Study of Mechanical Properties of Porcelain Restorative Material By Using CO₂ Laser Beam

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Abstract
The aim of this research is to study the mechanical properties of porcelain restorative material by using CO2 laser beam. (10) specimens of porcelain material have been prepared. They divided into two groups with dimensions (4*10mm) & (6*10mm) respectively.

Eight of these specimens are irradiated by CO₂ laser device at different laser powers (2,3,4,& 5) Watt at a fixed time (20 sec). The mechanical properties which was tested, such as micro-hardness, diametrical strength, density, and porosity. The value of micro-hardness, diametrical strength, density are increased at different laser power except (3W), because internal deformation occurred in this laser power density up to (3W). Glazed layer may be occur because the effect of (4,5) Watt laser, consequently the value of porosity decreased.

دراسة الخصائص الميكانيكية لمواد حشوات البورسلين باستخدام ليزر ثنائي اوكسيد الكربون

الخلاصه

يهدف البحث إلى دراسة الخصائص الميكانيكية لحشوات البورسلين باستخدام ليزر ثنائي اوكسيد الكربون.

تم تحضير 10 عينات من مادة البورسلين قسمت إلى مجموعتين بقياس (6*10 ملم) و (4*10 ملم) على التوالي. ثمانية من هذه العينات شععت بواسطة ليزر ثنائي اوكسيد الكربون بقدرات (2,3,4,5 واط) وزمن تشعيع ثابت مقداره (20 ثا). تم اختبار الخصائص الميكانيكية مثل اختبار الصلادة الدقيقة والكسر المحوري للقوة والكثافة والمسامية. وجد إن قيمة الصلادة الدقيقة والكسر المحوري للقوة والكثافة ازدادت عند قدرات الليزر المختلفة ماعدا (3 واط) بسبب حدوث تشوه داخلي عند استخدام هذه القدرة. ولكن عند استخدام قدرات أكثر من (3 واط) وجد حدوث طبقة منصهرة ناتجة عن تأثير القدرات (4 و 5 واط). ولهذا السبب فان قيمة المسامية سوف تقل.

1-Introduction

Since its invention in 1960, the laser has found diverse application in engineering and industry because of its ability to produce high power beams. In the field of metal processing, laser applications include welding, drilling, cutting, scribing, machining, heat treatment, cladding and alloying. In other fields, such as medical surgery, laser are also used extensively [1].

Lasers are used in a wide range of applications such as, laser surgery, heat treatment, welding, drilling. The number and type of applications increase daily [2].

The porcelain has been playing an important role in restorative dentistry because it allows efficient

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Eng.& Tech. Journal ,Vol.28, No.7,2010

Study of Mechanical Properties of Porcelain Restorative Material By Using CO_2 Laser Beam

restorations with great color stability and resistance [3].

mains frequency can be increased [2-4].

2- Theoretical background

Laser can deliver very low power (millwatt) to extremely high power (kilowatt), focused power with a precise spot size/dimension and interaction/pulse time on to any kind of substrate through any medium. Laser is distinguished from other electromagnetic radiation mainly in terms of its coherence, spectral purity and ability to propagate in a straight line[4].

The first experiment with laser in dentistry was reported in study about the effect of a pulse Ruby laser on human caries by (Goldman et al, 1964) [5] .The results of that study showed that the effects varied from small (2-mm) deep holes to complete disappearance of the caries tissue, with some whitening of surrounding rim of enamel, indicating extensive destruction of caries areas along with create formation and melting of dentine. Further work in the 1970 focused on the effects of (Nd: YAG) and (CO_2) lasers on dental hard tissues [5].

Lasers have also been used for processing dental materials especially for fusing the materials on or onto tooth surfaces. In orthodontic, various types of lasers Nd: YAG, CO_2 and, Er: YAG have been suggested for preparing enamel surfaces for bracket adhesion. Although, some researches found laser irradiation effective for bracket adhesion on enamel surfaces, others have not found this action due to the bond strength, more often; lasers are recommended for debonding orthodontic brackets. Only a few studies have been performed on the laser treatment of dental porcelain

masses. The CO_2 laser is well suited for the treatment of porcelain materials because its emission wavelength is almost totally absorbed by porcelain [6].

3- Experimental

Experimental part includes:

1. Specimens preparation methods.
2. Specimens irradiation by CO_2 laser.
3. Mechanical properties measurements.
   Ø Micro-hardness.
   Ø Diametrical strength.
   Ø Density and porosity.

1. Specimens preparation method

In this research 10 specimens of porcelain were prepared, which consist from the following components as shown in table (1).

The porcelain powder was mixed with water to form a paste, this paste divided into 10 specimens, each specimen put by using a syringe 5cc to form the final shape which is require**.**

These 10 specimens have a cylindrical shape. These specimens are moist and have a different dimensions, so the dimension of these specimens must be standardized by using another process to get the required. This achieved by heating the specimens in a special programmable furnace type IVOCLAR program X_1.

Putting all the specimens carefully in the furnace and turn ON adjusting the temperature of the furnace on (600 ^{o}C) for a period time (15 min). Turned OFF the furnace and let the specimens in the furnace to reach the room temperature gradually.

This process was done to avoid instantiation any crack in the porcelain specimens and to get a

clear and clean surface and standard of all prepared specimens.

To get a smooth and unique shape a polishing process would done by using electrical diamond saw. The final shapes of the prepared specimens which are used in the present work (4x10 & 6x10 mm).

2. Specimens Irradiation by CO_2 Laser

The prepared specimens irradiated by transverse sealed CO_2 laser with output (16W), the laser device which is used in this work type DJG107-1518.Two groups of the specimens irradiated by laser. Four specimens having a dimension of (4x10mm). And four specimens having a dimension (6x10mm). The laser system produces maximum output 16W, in the present work 2-5W output power would be needed, so the laser system was calibrated between input current to the laser tube and output power by using (CO_2) power meter device type SJG-100W.Table (2) show this calibration

To get a perfect irradiation the specimens are put at the distance (5cm) from the laser tube aperture. The laser tube aperture has (10mm) spot size diameter. This spot cover the entire specimens surface. Also to achieve a precise alignment between the porcelain specimens and laser tube aperture. After the specimens aligned and the CO_2 laser device was turned ON the specimens strikes in different laser power which are (2, 3, 4,& 5) W respectively, at a fixed irradiation time which is 20sec.

3.   Mechanical Properties Measurements

Ø Micro-Hardness

Hardness not only considered as a physical property but as a complex function of a group of a physical properties shared in different degrees depends on the testing way and the environment in which the test done. The terms hardness according to Vickers method as the exposed load by (Kg) on the area of contact between diamond pyramid and the surface of the specimens in (mm^2).

Hardness is a key parameter in the choice of ceramic for abrasives, tool bits, bearings, wear resistant applications, and resistance to particulate erosion and ballistic impact. The hardness of a material is related to the material characteristics which give stiffness and strength. Hardness is an important characteristic of a material, as it contributes to resistance to erosion/wear processes. At high temperature, however, engineering alloys become "Softer" and so ceramics are often used to give wear resistance. The hardness of a material may be specified in terms of some standard test involving indenting or scratching of the surface of the material, the harder a material the more difficult it is to make an indentation or scratch.

Five specimens of dimension (4*10mm) were tested for micro-hardness procedure. The specimens were tested in digital micro hardness tester HVS-1000 by harden fixed time at 10 sec. Using Vickers method to calculate micro-hardness, considering one specimen which not irradiated by CO_2 laser beam and four specimens irradiated by CO_2 laser beam. These specimens were put in the micro-hardness device to know the hardness value of each specimen.

The results from micro-hardness test are in table 3.

Figure (1) shows the relation between power and micro-hardness value.

but if increase the power over 5 watt this do not lead to increase the micro-hardness because occurred deformation in specimens 3 as shown in the figure above due to the increase in the laser power.

Ø Diametrical Strength

The Five specimens from the previous process were tested for the diametrical strength. And this measurement will help to compare between the micro-hardness and diametrical strength test. This test was done by using Brazilian test device.

Diametrical strength method is plagued by common problem of precise machining of difficult to machine materials. Loading configuration is an important fact in the diametrical compression disk; Figure (2).

The stress distribution should be independent of length, provided a uniform compression stress applied. However, friction stress, as well as non uniform stresses, ordinarily results at contact points.

The simple theory describing the stress distribution under a uniform diametric a uniform tension field at the center of the disk.

The results from strength and diametrical strength are shown in table (4). Diametrical strength)

$$(s_D = \frac{2F}{pDt} \qquad ....(1)$$

where F is the applied load (N), D is the disk diameter and t is the thickness of disk.

The stress field in the transverse direction is highly dependent on the width of load application and becomes highly compressive the disk test has therefore been used to attempt to study biaxial stress failure response. Figure (3) shows the relation between power and strength value.

By using equation (1) to calculate the diametrical strength from the strength values as shown in figure (4).

Ø Density and Porosity

Five specimens of dimension (6*10) mm (four of them irradiated by CO$_2$ laser and the fifth one is not irradiated by CO$_2$ laser) were performed density and porosity test.

Bulk density and open porosity are determined by using Archimedes Method using distilled H$_2$O. The mass of material in air is divided by its buoyancy (reduction in weight) when suspended in a liquid medium to give a measurement of density.

The density of a material is:

Density = Mass/ Volume ...... (2)

There are three volume expressions in common use:

1. Apparent volume or bulk volume: includes the volume of the solid component, open pores and sealed pores, determined by the difference between the soaked weight (S) and the immerse weight (I) of the soaked piece.

2. True volume: The volume of the solid component only, is determined by crushing the piece into powder form so that all the pores are destroyed and using "Density Bottle" method.

3. Apparent solid-volume: The volume of the solid component and sealed pores only, is obtained from the difference between the dry weight (D) and the immersed weight (I) of the piece.

The densities and porosity expression are:

Apparent or bulk density (ρ_b) = mass/apparent volume = D/S-I

.... (3)

True density (ρ_t)= mass/true volume

Eng.& Tech. Journal ,Vol.28, No.7,2010

Study of Mechanical Properties of Porcelain Restorative Material By Using CO_2 Laser Beam

Apparent-solid (sintered) density= mass/apparent-solid volume

=D/D I ……. (4)

Percentage apparent porosity= open pore volume/total volume *100%

A.P% = S-D/S-I *100 ………(5)

Total (true) porosity % = 1- ρ_b/ρ_t *100 .... (6)

In this section firstly, calculate the porosity of the specimens which is irradiated by (2, 3, 4, and 5) Watt laser power.

In porosity measurement, calculate the weight of the specimens when they are dry, soaked and immersed, the results are shown in table (5).

Equation (6) was used to calculate the ratio of porosity as shown in Figure (5).

Porosity is almost present in ceramics prepared by powder compaction and heat treatment. Porosity is an important parameter to characterize ceramic microstructures, as are grain size, grain shape and phase arrangement.

Since properties of materials depend on their microstructure, this article will recall the main features of the porosity effects on the mechanical properties of ceramics. Specific attention will be paid to technical ceramics and the main interest will be devoted to thermal shock resistance, which largely determines the in-service life time of these materials.

After calculate the porosity, apparent or bulk density was calculated by using equation (4), the results were shown in Figure (6).

Calculate the apparent-solid (sintered) density by using equation (5), the results were shown in the Figure (7).

Conclusions

The important factors derived from study results at this work can be summarized as following:

1. The laser surfaces Harding for porcelain material change the physical and mechanical properties, the value of porosity decreased after irradiation by (2W) laser because of the glazed layer.

2. The CO_2 laser is well suited for the treatment of porcelain materials because its emission wavelength is almost totally absorbed by porcelain, by compare powers (2, 3, 4, 5) watt it is noted that the 2W is the best laser power for carrying out the present work.

3. For laser Harding on other hand, the surface temperature should be as high as possible with shortens time to complete the transformation and to heat a sufficient thick surface layer in a short time. A short time and high temperature gradients are also required to prevent heating of the bulk material and avoid break in the porcelain specimens.

4. The specimens irradiated by 3W laser internal deformation occur inside the specimen and this will reduce the mechanical properties of the material.

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Eng.& Tech. Journal ,Vol.28, No.7,2010

Study of Mechanical Properties of Porcelain
Restorative Material By Using CO_2 Laser
Beam

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Table (1) Composition of dental porcelain.

Material	Weight percent %
Silica	63
Alumina	17
Boroc oxide	7
Potash (K_2O)	7
Soda (Na_2O)	4
Other oxide	2

Table (2) Current/power calibration.

Current (mA)	Power (W)
1.8	1
2	1.5
2.4	2
2.8	2.5
3	3
3.2	3.5
3.4	4
3.8	4.5
4	5

Table (3) power and micro-hardness

Power (W)	Hardness (HV)
0	580
2	660
3	630
4	663
5	670

Table (4) power, strength, and diametrical strength.

Power (W)	Strength (kN)	Diametrical strength (MPa)
0	1.1	17.5
2	1.6	25.5
3	1.3	20.7
4	1.8	28.7
5	2	31.8

Table (5)Power and dry, soaked, immersed specimens weight.

Power (W)	Dry specimens weight (g)	Soaked specimens weight (g)	Immersed specimens weight (g)
0	1.22	1.25	0.72
2	1.48	1.53	0.88
3	1.34	1.37	0.81
4	1.40	1.43	0.83
5	1.43	1.45	0.87

1311

Eng.& Tech. Journal ,Vol.28, No.7,2010

Study of Mechanical Properties of Porcelain Restorative Material By Using CO₂ Laser Beam
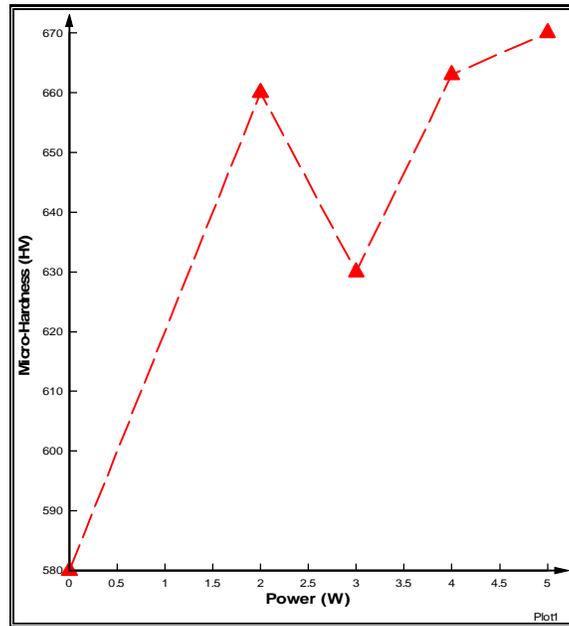
Figure (1) Shows the relation between power and micro-hardness
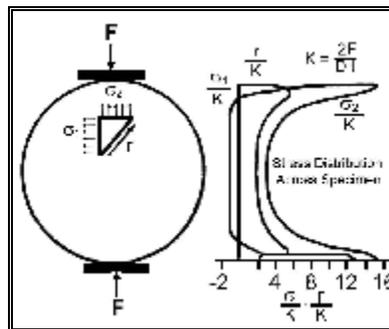
Figure (2) Diametrical strength specimen [7]

1312

Eng.& Tech. Journal ,Vol.27, No.7,2010

Study of Mechanical Properties of Porcelain

Restorative Material By Using CO₂ Laser Beam
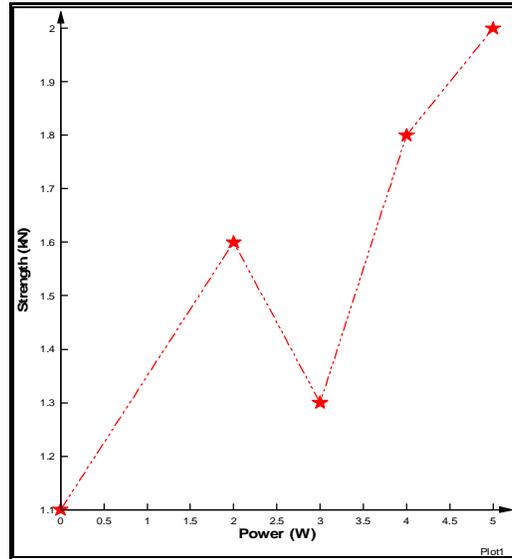
Figure (3) Shows the relation between power and strength
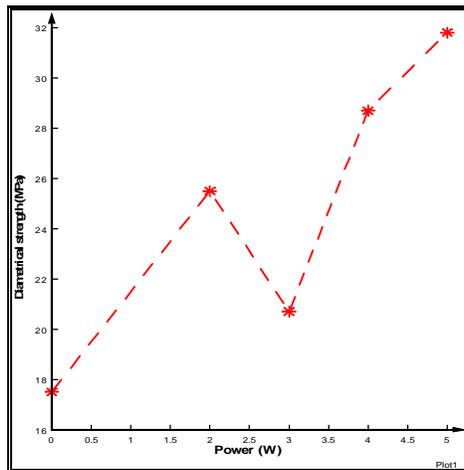
Figure (4) Shows the relation between Power and Diametrical strength
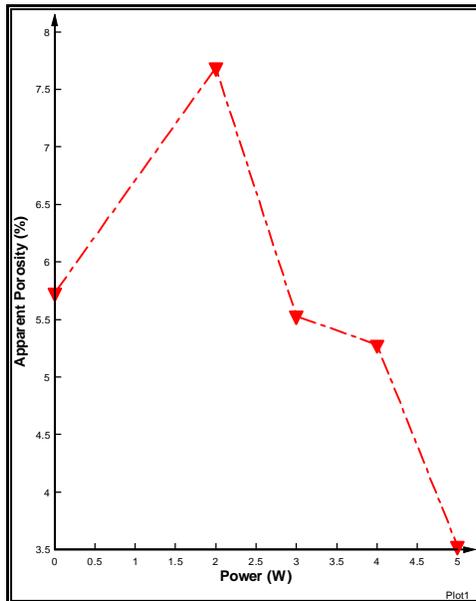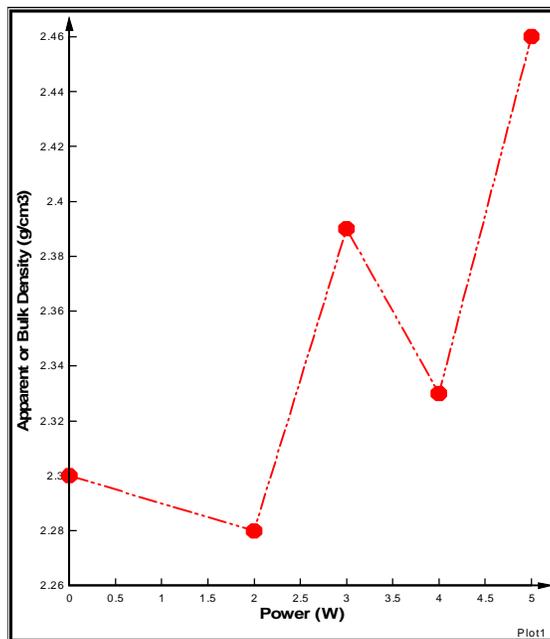
1313

Eng.& Tech. Journal ,Vol.27, No.7,2010　　　**Study of Mechanical Properties of Porcelain**

Restorative Material By Using CO₂ Laser Beam

Figure (5) Power and porosity

Figure (6) Power and apparent or bulk density

1314

Eng.& Tech. Journal ,Vol.27, No.7,2010

Study of Mechanical Properties of Porcelain
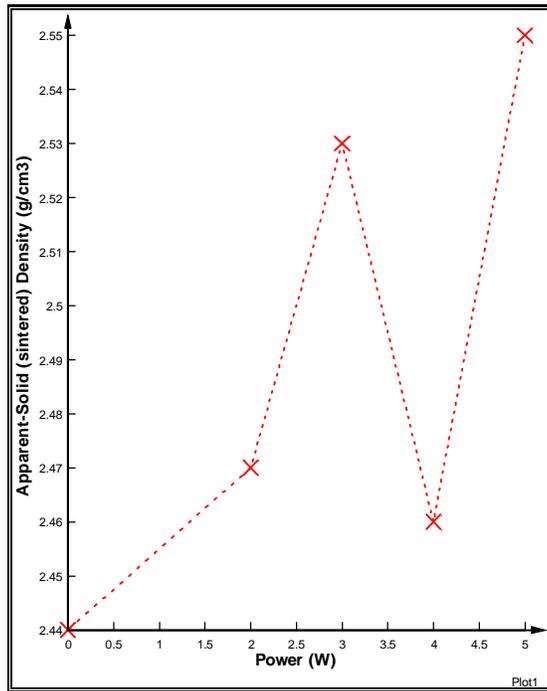
Restorative Material By Using CO₂ Laser Beam

Figure (7) Power and apparent- solid (sintered) density