that the longer timing of HF-etching increased the value of adhesive strength, in which a significant influence was found statistically. The reason behind this behaviour due to the basic characteristic of dental feldspars that were used. The Vita VMK master is consisted of two main constituents, i.e., sodium and potassium silicate compounds, combined with 15-25% of quartz crystal to improve the glassy matrix due to the mechanical improvement. Subsequently, during sintering around 950°C, leucite is formed in two phases, which are crystalline structure in high amount and glass phase. Therefore, in order to achieve surface roughness on the dental porcelain surface, a relatively longer time in lower concentration of HF is required to create roughness on the crystalline structure (as the glassy phase and residual quartz are the first two-compounds that would dissolve due the presence of HF). However, a study using HF concentrations of 9.6% with an etching-time at most 2 minutes demonstrated the adhesion strength behaviour depends on the ratio of the resin and the filler [6].

Our findings in adhesive effects also indicated that the adhesion strength of the packable and ceromer resin composites occurred due to the prolonged exposure to fluoride etching that dissolve the glass phase in high amounts. Therefore, increasing the surface roughness (Fig. 2) could be obtained in higher timing and could provide deeper and clearer pores. As a result, these surface modifications will facilitate the wettability of silane to coupling to porcelain as well as to attach the resin composites. This also allows the formation of mechanical interlock between the resin and porcelain. The results of this study were in accordance with a result conducted by a study which concluded a longer hydrofluoric acid etching time with time variations from 0 to 2 minutes, resulting in a higher sticky strength value, indicating smaller concentration requires longer ecthing time[20]. In this study, the value of adhesive strength continued to increase in line with the increase of etching-time, possibly due to the difference in treatment after etching as well as the application of acetone that is useful for removing crystal residues. As an example, salts that are insoluble in water, firmly attached to the surface of porcelain are difficult to remove, thus; it will affect the physical properties[29]. Hence, the ideal duration of etching-time in resin composite for repairing materials is for 4 minutes with adhesive strength value of 5.17 MPa on packable and 8.36 MPa in ceromers.

In term of clinical application, the value of adhesive strength could not be taken as an acceptable indicator, thus; analysis of failure types at the same time would determine the repairment methods [30]. The type of failure of the restorative composite resin packable and ceromer found that the cohesive type was greater than the adhesive, with the longer the etching time the greater the number of cohesive fractures [9,28]. This is because a longer etching time of HF will affect the physical properties of porcelain in the form of reducing fatigue and flexural strength which will weaken the porcelain thereby increasing the risk of fracture. increase the occurrence of cohesive failure in porcelain material because the longer the action of the acid, the rougher the porcelain surface. As the surface roughness allows the penetration of ceromer into the voids and fissure, adhesive bonds occurred. Thus, the adhesive failure in ceromer (Figure 4B) indicated that surface roughness contributed significantly to the adhesive interaction (such as van der waals interaction) between the porcelain and ceromer itself. In addition, cohesive fracture also occurs because the adhesive strength of porcelain is lower than adhesive features within silane as coupling agent. Likewise in the study of Mokhtarpour, Alaghehmand and Khafri (2017) which found that cohesive failure increased with longer etching time starting from 20 seconds, 1 and 2 minutes[31]. In other words, a good adhesion between porcelain and packable material occurs because the silane coupling-agent contains 3-MPS material. However, in ceromer resin composites, the number of adhesive failure types was found more than those in packable group, probably due to the imperfection during light curing (LED) which should have used the factory default such as SHOFU's Solidilite V.

The limitation in this study is that the average adhesive strength value follows within the acceptable range of adhesive strength with increased in adhesive repair capacity between the Filtek Z250 and Ceramage[32]. for the restorative packable material group; 4.43 MPa for the ceromer group. The reason behind this is due to the use of available repairment kit and etching-time. The simulation of clinical condition of orals within a short-time also becomes limitation as well as not performing thermocycling as life-time tests to show durability bond between the porcelain and repairment materials. To the best of our knowledge, the use of ceromer as indirect restoration may not have been done in previous studies. This ceromer material can be used as an intraoral restorative material because it is a resin composite with porcelain particles with the highest filler percentage content of more than 70%, thereby improving the physical and mechanical properties of the material. The ceromer resin composite in this study showed a higher adhesive strength value than the packable which was generally used clinically in intraoral treatments, increasing the durability and life of the restoration.

Conclusions

The optimum etching-time for surface modification was found in 4-minutes, indicated by the presence of numbers of pores with deeper topographic based on the AFM results. Shear-bond measurement also confirmed the 4-minutes of etching-time with higher adhesive value for 2.73±1.69 MPa for packable resin, and 4.43±2.43 for ceromer indicating the penetration of resin on the porcelain surface. Although adhesive failures were found in SEM results, the use of ceromer that has been commonly utilized as indirect restoration could be alternatives in intraoral treatments for cohesive fractures during PFM restorations.

Declaration of Interest

The authors report no conflict of interest.

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