Journal of Ovonic Research Vol. 6, No. 5, September-October 2010, p. 227 – 238

EVALUATION OF HARDNESS, SURFACE MORPHOLOGY AND STRUCTURE OF LASER IRRADIATED CERAMICS

R. MOHAMMED ABDALLAH, I. MOHAMMED HAMMOUDA[a], M. KAMAL[b*], O. BADIE ABOUELATTA[c], A. ABD EL-SALAM[d]
Assistant Lecturer, Dental Biomaterials Department, Faculty of Dentistry, Mansoura University.
[a]Professor and Chairman of Dental Biomaterials Department, Faculty of Dentistry, Mansoura University
[b]Professor of Solid State Physics (Metal Physics), Faculty of Science, Mansoura University.
[c]Assistant Professor of Production Engineering and Machine Design Department, Faculty of Engineering, Mansoura University
[d]Assistant professor of Dental Biomaterials Department, Faculty of Dentistry, Mansoura University

Glazing of ceramic surfaces is recommended in order to improve the physical properties of dental ceramics. Conventional methods for the surface treatment of dental ceramic materials are not capable of creating a smooth surface without microcracks. The special radiation characteristics of both XeCl excimer and CO_2 lasers make them suitable to treat ceramic surfaces in order to produce a glazed surface. The aim of this study was to investigate the surface hardness of dental ceramics after their glazing with both XeCl excimer and CO_2 lasers. Materials and methods: 70 specimens were prepared from both dental porcelain and In-Ceram Alumina (35 specimens each). In hardness test, 25 specimens of each ceramic material were divided into 5 specimens that were conventionally glazed, 10 specimens were excimer laser glazed with two different energy densities, and 10 specimens were glazed with CO_2 laser at two different power settings. The surface hardness was measured in (Kg/mm^2) using Vickers microhardness tester. In addition, SEM and X-ray diffraction analysis of the changes in surface structure were conducted. The results were analyzed and compared using one way ANOVA and LSD statistical tests at a level of significance of 0.05% ($p < 0.05$). Results: Statistical analysis of the results revealed insignificant increase in hardness values of 2 watt CO_2 laser and 1.5 $Joule/cm^2$ excimer laser glazed porcelain specimens. Also, there was insignificant increase in hardness values of 2 and 10 watt CO_2 laser glazed In-Ceram Alumina specimens. 10 watt CO_2 and 6.2 $Joule/cm^2$ excimer lasers glazed porcelain specimens demonstrated significant increase in their hardness values. In-Ceram Alumina specimens showed significant increase in their hardness values glazed with both energy densities of excimer laser. Scanning electron microscope images declared an increase in homogeneity and smoothness of the surfaces of laser glazed specimens especially those glazed with higher power setting of CO_2 laser and higher energy density of excimer laser when compared to conventionally glazed specimens. X-ray diffraction charts of both the control and laser glazed specimens are nearly identical, indicating that laser glazing had no effect on their internal microstructure and it was just a surface treatment. Conclusion: laser glazing improves surface hardness and smoothness of ceramic surfaces without affecting their internal structures.

(Received October 13, 2010; accepted October 20, 2010)

Keywords:Hardness, Laser, Ceramics, Surface morphology

* Corresponding author: kamal422002@yahoo.com

1. Introduction

Today, porcelain plays a vital role in restorative dentistry. As demands for esthetic dental restorations continue, new technologies will improve the material properties and develop new methods for its use. [1]. The development of ceramic systems more resistant to chewing stresses has allowed the fabrication of all ceramic restorations without metallic infrastructure. [2]

The high crystalline content ceramic framework of metal-free bonded prostheses and implant abutments made from glass-infiltrated ceramic core, is often exposed to the oral environment without a ceramic veneer. This is especially true for inadequate tooth preparation and bonded prostheses, in which the palatal extension of the prosthesis is usually uncovered. [3] Besides, the veneer layer over glass-infiltrated ceramic core may be subjected to brittle fracture and removed through use and accidental damage causing direct contact between the core material and the opposing human enamel or restoration. [4] The bulk of core materials could also be exposed in non-aesthetic areas that require additional strength, such as the connector regions. [5] In these cases, the framework ceramic surface should be as smooth as possible, with the aim of minimizing the bacterial colonization and dental biofilm formation. [6]

In fact, a surface compression layer was found to occur on a wide range of ceramic materials following different treatment processes that acts to strengthen ceramic material. It can be achieved by thermal tempering, machining and polishing and the application of a glazing layer with a lower coefficient of thermal expansion than the adjacent ceramic material. [7]

The special characteristics of XeCl excimer laser radiation, particularly its very high energy density and the possibility of guiding the laser beam through flexible quartz glass fibers, made this laser system a very promising technique for working ceramic materials. [8] In accordance with, is the CO_2 laser which is well suited for the treatment of porcelain materials because its emission wavelength is almost totally absorbed by porcelain. [9]

Previous studies with Al_2O_3, zirconia, SiC and $Y–Cu_3–O_7$ ceramics of non dental origin have demonstrated an improvement in the physical characteristics of the ceramic surface, e.g. reduced roughness and increased fracture strength. It was suggested that laser treatment of ceramic surfaces inhibits the formation of micro cracks, leading to greater mechanical resistance of the ceramic.[10]

Therefore, we are aiming from this study to evaluate surface morphology, structure and hardness of both conventional dental porcelain and the In-Ceram Alumina materials after their glazing with both XeCl excimer and CO_2 lasers.

2. Materials and methods

I. Materials

- Conventional feldspathic porcelain: Vitadur N (VITA Zahn Fabrik H. Rauter GmbH and Co.KG. Postfach 1338D-17880 Bad Sackingen. Germany).
- Dental ceramic, namely Vita In-Ceram Alumina (VITA Zahnfabrik H. Rauter GmbH & Co. KG Postfach 1338D-79704 Bad Sackingen. Germany).

II. Methods

A total number of 70 specimens were prepared for this study. The prepared specimens were irradiated with two different types of lasers.

1.1. Hardness test

1.1.1 Preparation of the specimens

A stainless steel mold was used to fabricate 50 disc shaped specimens, 25 for each type of ceramic material, measuring 10 mm in diameter and 2 mm in thickness. [11]

- **Preparation of porcelain specimens**

Porcelain powder was mixed with distilled water to form slurry. The mixed slurry was loaded into a stainless steel mold. The slurry was then condensed. The water expressed during condensation was periodically blotted away using an absorbent tissue. The specimens were placed

on a firing tray. They were dried and sintered in a vacuum furnace according to the manufacturer's specification (at 940° C). [12]

The prepared 25 specimens were then divided as follows:

1-Five specimens of conventional dental porcelain were auto-glazed by melting them at 940 °C for 1 minute to provide the glaze layer (control). [13]

2- Ten specimens of conventional dental porcelain were glazed with CO_2 laser device (Novapulse LX-20SP, Luxar, Bothell, Wash) with two different power settings, 2 and 10-watt (5 specimens each) in the superpulse mode (15 msec, 2Hz).

3- Ten specimens of conventional dental porcelain were glazed with excimer laser device (Lambda-physik, Model Optex, Germany) filled with xenon and chlorine as the laser medium, emitting ultraviolet radiation at a wavelength of 308 nm with two different energy densities, 1.57 and 6.28 J/cm^2 (5 specimens each).The maximum energy of the radiation was 120 mJ, and the pulse duration was in the range of 60 ns. The repetition rate was 40 laser pulses per second.

- **Preparation of In-Ceram Alumina specimens**

A stainless steel mold was used to fabricate aluminum-oxide specimens. Impression of the metal mold was made with the putty/wash technique using vinyl polysiloxane impression (Zetaplus; Zhermack Spa, Badia Polesine, Rovigo, Italy). The impression was poured with In-Ceram Special Plaster (VITA Zahnfabrik).The aluminum oxide powder was mixed with a special liquid (Vita In-Ceram Alumina mixing liquid;Vita Zahnfabrik) as instructed by the manufacturer. [14] The slurry mixture was then painted over the special plaster die and fired at 1120°C in the oven (InCeramat; Vita Zahnfabrik) for 10 hours. Glass infiltration was obtained by coating the aluminum oxide framework with a glass powder (silicate-aluminum-lanthanum) distilled water mixture and firing in the furnace for 4 hours at 1100°C. Finally, excess glass was removed by airborne-particle abrasion with 50μm alumina powder. [14]

The prepared 25 specimens were then divided as follows:

1- Five specimens of In-Ceram Alumina were heat treated with two cycles: the first at 960°C×1 min and the second at 940°C×1 min which correspond to those recommended by the manufacturer for auto-glazing of the veneering porcelain used on In-Ceram Alumina (control). [15]

2-Ten specimens of In-Ceram Alumina were glazed with CO_2 laser at two different power settings 2 and 10 watt (5 specimens each).

3- Ten specimens of In-Ceram Alumina were glazed with excimer laser with two different energy densities, 1.57 and 6.28 J/cm^2, (5 specimens each).

1.1.2 Conduction of the test

Before conducting the test, surfaces of all specimens were thoroughly inspected by a magnifying lens to exclude specimens with any surface defect. A micro-hardness tester (Digital Vickers Micro-hardness tester (FM-7) Japan) using a Vickers indenter and a load of 200 g for 30 seconds was used. Five measurements were made for each specimen, and the mean value of each specimen was calculated. [16]

1.2. Scanning electron microscope analysis:

A total number of 10 photomicrographs were taken to be representatives for the following specimens:

1- One specimen of conventional dental porcelain that was auto-glazed (control).

2- Two specimens of conventional dental porcelain that were glazed with CO_2 laser device with two different power settings, 2 and 10-watt (One specimen for each power settings).

3- Two specimens of conventional dental porcelain that were glazed with excimer laser device with two different energy densities, 1.57 and 6.28 J /cm^2 (One specimen for each energy density).

4- One specimen of In-Ceram Alumina that was heat treated with two cycles which correspond to those recommended by Vita for the auto-glazing of the veneering porcelain used on In-Ceram Alumina (control).

5-Two specimens of In-Ceram Alumina that were glazed with CO_2 laser at two different power settings 2 and 10 watt (One specimen for each power settings).

6- Tow specimens of In-Ceram Alumina that were glazed with excimer laser with two different energy densities, 1.57 and 6.28 J/ cm^2 (One specimen for each energy density).

The photomicrographs were used to observe the surface topography of the specimens. The specimens were sputter-coated with 25 to 30 μm of gold **(**Hummer VII Sputtering System; Anatech Ltd, Alexandria, Va) and examined at original magnification ×200 with scanning electron microscopy **(**Electron probe micro-analyzer operating at 30 KV Joel Type JXA-840A, Japan**).** [(5)]

1.3. X-ray diffraction analysis:

A total number of 10 specimens, 5 specimens for each type of ceramic materials were divided and treated as those used for the scanning electron microscope analysis. The specimens were then placed in the holder of a Siemens diffractometer **(**Diffractometer D5000, Siemens, Germany) and scanned using Cu Kα X-ray from 20 to 40° 2θ degrees; a step size of 0.04° and 5 s-step interval were used. [(5)]

3. Results

The results of laser–ceramic glazing were categorized as follows:

3.1. Hardness

Mean hardness values of porcelain specimens glazed with the conventional method (control) and those glazed with both CO_2 and excimer lasers are presented in Table 1**.** One-way ANOVA demonstrated significant difference between the mean hardness values of dental porcelain glazed with different methods ($P \leq 0.001$).

Statistical analysis of the results (LSD test) revealed significant differences between 10 watt CO_2 laser and 6.2 Joule/cm^2 excimer laser groups when compared to that of conventionally glazed group (control) ($P \leq 0.05$). Also, there were significant differences between the two groups of CO_2 laser (2 watt, 10 watt) and also between the two groups of excimer laser (1.5 Joule/cm^2 and 6.2 Joule/cm^2) ($P \leq 0.05$).

Significant differences were also noticed between 2 watt CO_2 laser and 6.2 Joule/cm^2 excimer laser groups and also between 10 watt CO_2 laser and 1.5 Joule/cm^2 excimer laser groups ($P \leq 0.05$).On the other hand, there were no significant differences noticed between the control group, 2 watt CO_2 laser and 1.5 Joule/cm^2 excimer laser groups. Also, there was no significant difference between 10 watt CO_2 laser and 6.2 Joule/cm^2 excimer laser groups.

Mean hardness values of In-ceram alumina specimens glazed with different methods were presented in Table 1.One-way ANOVA demonstrated significant difference between the mean hardness values of In-Ceram alumina specimens glazed with different methods ($P \leq 0.001$).

Statistical analysis of the results (LSD test) revealed significant differences between 1.5 Joule/cm^2 excimer laser and 6.2 Joule/cm^2 excimer laser when compared to that of conventionally glazed group (control) ($P \leq 0.05$).There were also significant differences between 2 watt CO_2 laser group and those glazed with the two groups of excimer laser (1.5 Joule/cm^2 and 6.2 Joule/cm^2) ($P \leq 0.05$).A significant difference was also noticed between 10 watt CO_2 laser group and 6.2 Joule/cm^2 excimer laser group ($P \leq 0.05$). On the other hand, there were no significant differences between the different groups (conventional glazing (control) group and the two groups of CO_2 laser) ($P > 0.05$). At the same time, there were also no significant differences between 10 watt CO_2

laser and 1.5 Joule/cm^2 excimer laser and also between the two groups of excimer laser on the recorded hardness values in In-Ceram Alumina (P>0.05).

3.2. Scanning electron microscope:

SEM observations of conventionally glazed porcelain specimen (control) showed uneven and rather slightly granular surface feature (Figure 1). The scanning electron micrographs of CO_2 laser glazed porcelain specimens had rather more homogenous surfaces than the control specimen. In case of low power setting (2 watt), the peaks in the structure of the irradiated surface have been in part melted together. However, there were wide areas with fissures between the former peaks of the surface structure.k *glazing methods.*

Material	Dental porcelain				In-ceram alumina			
Groups	Mean ± SD	F-Value	P-Value	LSD	Mean ± SD	F-Value	P-Value	LSD
Conventional glazing(Control)	422.6±34.3175 ^{DB}	13.455	0.001	68.96	768.6±70.1413 ^{DC}	7.652	0.001	119.2
2 watt CO_2 laser	455.6 ± 63.2528 ^{CB}				796.6 ± 64.8984 ^{C}			
10 watt CO_2 laser	539.1 ± 43.3307 ^{A}				860.8± 64.8128 ^{BDC}			
1.5 Joule/cm^2 Excimer laser	470.2 ± 41.5707 ^{B}				961.4 ± 92.4219 ^{AB}			
6.2 Joule/cm^2 Excimer laser	595.0 ± 14.2824 ^{A}				980.0 ± 87.4643 ^{A}			

Means with different superscripts are significantly different at P-value ≤ 0.05.

On the other hand; at higher power setting (10 watt), the specimen had smoother surface and much more homogenous structure. The scanning electron micrographs of excimer laser glazed porcelain specimens appeared to have larger areas of fusion with much more smoothness and homogeneity in the surfaces especially with higher energy density (6.2 J/cm^2). The black arrows referred to the emergence of shallow splodgy areas of melting (Figure 2)**.**

Figure 3 illustrated the scanning electron micrograph of conventionally glazed In-Ceram Alumina specimen. The figure showed slight alterations of the surface structure. The surface had wide areas without any changes except the presence of small crater like irregularities in and around glazed patches with numerous cracks formation. The surfaces of both CO_2 and excimer laser glazed In-Ceram Alumina specimens had much greater number of fused zones of melting and became more homogenous and smoother in shape with decreased number of craters and fissures especially at higher power setting of 10 watt CO_2 laser (Figure 4) and higher energy density of 6.2 J/cm^2 excimer laser.

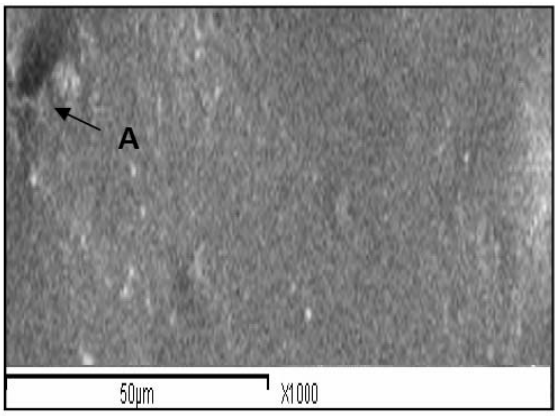

Fig. 1: Scanning electron micrograph of porcelain specimen subjected to conventional glazing. A: Refers to large void formation.

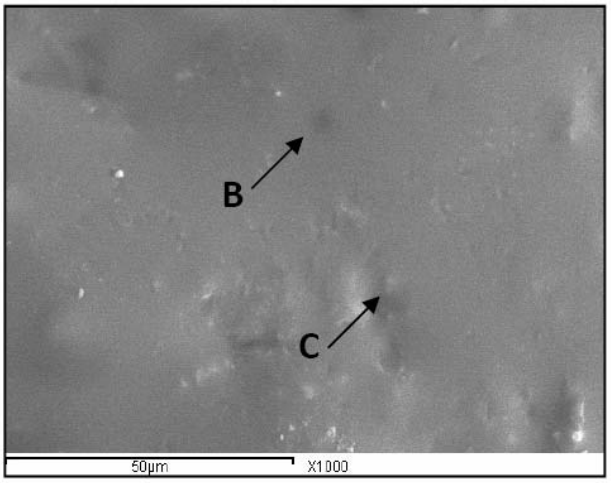

Fig. 2: Scanning electron micrograph of porcelain specimen subjected to 6.2 Joule/cm^2 excimer laser glazing. B, C: refer to shallow splodgy areas of melting.

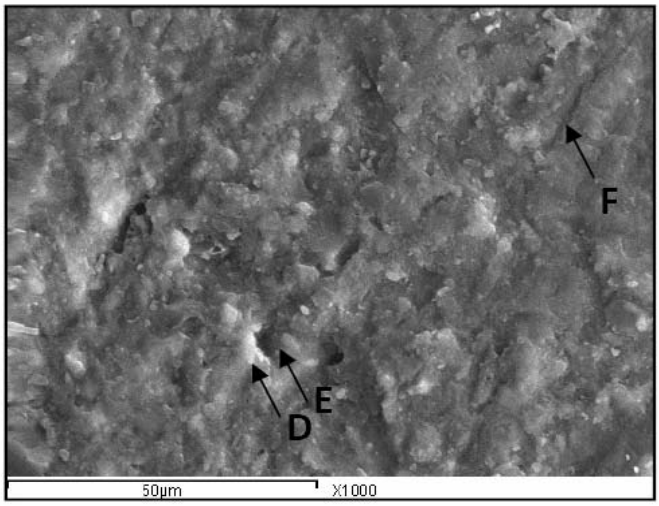

Fig. 3 Scanning electron micrograph of In-ceram alumina specimen subjected to conventional glazing. D: refers to glazed patches, E: shows crater like irregularity and F: shows crack formation.

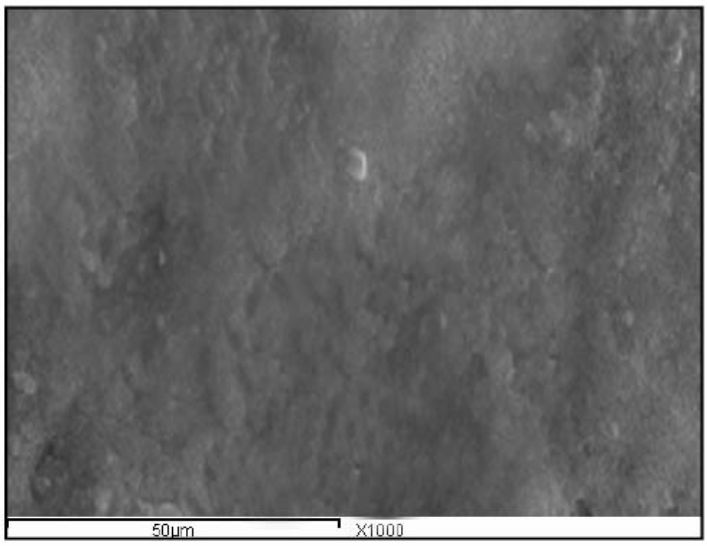

Fig. 4: Scanning electron micrograph of In-ceram alumina specimen subjected to 10 watt CO_2 laser glazing.

3. X-ray diffraction analysis

The internal structures of both control and laser glazed specimens were determined using an X-ray diffractometer. The structural changes were correlated to the investigated properties. The charts obtained from the specimens were presented in Figures which are plots of relative intensity (counts per second) versus diffraction angle (2θ). The X-ray analysis of both porcelain and In-ceram alumina specimens detected diffraction peaks that corresponded to crystalline phases present in both materials indicating that the materials had predominantly crystalline structure.

In case of porcelain specimens, the charts showed the appearance of potassium aluminum catena-disilicate (leucite) crystals having a body-centered tetragonal lattice structure as indicated by the ASTM card # 22-675 (Figures 5A, B).The diffraction pattern of 2 watt CO_2 laser glazed specimen showed that there was no remarkable change in the intensities of potassium aluminum catena-disilicate bands when compared to those of the control specimen. On the other hand, the diffraction pattern of 10 watt CO_2 laser glazed specimen showed that there was a remarkable decrease in their

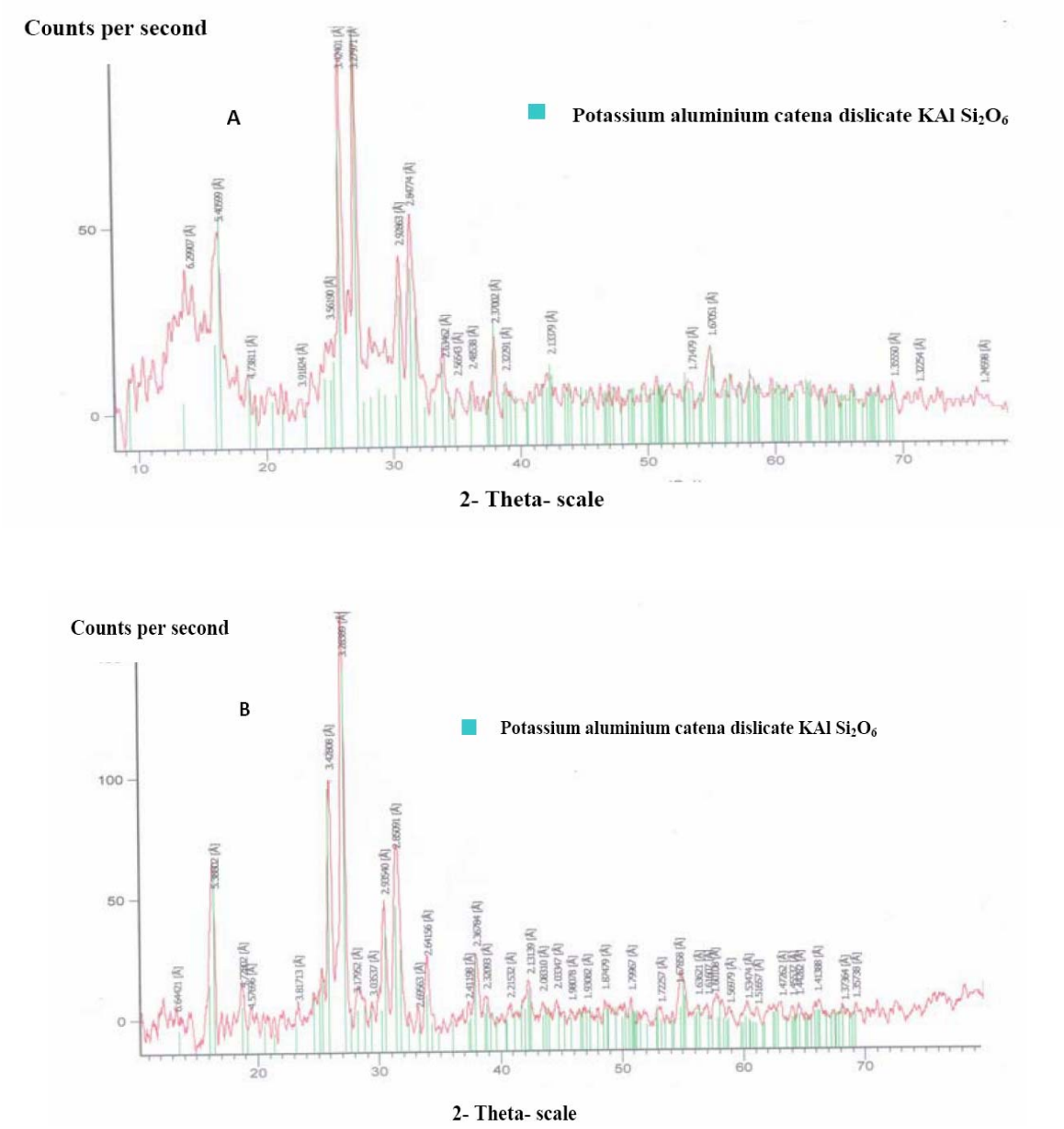

Fig. 5: Representative X-ray spectrum of porcelain specimens subjected to A: Conventional glazing, B: 10 watt CO_2 laser glazing.

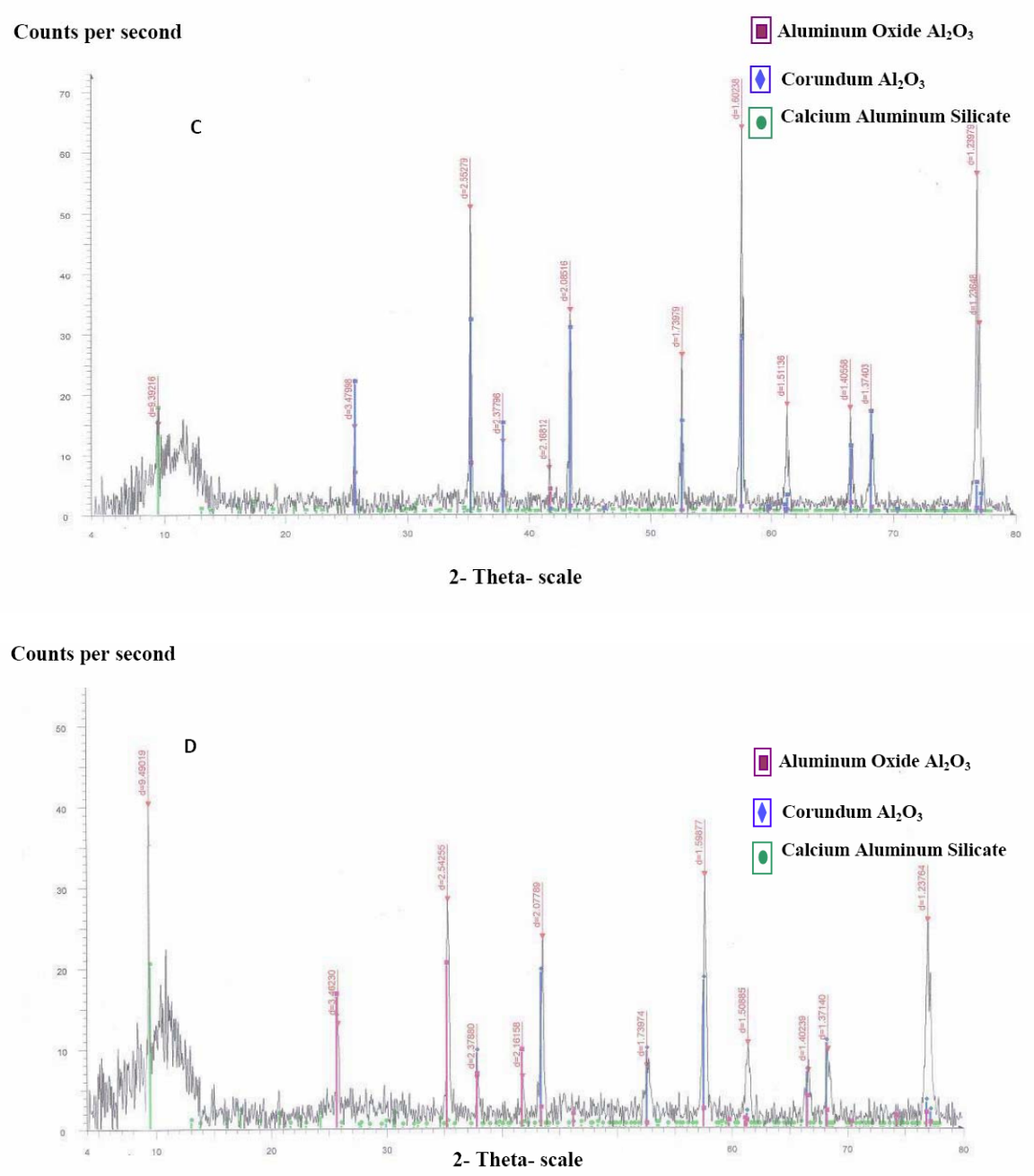

Fig. 6: Representative X-ray spectrum of In-Ceram Alumina specimens subjected to C: Conventional glazing, D: 6.2 Joule /cm^2 excimer laser glazing.

intensities which appeared at (2θ) =16.39°, 26.02°, 30.52° and 31.41° with their corresponding (d) space = 5.405Å, 3.424Å, 2.928Å and 2.847Å respectively (Figure 5 B). In case of 1.5 Joule/cm^2 excimer laser glazing, there was a remarkable decrease in the intensities which appeared at (2θ) =30.52° and 31.41° with their corresponding (d) space = 2.928Å and 2.847Å respectively. Also, the intensities of the bands decreased at (2θ) =30.52° and 37.96° with their corresponding (d) space = 2.928Å and 2.370Å respectively, in case of 6.2 Joule/cm^2 excimer laser glazing.

On the other hand, the charts of In-Ceram Alumina specimens dictated the appearance of aluminum oxide, corundum and calcium aluminum silicate bands having rhombohedral, hexagonal

and triclinic structures respectively as indicated by the ASTM card # 10-173 for both aluminum oxide and corundum and ASTM card # 20-20 for calcium aluminm silicate (Figure 6 C, D). The diffraction patterns of both 2 watt CO_2 and 6.2 Joule/cm^2 excimer laser (Figure 6 D) glazed In-Ceram Alumina specimens demonstrated a remarkable decrease in the intensities of corundum and aluminm oxide bands appeared at (2θ) =35.12°, 43.36°, 52.55°, 57.46°, 66.46° and 76.82° with their corresponding (d) space=2.552Å, 2.085Å, 1.739Å, 1.602Å, 1.405Å, and 1.239Å respectively, when compared to those of the control specimens. While in case of 10 watt CO_2 laser glazed specimen, the band intensity decreased more at (2θ) =76.82° and (d) space = 1.239Å (Figure 11). Also, the intensities decreased remarkably at (2θ) =43.36°, 52.55°, 57.46° and 76.82° with their corresponding (d) space = 2.085Å, 1.739Å, 1.602Å and 1.239Å respectively, in case of 1.5 Joule/cm^2 excimer laser glazing.

The diffraction pattern of 2 watt CO_2 laser glazed In-Ceram Alumina specimen showed that there was a slight increase in the intensity of calcium aluminum silicate band appeared at (2θ) =9.39° and (d) space = 9.402Å when compared to that of the control specimen. While in case of 10 watt CO_2 laser glazed specimen, the band intensity increased more at (2θ) =9.33° and (d) space = 9.464Å. In case of 1.5 joule/cm^2 excimer laser glazing, there was a very remarkable increase in the intensity which appeared at (2θ) =9.37° and (d) space = 9.426Å. Also, the intensity of the band increased remarkably at (2θ) =9.31° and (d) space = 9.490Å in case of 6.2 Joule/cm^2 excimer laser glazing (Figure 6 B)**.**

4. Discussion

The effect of laser glazing of both dental porcelain and In-Ceram alumina materials on their properties differ according to variation in energy density of excimer laser and power setting of CO_2 laser. According to hardness results, porcelain specimens glazed with both 2 watt CO_2 laser and 1.5 Joule/cm^2 excimer laser showed an insignificant increase in their hardness values while those glazed with both 10 watt CO_2 laser and 6.2 Joule/cm^2 excimer laser showed a significant increase in their hardness values when all of them are compared to those subjected to conventional glazing. In-Ceram Alumina specimens exhibited an insignificant increase in their hardness values in all groups of glazed specimens except those glazed with both1.5 and 6.2 Joule/cm^2 excimer laser.

The hardness results coincide with the findings of Kazuyuki and Tomozawa, (1987) who declared that the thermal effect of laser would melt a thin superficial layer of ceramic surface and this layer would fill in surface flaws, reducing their depth and blunting the flaw tips. This should provide an increase in hardness because, for a given ceramic material, strength and hardness would increase with decreasing flaw depth and sharpness.[18] Also, Binns, (1983) found that the melted superficial layer of ceramic material has a lower thermal expansion coefficient than the leucite-rich interior. This would place the outer surface in compression when cooled. The compressive stress state would diminish the local tensile stress produced from applied loading at surface flaws, thereby necessitating the need for increased applied loading to initiate flaw propagation from the external surface. [19]

These hardness results are in contrast with those of Mackert et al., (1994) who indicated that the size of leucite particles in feldspathic porcelain increases during heating process with laser irradiation. This can increase the probability of microcracking thus decreasing the hardness of ceramic materials. [20]

Scanning electron microscope images declared the increase in homogeneity and smoothness of the surfaces of laser irradiated specimens especially those irradiated with higher power of setting of CO_2 laser and higher energy density of excimer laser when compared to conventionally glazed specimens where more glassy matrix was dissolved resulting in an increase in fusion, homogeneity of crystallization and reduction of voids.

These results were attributed to the laser thermal effect which causes melting of a thin superficial layer of ceramics. [21] This leads to the deposition of high amounts of radiation energy in a well defined part of the ceramic surface over an ultrashort period of time, causing the accumulation of a very high energy density. [22] The radiation energy is thermalized and the

temperature, in a thin superficial layer, rises. [23] As the ceramic is manufactured with very small crystallites, its extremely low porosity may lead to scattering losses. [24]

This explanation seemed to coincide with that of Schmage et al., (2003) who found that a glazed surface layer on ceramics will be formed with Nd:YAG laser irradiation. [25] This opinion was also in agreement with that of Folwaczny et al., (1998) who concluded that the physical roughness of dental ceramic surfaces can be significantly reduced by 308 nm excimer laser irradiation. [23]

X-ray diffraction was performed to evaluate internal structure of the studied specimens. The diffraction patterns of both porcelain and In-Ceram Alumina specimens demonstrated sharp well-defined peaks which indicated that both materials having predominantly crystalline structure with very few broad bands which corresponded to the amorphous glassy phase. However, it is clear from the charts that the X-ray diffraction traces of both the control and laser glazed specimens are identical with each other; meaning that there was no change in the number of peaks nor their positions, indicating that laser glazing had no effect on the internal microstructure of both porcelain and In-Ceram Alumina and it was just a surface treatment. It was clear from the diffraction patterns of the specimens that the effect of laser glazing was just localized to changes in the intensities of the peaks.

In all X-ray diffraction patterns of porcelain specimens, the measured peak positions belonged to peaks of potassium aluminum catena-disilicate (leucite) crystal which has a body-centered tetragonal lattice structure. The leucite peaks of 10 watt CO_2 laser, 1.5 Joule/cm^2 and 6.2 Joule/cm^2 excimer laser glazed porcelain specimens demonstrated a remarkable decrease in their intensities with the exception of 2 watt CO_2 laser glazed specimens which showed no change in their intensities. This could be explained by the thermal effect of laser in providing energy sufficient to make slight changes in the atomic positions or causing slight overlapping of some atomic planes over each others. In case of lower power setting of 2 watt CO_2 laser glazed specimens, the energy might be not sufficient enough to cause this effect.

The charts of In-ceram alumina specimens dictated the appearance of aluminum oxide, corundum and calcium aluminum silicate bands having rhombohedral, hexagonal and triclinic structures respectively. The peaks of both corundum and aluminum oxide in all In-Ceram Alumina specimens exhibited a remarkable decrease in their intensities. This could be explained as mentioned before in case of porcelain specimens by the thermal effect of laser in providing energy sufficient to make slight changes in the atomic positions or causing slight overlapping of some atomic planes over each others. However, calcium aluminum silicate bands exhibited a remarkable increase in their intensities in all In-Ceram Alumina specimens except 2 watt CO_2 laser glazed specimens which exhibited a slight increase in the intensities. This could be explained by the effect of thermal energy of laser in rearranging the atomic positions which increased the degree of ordering in the structures and consequently the intensities increased.

References

[1] Leinfelder K F. Porcelain esthetics for the 21st century. JADA; **131**, 47S (2000)

[2] Hondrum S O. A review of the strength properties of dental ceramics. J Prosthet Dent; **67,** 859 (1999).

[3] Kantorski KZ, Valandro LF, Scotti R, Della Bona A, Bottino MA. Surface roughness of glazed feldspar,alumina and zirconia-based ceramics Cienc Odontol Bras **9,** 12 (2006).

[4] Delong R, Sasik C, Pintado MR, Douglas WH. The wear of enamel when opposed by ceramic systems. Dent Mater; **5,** 266 (1989).

[5] Albakry M, Guazzato M, Swain MV. Fracture toughness and hardness evaluation of three pressable all-ceramic dental materials. J Dent; **31,** 181 (2003).

[6] Rimondini L, Cerroni L, Carrassi A, Torricelli P. Bacterial colonization of zirconia ceramic surfaces: an in vitro and in vivo study. Int J Oral Maxillofac Imp; **17,** 793 (2002).

[7] Fairhurst C W, Lockwood P E, Ringle R D, Thompson W O. The effect of glaze on porcelain strength. Dent Mater; **8,** 203 (1992).

[8] Toenshoff H K, Butje R, Koenig W, Trasser F J. Excimer laser in material processing. CRIP Annals; **37,** 681 (1988).
[9] Akova T, Yoldas O, Toroglu M S, Uysal H. Porcelain surface treatment by laser for bracket-porcelain bonding. Am J Orthod Dentofacial Orthop. **128,** 630 (2005)
[10] Jervis T R, Nastasi M, Hubbard K M, Hirvonen J. Excimer laser surface processing of ceramics: process and properties. J Am Ceram Soc; **76**, 350 (1993).
[11] Al-Shehri S. Relative fracture toughness and hardness of dental ceramics. Saudi Dental Journal **14**, 67 (2002).
[12] Lee YK, Park HY, Shim JS, Kim KN, Lee KW. Effect of water content on the mechanical strength of dental porcelain. Journal of Non-Crystalline Solids **349,** 200 (2004).
[13] Aksoy G, Polat H, Polat M, Coskun G. Effect of various treatment and glazing (coating) techniques on the roughness and wettability of ceramic dental restorative surfaces. Colloids and surfaces B: Biointerfaces; **53,** 254 (2006)
[14] Uludag B, Usumez A, Sahin V, Eser K, Ercoban E. The effect of ceramic thickness and number of firings on the color of ceramic systems: An in vitro study. J Prosthet. Dent **97**, 25 (2007).
[15] Guazzato M, Albakry M, Quach L, Swain MV. Influence of grinding, sandblasting, polishing and heat treatment on the flexural strength of a glass-infiltrated alumina-reinforced dental ceramic. Biomaterials; **25,** 2153 (2004)
[16] Schuh C, Kinast EJ, Mezzomo E, Kapczinski MP. Effect of glazed and polished surface finishes on the friction coefficient of two low-fusing ceramics. J Prosthet Dent **93,** 245 (2005).
[17] Turker SB, Biskin T. Effect of three bleaching agents on the surface properties of three different esthetic restorative materials. J Prosthet Dent **89**, 466 (2003).
[18] Kazuyuki H, Tomozawa M. Dynamic fatigue of treated high-silica glass: explanation by crack tip blunting. J Am Ceram Soc **70,** 377 (1987).
[19] Binns DB. The chemical and physical properties of dental porcelain. In: Dental ceramics, proceedings of the first international symposium on ceramics. McLean JW, editor. Chicago: Quintessence Publishing Co., Inc. 41-82, 1983
[20] Mackert JR Jr, Rueggeberg FA, Lockwood PE, Evans AL, Thompson WO. Isothermal anneal effect on microcrack density around leucite particles in dental porcelain. J Dent Res **73,** 1221 (1994).
[21] Lee SZ, Zum Gahr KH. Surface treatments of Al_2O_3-ceramics by CO_2-lasers. Materials science and engineering **23,** 117 (2004).
[22] Grobmann J, Emmel A, Schubert E, Bergmann HW. Generation of new surface conditions on SiC materials by excimer laser irradiation: mechanisms–properties–applications. Laser and Optoelectronic **26,** 34 (1994).
[23] Folwaczny M, Mehl A, Haffner C, Hickel R. Polishing and coating of dental ceramic materials with 308 nm XeCl excimer laser radiation. Dent Mater; **14,** 186 (1998).
[24] Lu J, Prabhu M, Song J, Li C, Xu J, Ueda K, et al. Optical properties and highly efficient laser oscillation of Nd:YAG ceramics. Applied Physics B Lasers and Optics **71,** 469 (2000).
[25] Schmage P, Nergiz I, Herrmann W, Ozcan M: Influence of various surface-conditioning methods on the bond strength of metal brackets to ceramic surfaces. Am J Orthod Dentofacial Orthop; **123,** 540 (2003).