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Research Article

Role of CO_2 Laser on SBS between Dental Porcelain and Composite Resin Repair Process

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Background. The surface modification of porcelain material can be conducted by mechanical, chemical, or laser means. This study investigated the CO_2 laser effect on porcelain to enhance bonding with composite resin. *Materials and methods*. A total of 33 blocks of feldspathic porcelain were randomly divided into 3 groups of 10. Additionally, three specimens were used in scanning electronic microscopy and energy-dispersive spectroscopy tests. Group I was treated with 9.5% hydrofluoric acid (HF), Group II with a 5 W CO_2 laser, and Group III with CO_2 followed by etching with 9.5% HF. Then, a Bisco intraoral repair kit was used, followed by the application of repair composite resin (Tetric N Ceram) on the porcelain surface using a Teflon mold and light-curing source. Shear bond strength (SBS) was assessed by using a digital universal testing machine, and failure modes were evaluated. Data were analyzed by analysis of variance (ANOVA) and least significant difference test. *Results*. A high significant difference in roughness and SBS was found amongst the tested groups $P < 0.001$. SBS and roughness for Group III were significant at $P < 0.05$, and the lowest value was observed in Group II. The cohesive mode of failure was dominant in Groups I and III, whereas adhesive failure was dominant in Group II. *Conclusion*. The surface treatment of porcelain with CO_2 laser followed by HF application can enhance roughness and SBS, and can be recommended when extra retention during repair indication.

1. Introduction

Dental porcelain fracture is the most common complication in recent years owing to the increased demand for esthetics. Porcelain chipping can occur in all-ceramic systems, as well as porcelain fuzed with metal [1, 2]. Some of the factors contributing to porcelain fractures include occlusal forces, impact load, incompatible coefficient of thermal expansion between the two materials, insufficient tooth preparation, improper design, and trauma [3, 4].

The fracture of dental porcelain may require the replacement of the prosthesis, but small cohesive chipping can be repaired intraorally. Intraoral repair is low cost, is less traumatic to the dental abutment or pulp, and can be performed with a single session. Usually, the broken part is repaired with composite resin [5].

The durability of composite repair primarily depends on the quality of the bond between the porcelain surface and the restoration. Various techniques can be used to improve the micromechanical retention of composites, such as air abrasion, diamond bur grinding, acid etching, tribiochemical coating, and laser. The application of silane after surface treatment establishes a reliable and long-lasting bond owing to its ability to bind the organic and inorganic compounds together and contribute to chemical bonds [6, 7].

Different modalities such as etching with hydrofluoric acid (HF), silane application, sandblasting, and laser irradiation, have been proposed to enhance the bond strength of resin composites or resin cement to feldspathic porcelain. Evidence indicates that silane treatment can increase bond strength by forming a chemical link between porcelain and composite [8, 9]. Several investigations have shown that etching with HF acid can provide adequate bond strength. Nevertheless, this method still have restrictions and may harm oral soft tissues, requiring special precautions and preparations [10].

The surface conditioning of tooth structures and dental materials are some of the most prevalent laser applications in dentistry. Ceramic substrates can be conditioned using several technologies, including Er:YAG, Nd:YAG, Er, Cr, YSGG, and CO_2 lasers [11]. The preference for this recently created approach is increasing owing to its safety and efficacy [12, 13]. Lasers are capable of accumulating large quantities of energy and concentrating it on a target area that is primarily absorbed on the surface of opaque substances. In certain instances, lasers trigger chemical reactions and morphological changes, whereas in others, they only create physical modifications [14, 15].

CO_2 laser has a gas-active medium, emits light with a wavelength of 10,600 nm, and is mostly absorbed by water and hydroxyapatite. The applied energy is easily absorbed by hard tissue, whereas it generates instantaneous heat accumulation in irradiated inorganic components, resulting in the carbonization of organic components and cracking, melting, and carbonization [16]. Fractional CO_2 has various advantages over traditional irradiation, including reduced handpiece movement, the creation of multiple irradiated areas at distinct distances, and a consistent etching pattern, as well as reduced heat damage to the underlying tissue [17].

The present study aimed to assess the efficacy of fractional CO_2 laser considering the power-variation effect and intervals of scans compared with the HF effect. Our null hypothesis assumed that fractional CO_2 laser had no positive effect on the shear bond strength (SBS) of repaired porcelain by using composite resin.

2. Material and Methods

2.1. Specimen Preparation and Grouping. Thirty-three unglazed feldspathic ceramic (DeguDent, Concern Ceram Love, Dentsply, Germany) samples prepared in a disc form with final dimensions of 10 mm diameter and 3 mm thickness were used to analyze the repair SBS after different methods of surface treatment.

Standardisation for all specimens' working surfaces was conducted, including polishing with 800 and 1,000-grit silicon wet sandpaper for 2 min each and a speed of 500 rpm on the device (MP-1s metallographic grinder and polisher machine, China).

To remove sanding contaminants, the specimens were ultrasonically cleaned with distilled water and dried in air before laser treatment. To exclude surface-variation impact, all specimens' surface roughness was examined using a profilometer (SRT-6210, China).

Each disc was embedded in a self-cure acrylic resin mold ($2 \times 2 \times 3$ cm^3) for easy handling.

Group I (HF) (control group): 9.5% HF application

Group II (CO_2): fractional CO_2 laser system 10,600 nm wavelength (CO_2 fractional laser, Brochure/JHC118, China), 5 W power, 2 scans, 0.2 mm distance, and 0.5 ms duration. These parameters were selected based on pilot-study results depending on the roughness and cracks of free surface,

Group III (CO_2+ HFA): identical CO_2 laser irradiation as described in the laser group followed by the identical description of HF etching the HFA group.

2.2. Fourier Transform Infrared (FTIR) Test. FTIR test was performed using Shimadzu IR-Affinity-1 system (Japan) to obtain the transmission spectra of the tested ceramic at different wavelengths and observe the behavior of porcelain at CO_2 laser wavelength.

2.3. Optical Light Microscopy Image. Surface morphology was examined with an optical microscope (Euromex microscopic reflection/transmission, Netherlands). Photographs of different magnification powers were captured to analyze laser–porcelain interaction for comparison.

2.4. SEM and EDS Analyses. The surface morphology and chemical composition of the ceramic surface of each group were metalized with gold palladium and examined using a scanning electronic microscopy (SEM) system equipped with an energy-dispersive spectroscopy (EDS) system (Thermo Scientific™ Axia™ Chemi SEM, Hungary).

2.5. Surface Roughness. Surface roughness (Ra) was measured using a profilometer (SRT-6210). The device comprised a diamond stylus with 5 μm radius positioned perpendicularly to the surface of the sample, and 0.25 mm was the cutoff level. The average of three readings was set as the Ra of the specimen.

2.6. Repair Composite Application. Composite resin (Tetriv N-Ceram, Ivoclar Vivadent, Germany) application was conducted with the aid of a Teflon mold having dimensions of $4 \times 4 \times 2$ mm^3. An intraoral repair kit (Bisco intraoral repair kit, Schaumburg, USA) was used according to the manufacturer's recommendations. Afterward, the composite resin was incrementally filled and light cured with a light-curing device (Gulin woodpecker, LED. F, China) for 30 s each and a distance of 1 mm [18].

(1) For Group I, 9.5% HF etchant (Porcelain Etchant, Bisco, Schaumburg, IL 60193, USA) with a volume of 20 μL was used for 90 s according to the manufacturer's recommendations, rinsed for 90 s, and dried. Meanwhile, the Group II specimens' surface was treated with a CO_2 laser using the recommended parameters, for Group III procedure of Group II followed by procedure of Group I.

(2) Porcelain primer (20 μL) was applied, left for 30 s, and dried.

(3) Porcelain bonding resin (20 μL) was applied over the whole surface and light cured for 40 s with 1,000 mW/cm^3 to 1,200 W/cm^3 light intensity. The curing device (Gulin woodpecker, LED. F, China) was used for 30 s at a distance of 1 mm.

(4) Teflon mold was applied over the specimen, and then the composite resin was incrementally applied to fill the mold to 1 mm per layer and then light cured.

For conditioning, the specimens were placed in a 37°C distilled water bath (HH-2 Numerical Show Constant Temperature Water-Bathing Boiler, China) for 24 hr.

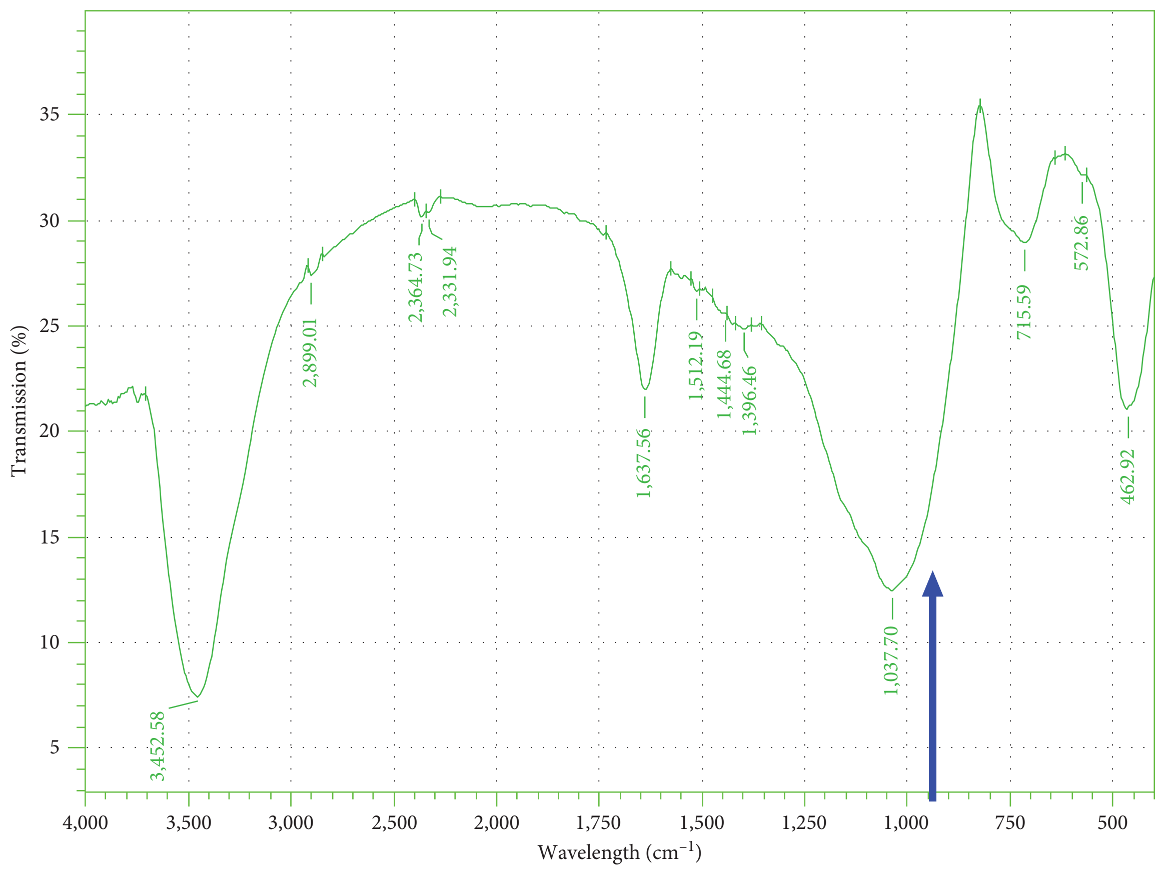


Figure 1: Tested porcelain peak absorption and transmission values, blue arrow shows the transmission peak at CO_2 laser wavelength 10,600 nm.

2.7. SBS Test. Each specimen was placed in a metal holder by using an electronic universal testing machine (XWW-50KN, China). Using a chisel directed to the composite–porcelain interface, the force was applied with a crosshead speed of 0.5 mm/min. The maximum load at the failure of the composite was recorded [18].

$$SBS = \text{max load (N)}/\text{bonding area (mm)}^2$$

2.8. Failure Mode. The failure mode of the bonding interface was observed by two researchers using a stereomicroscope (Hamilton microscope, Korea). The failure modes were deemed as adhesive, cohesive, or mixed.

Complete separation of the composite from the ceramic surface was defined as adhesive, and complete fracture of the composite or ceramic surface was defined as cohesive. The failure that included cohesive or adhesive was defined as mixed [18].

2.9. Statistical Analysis. The obtained data were subjected to one-way ANOVA test to compare the means of various groups with one another. The results are expressed as the mean ± standard deviation. A P value >0.05 was considered statically nonsignificant; P values <0.05 and <0.01 were considered significantly different; and $P<0.001$ was considered highly significantly different, respectively. The least significant difference test (LSD) was used to calculate the significant differences between every two groups.

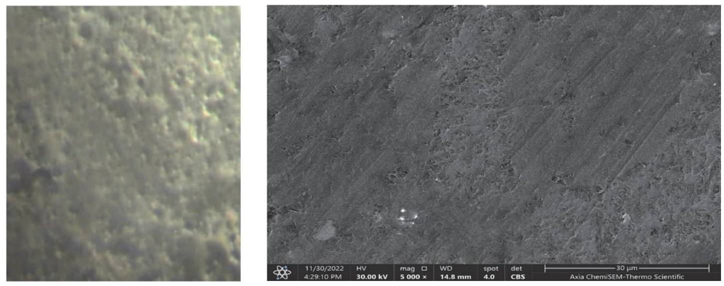
3. Results

FTIR analysis showed that the porcelain absorption peak was high, with a transmission percentage of 13% (Figure 1), indicating high absorption.

3.1. Optical Microscopy and SEM Analysis. The surface morphology of porcelain specimen was examined by optical microscopy and by SEM. The images show the surface morphology of untreated specimen (Groups I, II, and III) with different surface modifications, as shown in Figures 2–4.

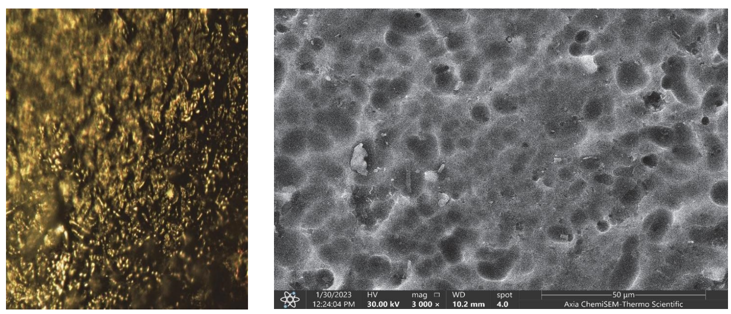
Morphological characterization of untreated specimen (Figure 2) revealed a smooth surface, whereas the control group (Figure 3) exhibited small and large microporosities as a three-dimensional network of canals and voids. For Group II, a shallow effect was observed on the porcelain surface, as shown in Figure 4. Group III showed a deeper effect of HF on the laser-treated area.

3.2. EDS Analysis. EDS analysis of the tested groups (Table 1) revealed no change in chemical composition compared with the untreated surface, with only a variation in percentage of elements in Group II with decreased C%.



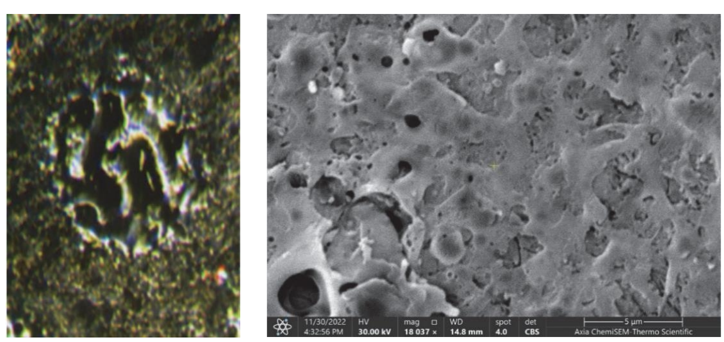
(a) (b)

Figure 2: Surface morphology of untreated porcelain group (a) microscopic picture 40x with scale bar = 2 mm and (b) SEM 5,000x.

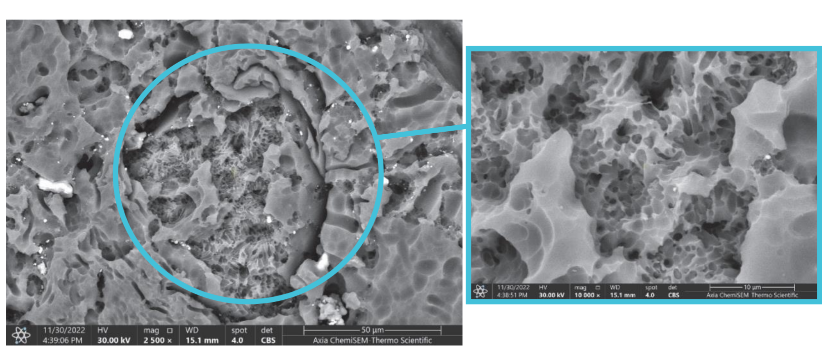


(a) (b)

Figure 3: Surface morphology of Group I (a) microscopic picture 40x with scale bar = 2 mm and (b) SEM 3,000x.



(a) (b)



(c)

Figure 4: Surface morphology of Group II; (a) microscopic picture 40x with scale bar = 2 mm, (b) SEM picture 18,000x, and (c) SEM of group III at 2,500x.

Table 1: Description of element concentration after each etching method and comparison with the control group.

Element	No treatment		HF (control)		CO_2		$CO_2 + HF$	
	Atomic (%)	Weight (%)	Atomic (%)	Weight (%)	Atomic (%)	Weight (%)	Atomic (%)	Weight
C	22.2	13.3	24.2[a]	14.2[a]	21.5[b]	12.9[b]	48.8[a]	29.0[a]
O	40.0	31.9	37.0[b]	28.9[b]	40.7	32.4	17.5[b]	13.8[b]
Na	2.7	3.1	4.7[a]	0.1[a]	2.7	3.0	0.4[b]	0.5[b]
Al	5.5	7.4	5.0[b]	6.5[b]	5.6	7.5	1.4[b]	1.9[b]
Si	24.5	34.2	23.6[b]	32.4[b]	24.2	33.8	23.6[b]	32.8[b]
K	5.0	9.8	3.4[b]	6.5[b]	5.4	10.4	0.6[b]	1.2[b]
Bi	0.0	0.3	–	–	–	–	–	
Ca	–	–	1.8[a]	2.6[a]	–	–	0.3[b]	0.6[b]
Ba	–	–	0.4[a]	2.6[a]	–	–	–	–
F	–	–	–	–	–	–	2.6[a]	2.5[a]
Fe	–	–	–	–	–	–	2.1[a]	5.9[a]
Zr	–	–	–	–	–	–	2.6[a]	11.9[a]

[a]Indicate increased element percentage and [b]indicate decreased element percentage than untreated surface.

For Groups I and II, considerable changes in the chemical composition and concentration of elements were observed. Group I showed an increase in C, Na, and K, whereas Group III showed an increase in C and O_2 and a decrease in Na, Al, Si, and K. Additionally, new elements could be determined. Figures 5–8 show the analyzed area, count map, and element distribution in all groups.

4. Discussion

4.1. Surface Roughness. As shown in Figure 9, the mean surface roughness of the tested groups before and after laser treatment and acid application, highest mean value was recorded in Group III. Statistical description and analysis are shown in Table 2 which indicate significant difference between tested groups.

4.2. SBS. As shown in Figure 10, the mean SBS of the tested groups, the highest mean value was recorded in Group III.

Statistical description and analysis are shown in Table 3 which indicate significant difference between tested groups.

4.3. Failure Mode Analysis. Failure mode analysis shows mostly adhesive failure mode among Group II while cohesive mode was dominant in Group IIII, for Group I both mixed and cohesive mode. Figure 11 and Table 4 show the distribution of failure mode in tested groups.

The percentage distribution of the failure mode within groups is shown in Table 4. The optical microscopic images of different failure modes are shown in Figure 12.

5. Discussion

In recent decades, the esthetic demand in dentistry has expanded to creating a pleasing smile with minimal invasiveness and limited scarification to the tooth structure. The technology and the material science introduced materials that directed to meet the patient restorative need and esthetic demand [19]. Lithium disilicate glass ceramic can be used as a veneer material cemented directly onto the tooth surface. Feldspathic porcelains are extensively applied as veneering materials for zirconia.

However, one of its disadvantages is fracturing or chipping, which may be due to the material's properties, an inadequate laboratory process, or clinically inadequate adjustment. To address such issues, the replacement of the prothesis or extraoral repair are routinely suggested. Intraoral repair with composite is the effective alternative considering its capacity to preserve the restoration and abutment, as well as its cost and time effectiveness [7, 20]. These features enhance the durability of restoration and minimize trauma to the prepared teeth [18].

Various acid concentrations can be used to modify the surface of silica-based ceramics and promote adhesion between the repair area and the substrate. The fundamental concept is to enhance surface quality and roughness by increasing surface area and retention. Special precautions must be followed by the dentist and patient to avoid harmful or bad effects of the acid on the soft tissue or teeth [21].

It is given that lasers are clean and easy to control, they are utilized in various dental applications with different wavelengths. Lasers have a variety of interactions with tissues or materials and can be used accordingly in cavity preparation, surface smoothing, or roughening, which can be compared with acid effect on the surface [22].

In the present study, CO_2 laser was used to modify the surface morphology and enhance the composite adhesion onto porcelain surface, so the null hypothesis was rejected. FTIR spectra indicated good interaction and response between fractional CO_2 laser and porcelain material, in agreement with previous studies [23, 24]. The surface roughness of the laser group was homogenous, shallow, and evenly distributed with no signs of carbonization or cracks. This finding indicated a positive interaction between laser and porcelain, as shown by light microscopy images. Meanwhile, specimens in Group I (control group) revealed deep porosity like honeycomb appearance, as confirmed by SEM results that showed increased roughness. For Group II, deeper porosity and roughness were

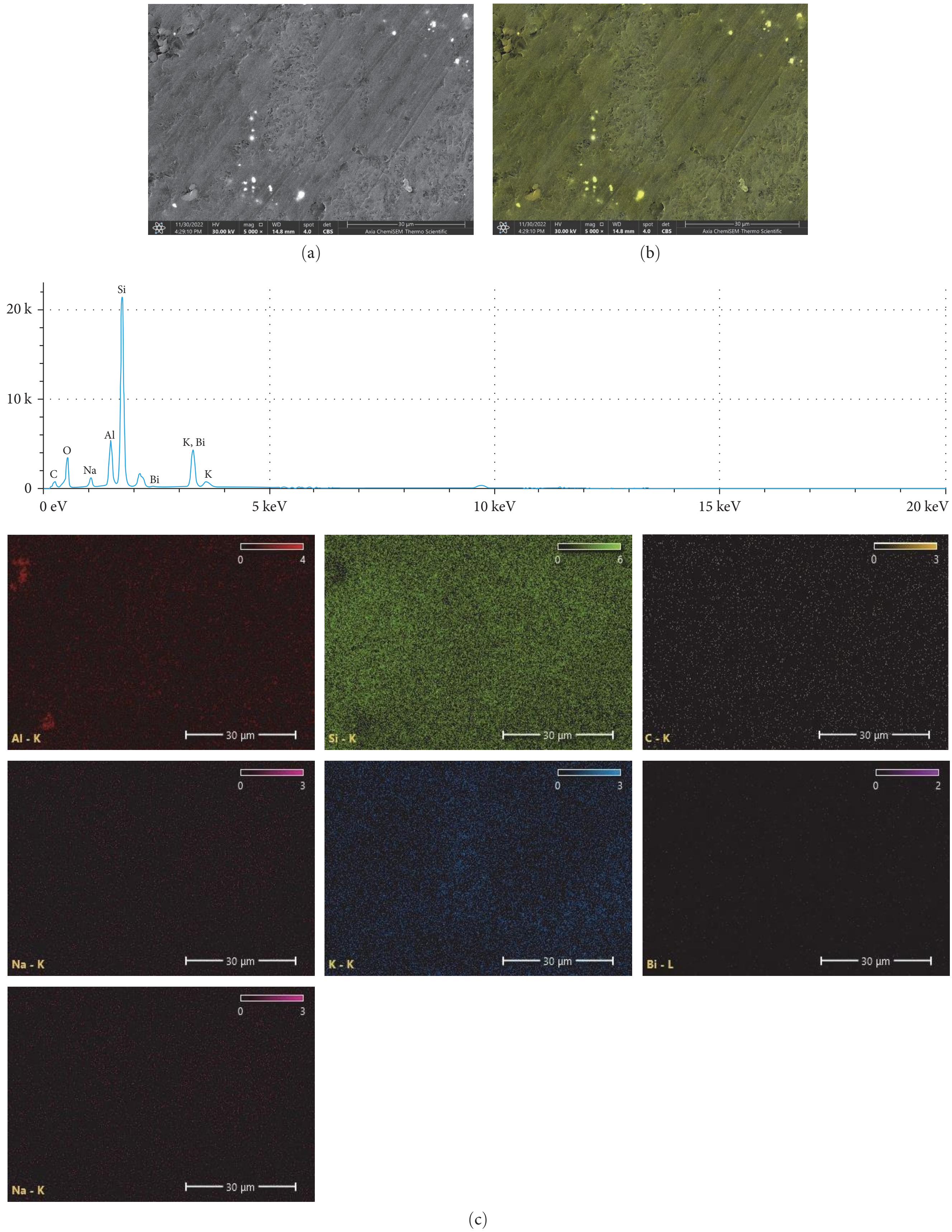


Figure 5: EDS analysis of untreated surface; (a) analyzed area, (b) count map, and (c) data map.

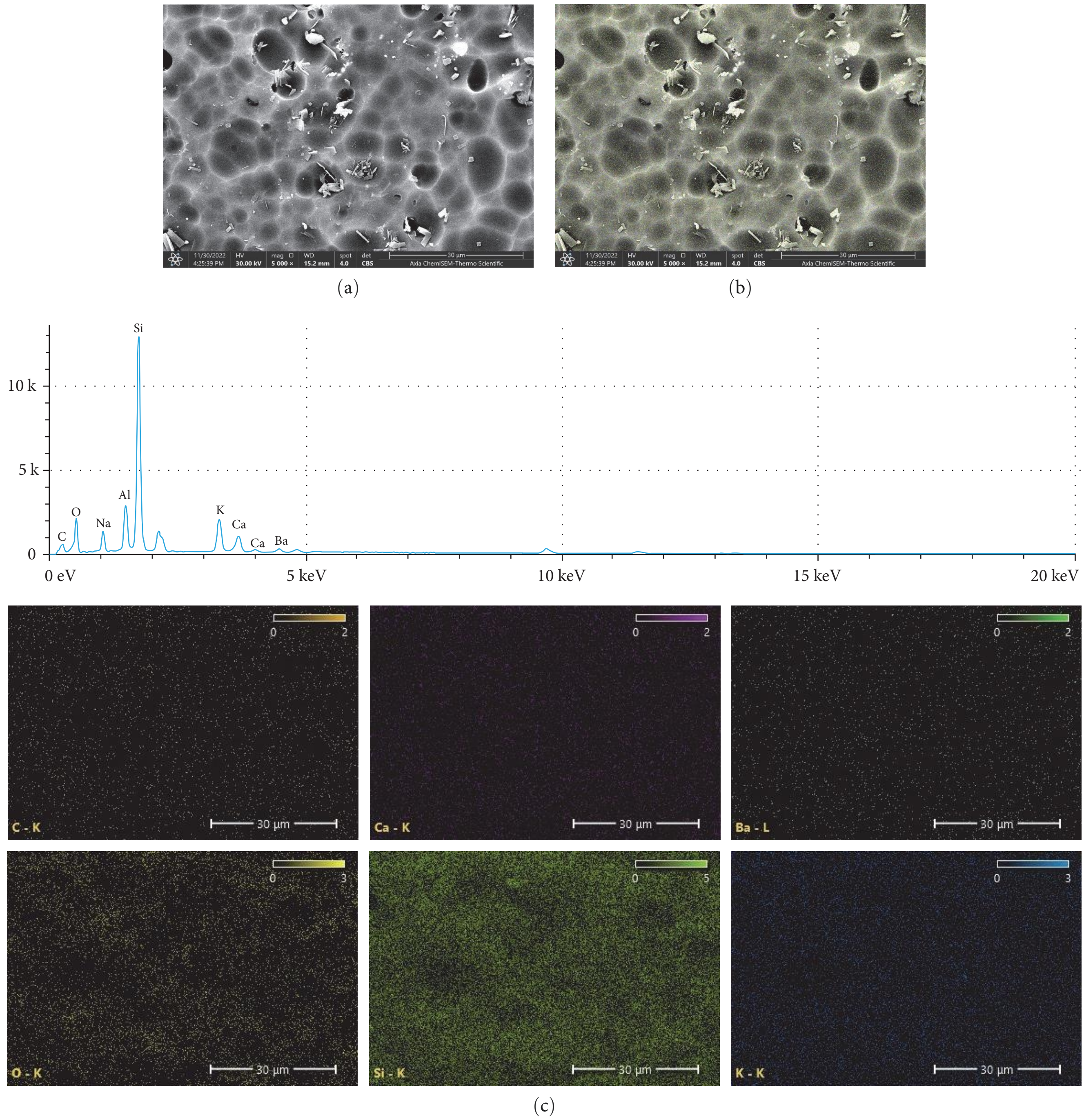


Figure 6: EDS analysis of Group I; (a) analyzed area, (b) count map, and (c) data map.

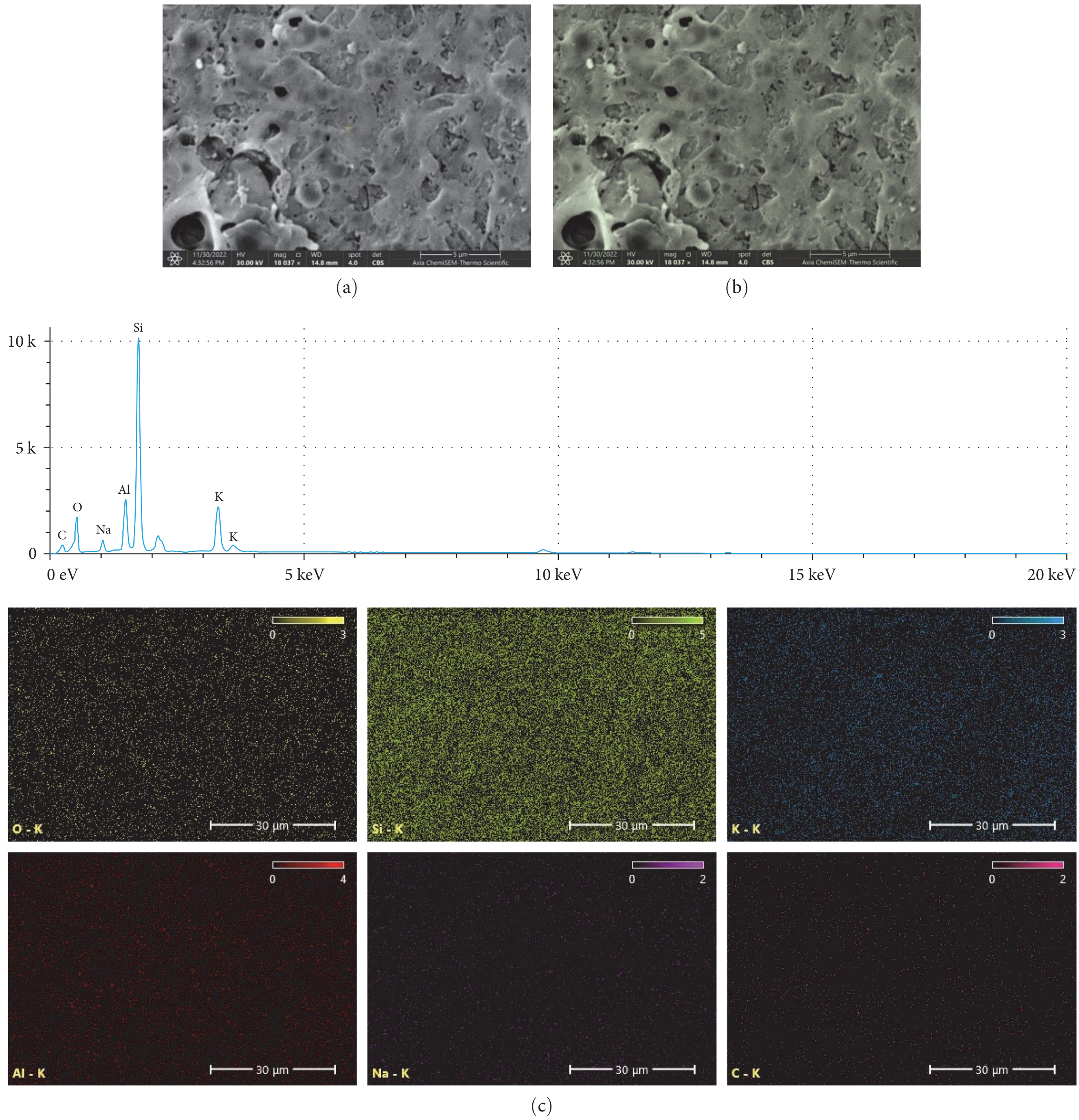


Figure 7: EDS analysis of Group II; (a) analyzed area, (b) count map, and (c) data map.

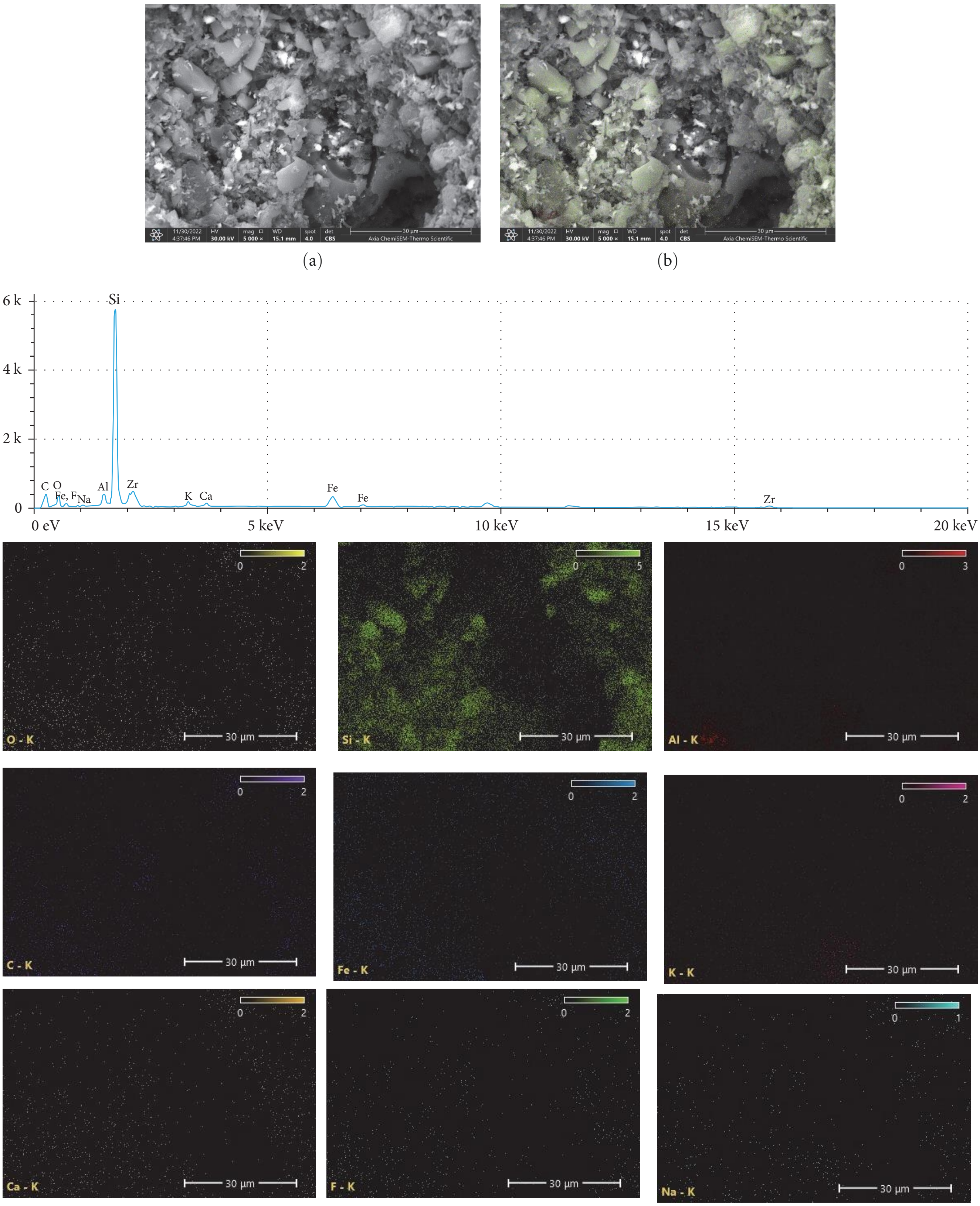


Figure 8: EDS analysis of Group III; (a) analyzed area, (b) count map, and (c) data map.

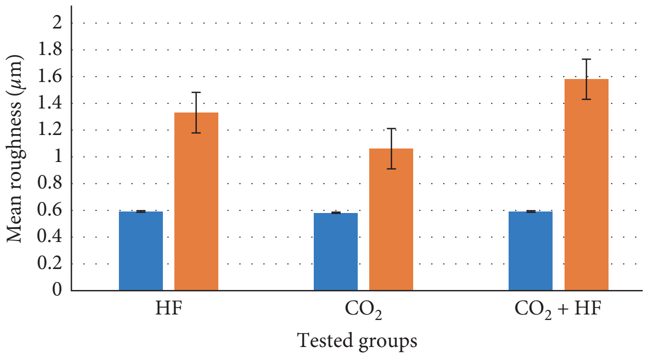


FIGURE 9: Shows the roughness before and after.

TABLE 2: ANOVA and LSD test for surface roughness between different groups.

Tested groups	Roughness before mean ± SD	Roughness after mean ± SD	*P*-value
HF	0.59 ± 0.05	B 1.33 ± 0.09	0.001 HS
CO_2	0.58 ± 0.05	C 1.06 ± 0.09	
CO_2 + HF	0.59 ± 0.05	*A 1.58 ± 0.07	

The letters (A, B, and C) represent the levels of significance in LSD, highly significant start from the letter (A) and decreasing with the last one. Similar letters mean there are no significant differences.

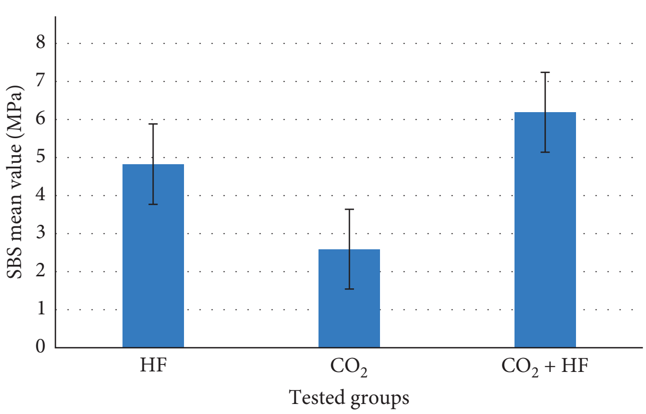


FIGURE 10: Shows mean value of SBS of the tested groups. SBS, shear bond strength.

TABLE 3: ANOVA and LSD test for SBS means of different groups.

Tested groups	SBS mean ± SD	*P*-value
HF	B 4.83 ± 1.11	0.001 HS
CO_2	C 2.59 ± 0.74	
CO_2 + HF	A 6.19 ± 0.99	

The letters (A, B, and C) represent the levels of significant, highly significant start from the letter (A) and decreasing with the last one. SBS, shear bond strength.

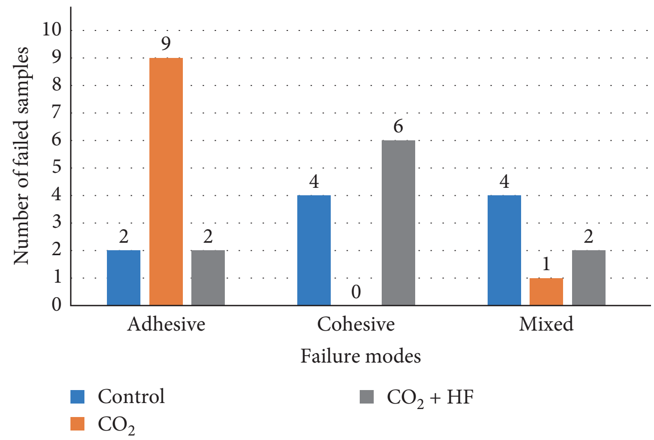


FIGURE 11: Distribution of failure modes among the groups.

TABLE 4: Shows the distribution rate of failure modes in different groups.

Mode of failure	Group I (control)	Group II	Group III
Adhesive	20%	**90%**	20%
Cohesive	40%	0%	**60%**
Mixed	**40%**	10%	20%

Bold values signify to make the test more prominent.

observed. These results agreed with those of Hakimaneh et al. [25].

EDS analysis showed that laser treatment did not change the chemical composition compared with the untreated surface and showed only a change in the percentage of component. These findings agreed with the result of a study performed by El Gamal et al. [26]. Conversely, the surface treatment of Groups I and III showed a change in chemical composition and introduction of new elements. The contents of Si, K, Al, O_2, and Na decreased, which can be attributed to the chemical interaction of HF with crystalline phase. The main crystalline component of dental porcelain was leucite (K_2O, Al_2O_3, and $4SiO_2$). Leucite dissolved more rapidly than the surrounding glass in HF acid, so etching may have produced microretentive channels in the porcelain where leucite had been, as proposed by Rekow et al. [27].

The laser setting applied in this study according to our pilot study to improve surface topography and increase surface roughness without cracks, highest mean of roughness can be observed. This surface-treatment method is recommended when extra retention is required as an alternative to using HF or laser alone, which is bound to increase the durability of the repair process and retention as a result. These findings agreed with those of Ahrari et al. [28]. Conversely, Akyıl et al. [29] reported that the use of HF acid after laser irradiation increased the SBS of resin composite to feldspathic porcelain, although the resultant bond strength is still lower than that achieved by applying HF acid alone. This finding could be attributed to the method of surface roughness evaluation which was analyzed

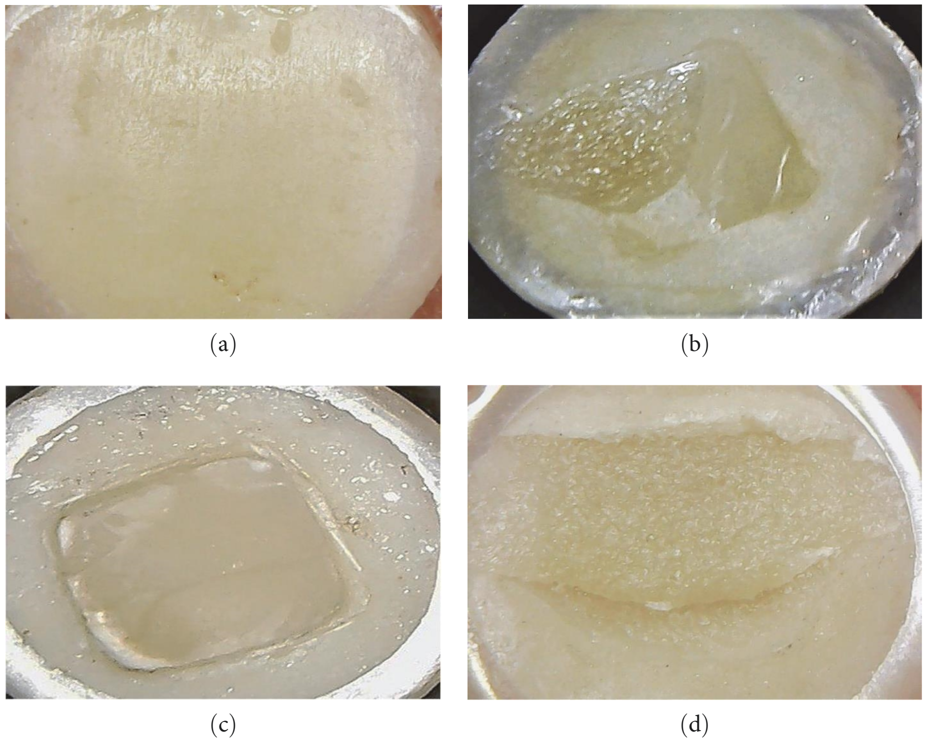


Figure 12: microscopic pictures of failure modes with magnification power 2x; (a) adhesive failure, (b) mixed failure, (c) cohesive failure with in the composite, and (d) cohesive failure with in porcelain.

by SEM only without actual measurement. According to the authors' knowledge and review, very few previous researchers have compared the laser effect and HF.

The most prevalent mode of failure was adhesion amongst the laser-treated specimens, whereas cohesive failure was higher in the combined surface treatment. The increased roughness and surface area created mechanical interlocking between the composite and the porcelain, leading to increased shear strength and cohesion between the two materials. Furthermore, the pattern of surface roughness may play a role in the integration between the composite resin repair material and the porcelain. The flow of the material and surface wettability may also enhance or interfere with this integration, as also presented by Vrochari et al. [30].

This study has some limitations and clinical significance. The surface treatment with laser followed by HF was favorable to obtaining extra retention to repair porcelain with composite. More studies considering other types of CO_2 laser as continuous or pulsed types are required to determine the effect on of intraoral repair material.

6. Conclusion

With the limitations of this in vitro study taken into consideration, the following conclusion was drawn:

(i) The combined surface treatment of porcelain with laser followed by HF is recommended when extra or high retention is required for the repair of feldspathic porcelain with composite over HF and laser alone.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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