Chapter One

Introduction and Basic Concepts

1.1 Introduction

Nowday's diode lasers are used in many applications including spectroscopy, communication, industry, holography and also in medical fields, one of these fields is dentistry. Different types of lasers are used for hard and soft tissues treatment beside usage of lasers in dental materials preparation. One of the promising application is the filling hardening (Ahmed, M. M. *et al*., 2014).

Most lasers are heat-producing devices converting electromagnetic energy into thermal energy. These lasers find uses in oral surgery for cutting or coagulating soft tissues or in the welding of dental prostheses. More recently, new types of lasers have offered non-thermal modes of tissue interaction, called photo-ablation, photo-disruption and photo-chemical effects. Basic and clinical research is being carried out into the applications of these devices in dentistry. However, much development will be required before lasers can replace conventional surgical methods for treating oral cancer or indeed replace the conventional bur for excavating carious lesions (Niemz, M. H., 2013).

Hardness is indicative of the ease of finishing of a structure and its resistance to in service scratching, finishing or polishing a structure is important for esthetic purposes and scratches can compromise fatigue strength and lead to primitive failure. Hardness of dental fillings is very important because it determines the life time of the filling material and its ability to do the required function. The most common methods of testing the hardness of restorative materials are Brinell, Knoop, Vickers and rockweel tests where, each of these tests differs slightly from the other (Almuslet, N. *et al*., 2011).

1.2 Aim of this work

This work aimed to enhance the hardness of human teeth filler material (Amalgam), in a short possible time via irradiation by low level laser. The materials were subjected to diode laser with wavelength 671 nm and power 100 mW for 30 second.

1.3 Thesis structure

Chapter one presents the definition, basic concepts of laser and its characteristics, laser matter interaction, diode lasers, filling teeth and its types and the hardness testing.

Chapter two covers the experimental part of this work, the material used and the laser device, rockweel hardness device and the setup that were used to enhance the hardness of amalgam.

Results, discussion, conclusions and recommendations are presented in chapter three.

1.4 Principle and construction of lasers

The word laser is an acronym for Light Amplification by Stimulated Emission of Radiation. The laser makes use of processes that increase or amplify light signals after those signals have been generated by other means. These processes include stimulated emission (a natural effect that was deduced by considerations relating to thermodynamic equilibrium) and optical feedback present in most lasers (usually provided by mirrors). Thus, in its simplest form, a laser consists of a gain or amplifying medium (where stimulated emission occurs), and a set of mirrors to feed the light back into the amplifier for continued growth of the developing beam (Silfvast, W. T., 2004).

Basically, every laser system essentially has an active (gain) medium, placed between a pair of optically parallel and highly reflecting mirrors with one of them partially transmitting, and an energy source to pump the active medium.

The gain media may be solid, liquid or gas and have the property to amplify the amplitude of the light wave passing through it by stimulated emission, while pumping may be electrical or optical. The gain medium used to place between pair of mirrors in such a way that light oscillating between mirrors passes every time through the gain medium and after attaining considerable amplification emits through the transmitting mirror. Consider an active medium of atoms having only two energy levels excited level E_2 and ground level E_1.

If atoms in the ground state, E_1, are excited to the upper state, E_2, by means of any pumping mechanism (optical, electrical discharge, passing current, or electron bombardment), then just after few nanoseconds of their excitation, atoms return to the ground state emitting photons of energy $h\nu = E_2 - E_1$.

According to Einstein's 1917 theory, emission process may occur in two different ways, induced by a photon or it may occur spontaneously.

The former case is termed as stimulated emission, while the latter is known as spontaneous emission. Photons emitted by stimulated emission have the same frequency, phase and state of polarization as the stimulating photon; therefore they add to the wave of stimulating photon on a constructive basis, thereby increasing its amplitude to make lasing. At thermal equilibrium, the probability of stimulated emission is much lower than that of spontaneous emission. Most of the conventional light sources are incoherent (Singh, S. C., *et al.*, 2012).

1.5 Characteristics of laser light

The lasers light have several valuable characteristics not shown by light obtained from other conventional light sources, which make them suitable for a variety of scientific and technological applications. Their monochromaticity, directionality, laser line width, brightness and coherence of laser light make them highly important for various materials processing and applications.

1.5.1 Monochromaticity

Theoretically, waves of light with single frequency v of vibration or single wavelength λ is termed as single color or monochromatic light source. Practically, no source of light including laser is ideally monochromatic. Monochromaticity is a relative term. One source of light may be more monochromatic than others. Quantitatively, degree of monochromaticity is characterized by the spread in frequency of a line by Δv, linewidth of the light source or corresponding spread in wavelength $\Delta\lambda$. For small value of $\Delta\lambda$ frequency spreading Δv, is given as

$$\Delta v = -(c/\lambda^2)\ \lambda \qquad 1\text{-}1$$

and

$$\Delta\lambda = (c/_{v}{}^{2}) \qquad 1\text{-}2$$

The most important property of laser is monochromaticity. This based on the type of laser media which may be (solid, liquid, or gas) or molecular, atomic, or ions. The type of excitation, produced laser line consists of color bands that range from broad (as dye laser $\lambda \sim 200$) to narrow monochromaticity as good as a single line of lasing transition (Singh, S. C., *et al.*, 2012).

But such a single line also contains a set of closely spaced lines of discrete frequencies, known as laser.

1.5.2 Directionality

One of the most striking properties of laser is directionality, the energy was traveled to very long distances for remote diagnosis and communication purposes. In contrast, conventional light sources emit radiation isotropically therefore, very small amount of energy can be collected using lens. Beam of an ideal laser is perfectly parallel, and its diameter at the exit window should be same to that after traveling very long distances, although in reality, it is impossible to achieve. From the theory of diffraction, the circular aperture has angle of diffraction θ given by (Singh, S. C., *et al.*, 2012).

$$\theta = sin^{-1}(1.22\lambda/D) \qquad 1\text{-}3$$

Where

$\lambda \equiv$ wavelength and $D \equiv$ Diameter.

1.5.3 Coherence

Coherence is one of the striking properties of the lasers, over other conventional sources, which makes them useful for several scientific and technological applications. The basic meaning of coherence is that all the waves in the laser beam remain spatially and temporarily in phase. Photons generated through stimulated emission are in phase with the stimulating photons. For an ideal laser system, electric field of light waves at every point in the cross section of beam follows the same trend with time. Such a beam is called spatially coherent. The length of the beam up to which this statement is true is called coherence length (L_C) of the beam. Another type of coherence laser beam is temporal coherence, which defines uniformity in the rate of change in the phase of laser light wave at any point on the beam.

The time frame up to which rate of phase change at any point on the laser beam remains constant is known as coherence time (t_C). Coherence time (t_C) is also defined as the time taken by the atoms or molecules in active medium to emit a light wave train of length L_C. These two coherences are thus related by

$$t_C = L_C/c \qquad 1\text{-}4$$

The coherence time of the laser beam is almost inverse ($t_C \approx 1/\Delta v$) of the width. The lasers operating in the single mode (well-stabilized lasers) have narrow linewidth, therefore they exhibit higher coherence time and coherence length compared to those operating in multi mode.

Spatial and temporal coherences of continuous laser beams are much higher compared to those of pulsed laser systems because temporal coherence in the pulse lasers are limited by the presence of spikes within the pulse or fluctuation in the frequency of emission (Singh, S. C., *et al.*, 2012).

1.5.4 Brightness

Lasers are more intense and brighter sources compared to other conventional sources such as the sun. A 1mW He–Ne laser, which is a highly direction allow divergence laser source, is brighter than the sun, which is emitting radiation isotropically.

Brightness is defined as power emitted per unit area per unit solid angle (Singh, S. C., *et al.*, 2012).

1.5.5 Focusing of laser beam

In practice, every laser system has some angle of divergence, which increases the spot size of laser beam and reduces its brightness. If a convergent lens with suitable focal length is inserted in the path of a laser beam, it focuses laser energy into small spot area at focal point. If w_L is the radius of the beam and f is the focal length of convergent lens, then radius of the spot at focal point r_s is given as (Singh, S. C., *et al.*, 2012).

$$r_s = \lambda f / \pi w_L \qquad 1\text{-}5$$

Where

$\lambda \equiv$ Wavelength of laser beam and $D \equiv$ Lens diameter.

The whole aperture is illuminated by laser beam ($w_L = D/2$) then

$$r_s = 2\lambda f / \pi D \qquad 1\text{-}6$$

or

$$r_s = 2\lambda F/\pi \qquad 1\text{-}7$$

Where, F is the number of lenses, given by

$$F = f / D \qquad 1\text{-}8$$

1.6 Types of lasers

Depending on nature of the active media, lasers are classified into four main categories, namely, solid, liquid, diode and gas. Scientists and researchers have investigated a wide variety of active media of laser in each category since 1958, when lasing action was observed in ruby crystal.

1.6.1 Gas lasers

Gas lasers are widely available with almost all power (milliwatts to megawatts) and wavelengths (UV-IR), it can be operated in pulsed and continuous modes. Based on nature of active media, there are three types of gas lasers viz atomic, ionic and molecular. Most of the gas lasers are pumped by electrical discharge. Electrons in the discharge tube are accelerated by electric field between the electrodes. These accelerated electrons collide with atoms, ions or molecules in the active media and induce transition to higher energy levels to achieve the condition of population inversion and stimulated emission. An example of gas laser system is shown in Figure 1.1 (Singh, S. C., *et al*., 2012).

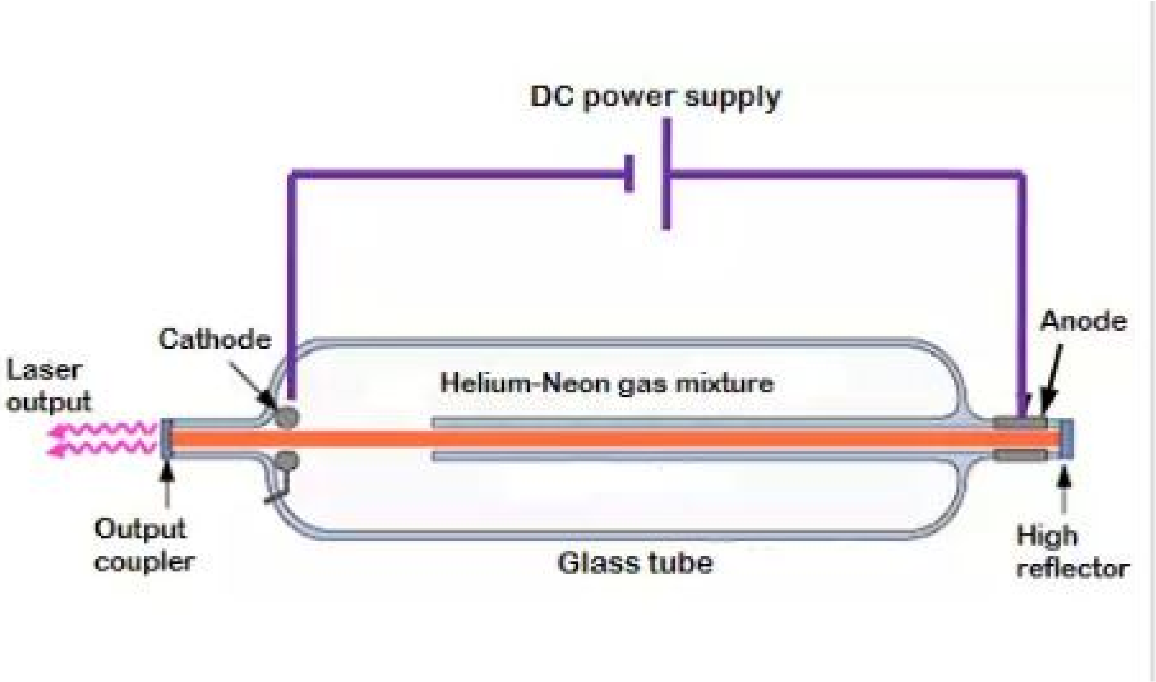

Figure 1.1. Basic geometry of a helium-neon laser system.

1.6.2 Liquid lasers

Liquids are more homogeneous as compared to solids and have larger density of active atoms as compared to the gasses. In addition to these properties liquid lasers do not offer any fabrication difficulties. Offer simple circulation ways for transportation of heat from cavity, and can be easily replaced.

When the solution of dye molecules is optically excited by a wavelength of radiation with good absorption coefficient, it emits radiation of longer wavelength, known as fluorescence. The energy difference between absorbed and emitted photons is mostly used by nonradiative transitions and creates heat in the system. Organic dye lasers, as tunable and coherent light sources, are becoming increasingly important in spectroscopy, holography, and in biomedical applications. A recent important application of dye lasers involve isotopes separation. Here, the laser is used to selectively excite one of several isotopes, thereby inducing the desired isotope to undergo a chemical reaction more readily. The dye molecules have singlet (S_0, S_1, and S_2) and triplet (T_1 and T_2) group of states with fine energy levels in each of them. Singlet and triplet states correspond to the zero and unit values of total spin momentum of electrons, respectively. According to selection rules for transitions in quantum mechanics, singlet–triplet and triplet–singlet transitions are quite less probable as compared to the transitions between two singlet or two triplet states. Optical pumping of dye molecules initially at the bottom of S_0 state transfers them to the top of S_1 state. Collisional relaxation of these molecules takes them to the bottom of S_1 state, from where they transit to the top of S0 state with stimulated emission of radiation. Most of the states in the complex systems are usually neither pure singlet nor pure triplet. Singlet states have small contribution of triplet and vice versa. In the case of most of the dye molecules, unfortunately, T_1 state lies just through nonradiative transitions (Singh, S. C., *et al.*, 2012).

Difference between T_1 and T_2 states is almost same as the wavelength of lasing transition, therefore emitted lasing radiation gets absorbed, which reduces laser gain and may cease the laser action. Therefore, some of the dye lasers operate in the pulsed mode with the pulse duration shorter than the time required to attain a significant population in the state T_1. Some of the dyes also absorb laser radiation corresponding to the transition from S_1 to upper singlet transitions. Therefore, one should select the dye molecule so that energy differences between these states do not lie between the ranges of laser radiation (Singh, S. C., *et al.*, 2012).

1.6.3 Solid lasers

A solid-state laser is a laser that uses solid as a laser medium. In these lasers, glass or crystalline materials are used. Ions are introduced as impurities into host material which can be a glass or crystalline. The process of adding impurities to the substance is called doping (Singh, S. C., *et al.*, 2012). The first solid-state laser was a ruby laser. It is still used in some applications. In this laser, a ruby crystal is used as a laser medium. Figure 1.2 shows a photo of Ruby laser system.

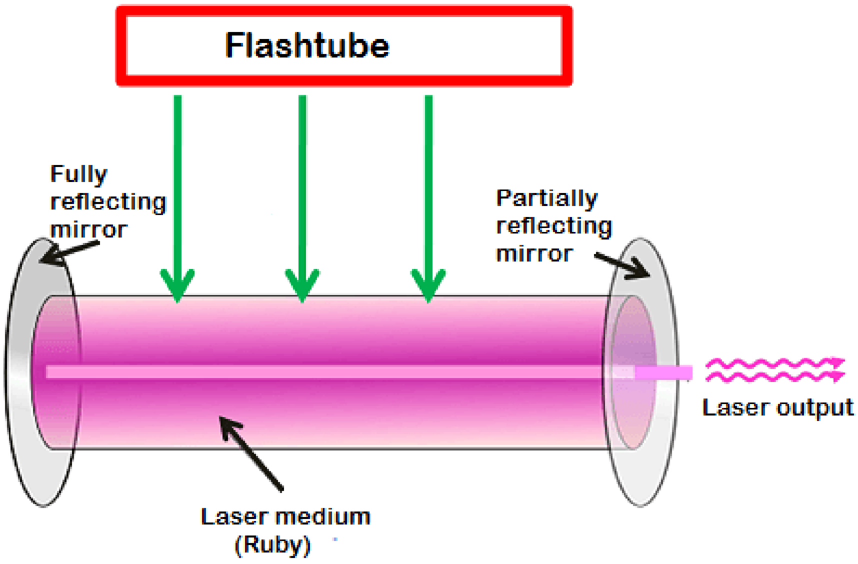

Figure 1.2. Basic geometry of Ruby laser system.

Pumping of electrons from the ground state to the excited state to achieve population inversion condition is an essential requirement for lasing. Optical pumping is the best and most efficient pumping method for solid state active media due to their broad optical absorption bands. A significant fraction of incident optical energy can be easily used for the pumping of ground state electrons using pulsed as well as continuous light sources (Koechner, W. and Bass, M., 2003).

Arrangement of host atoms around the doped ion modifies energy levels. Different lasing wavelength in the active media is obtained by doping of different host materials with same active ion (Singh, S. C., *et al*., 2012).

1.6.4 Semiconductor (Diode) lasers

Semiconductor lasers also known as quantum well lasers are considred smallest and cheapest type of laser. They are basically p-n junction diode, which produces light of certain wavelength by recombination of charge carrier when forward biased, very similar to the light-emitting diodes (LEDs).

LEDs emit radiation by spontaneous emission, while diodes laser emit radiation by stimulated emission. Operational current should be higher than the threshold value in order to attain the condition of population inversion. The active medium in a semiconductor laser is in the form of junction region of two-dimensional layers. No external mirror is required for optical feedback in order to sustain laser oscillation.

The reflectivity due to the refractive index differences between two layers or total internal reflection to the active media is sufficient for this purpose (Singh, S. C., *et al*., 2012). Figure 1.3 shows the basic geometry of semiconductor laser system.

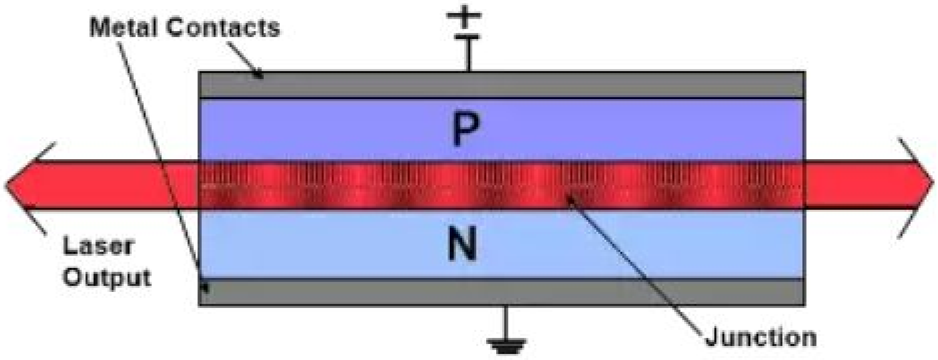

Figure 1.3. Basic geometry of semiconductor laser system.

1.7 Laser matter interaction

Matter can act on electromagnetic radiation in manifold ways. In Figure 1.4 a typical situation is shown, where a light beam is incident on a slice of matter. Which it may reflected and refracted, absorped and scattered.

In medical laser applications, however, refraction plays a significant role only at irradiating transparent media like corneal tissue. In opaque media, usually, the effect of refraction is difficult to measure due to absorption and scattering (Niemz, M. H., 2013).

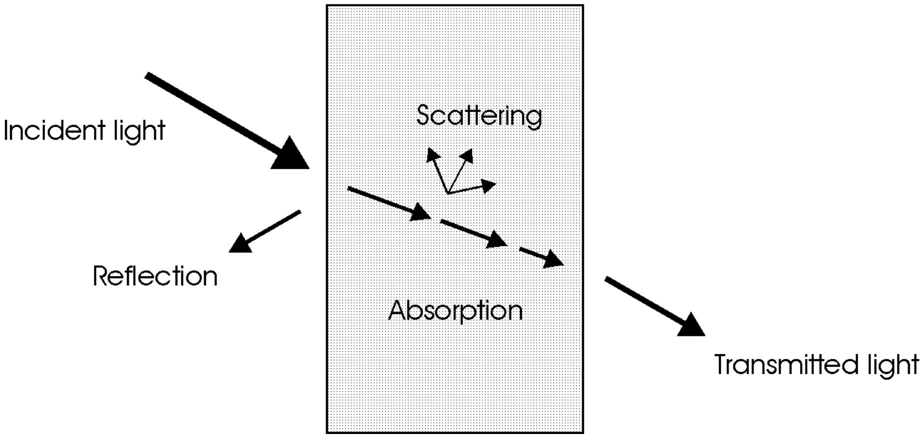

Figure 1.4. Geometry of reflection, refraction, absorption and scattering**.**

Only non-reflected and non-absorbed or forward scattered photons are transmitted by the slice and contribute to the intensity detected behind the slice. The ratio of transmitted and incident intensities is called transmittance. The losses reflection, absorption or scattering is dominant primarily depends on the type of material and the incident wavelength. The wavelength is a very important parameter indeed. It determines the index of refraction as well as the absorption and scattering coefficients. The index of refraction governs the overall reflectivity of the target. This index strongly depends on wavelength in regions of high absorption only (Niemz, M. H., 2013).

1.7.1 Reflection and refraction

Reflection is defined as the returning of electromagnetic radiation by surfaces upon which it is incident. In general. The simple law of reflection requires the incident wave and reflected beams and the reflecting surface to lie within one plane, called the plane of incidence. It also states that the reflection angle θ' equals the angle of incidence θ as shown in Figure 1.5 and expressed by

$$\theta = \theta' \quad 1\text{-}9$$

The angles θ and θ' are measured between the surface and the incident and reflected beams, respectively (Niemz, M. H., 2013).

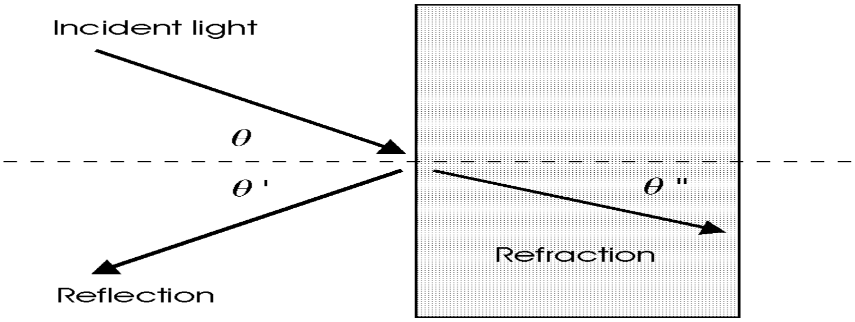

Figure 1.5. Geometry of specular reflection and refraction.

The surface it self is assumed to be smooth, with surface irregularities being small compared to the wavelength of radiation. This results called specular reflection. when the roughness of the reflecting surface is comparable or even larger than the wavelength of radiation, diffuse reflection occurs. Then, several beams are reflected which do not necessarily lie within the plane of incidence.

Diffuse reflection is a common phenomenon of all tissues, since none of them is provided with highly polished surfaces such as optical mirrors.

Only in special cases such as wet tissue surfaces might specular reflection surpass diffuse reflection. Refraction usually occurs when the reflecting surface separates two media of different indices of refraction. It originates from a change in speed of the light wave. The simple mathematical relation governing refraction is known as Snell’s law. It is given by

$$\sin \theta / \sin \theta'' = v/v' \qquad 1\text{-}10$$

where θ'' is the angle of refraction, v and v' are the speeds of light in the media before and after the reflecting surface, respectively (Niemz, M. H., 2013).

1.7.2 Absorption

During absorption, the intensity of an incident electromagnetic wave is attenuated in passing through a medium. The absorbance of a medium is defined as the ratio of absorbed and incident intensities. Absorption is due to a partial conversion of light energy into heat motion or certain vibrations of molecules of light without any absorption, i.e. the total radiant energy entering into and emerging from such a medium is the same. In contrast, media in which incident radiation is reduced practically to zero are called opaque. The terms “transparent” and “opaque” are relative, since they certainly are wavelength-dependent. Cornea and lens, for instance, mainly consist of water which shows a strong absorption at wavelengths in the infrared spectrum. Hence, these tissues appear opaque in this spectral region. Actually, no medium is known to be either transparent or opaque to all wavelengths of the electromagnetic spectrum. A substance is said to show general absorption if it reduces the intensity of all wavelengths in the considered spectrum by a similar fraction. Selective absorption, on the other hand, is the absorption of certain wavelengths in preference to others. The ability of a medium to absorbed electromagnetic radiation depends on a number of factors, mainly the electronic constitution of its atoms and molecules, the wavelength of radiation, the thickness of the absorbing layer, and internal parameters such as the temperature or concentration of absorbing agents. Two laws are frequently applied which describe the effect of either thickness or concentration and absorption, respectively (Niemz, M. H., 2013).

They are commonly called Lambert's law and Beer's law, and are expressed by

$$I(z) = I_0 \, exp(-\alpha z) \qquad 1\text{-}11$$

Where

z *is* denotes to the optical axis.

$I(z)$ ≡ the light intensity at a distance z.

I_0 ≡ the incident intensity.

α ≡ the absorption coefficient of the medium.

This law describe the same behavior of absorption, they are also known as the Lambert–Beer law.

$$z = 1/\alpha \ln I_0/I(z) \qquad 1\text{-}12$$

The inverse of the absorption coefficient α is also referred to as the absorption length L

$$L = 1/\alpha. \qquad 1\text{-}13$$

The absorption length measures the distance z in which the intensity $I(z)$ has dropped to 1/e of its incident value I_0.

1.7.3 Scattering

When elastically bound charged particles are exposed to electromagnetic waves, the particles are set into motion by the electric field. If the frequency of the wave equals the natural frequency of free vibrations of a particle, resonance occurs being accompanied by a considerable amount of absorption. Scattering, on the other hand, takes place at frequencies not corresponding to those natural frequencies of particles. The resulting oscillation is determined by forced vibration. In general, this vibration will have the same frequency and direction as that of the electric force in the incident wave. Its amplitude, however, is much smaller than in the case of resonance. Also, the phase of the forced vibration differs from the incident wave, causing photons to slow down when penetrating into a denser medium.

Hence, scattering can be regarded as the basic origin of dispersion. Elastic and inelastic scattering are distinguished, depending on whether part of the incident photon energy is converted during the process of scattering (Niemz, M. H., 2013).

The elastic scattering, where incident and scattered photons have the same energy, A special kind of elastic scattering is Rayleigh scattering. In Figure 1.6 a simple geometry of Rayleigh scattering is shown.

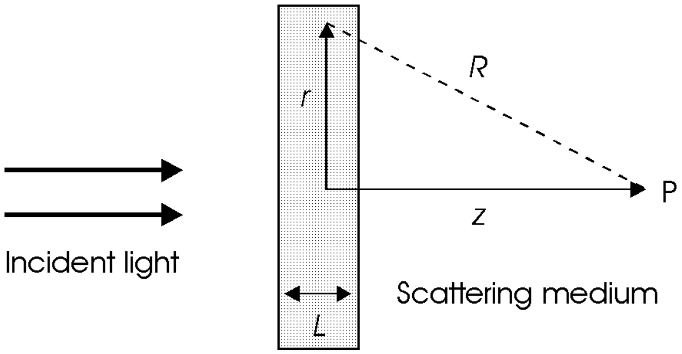

Figure 1.6. Geometry of Rayleigh scattering.

A plane electromagnetic wave is incident on a thin scattering medium with thickness *L*. At a particular time, the electric field of the incident wave can be expressed by

$$E(z) = E_0 \, exp(ikz) \qquad 1\text{-}14$$

Where

E_0 is the amplitude of the incident electric field, k is the amount of the propagation vector and z denotes the optical axis.

The loss in intensity due to scattering is described by a similar relation as absorption

$$I(z) = I_0\, exp(-\alpha_s z) \qquad 1\text{-}15$$

where

α_s is the scattering coefficient.

One important type of inelastic scattering is known as Brillouin scattering. It arises from acoustic waves propagating through a medium, thereby inducing inhomogeneities of the refractive index. Brillouin scattering of light to higher or lower frequencies occurs, because scattering particles are moving toward or away from the light source. It can thus be regarded as an optical Doppler effect in which the frequency of photons is shifted up or down (Niemz, M. H., 2013).

1.8 Optical properties of matter

The interaction of electromagnetic radiation with matter affected the optical properties of the material. The main interest will be focused on the visible part of the spectrum which has wavelength of 380 - 780 nm and power of 3.3 - 1.6 eV.

The electromagnetic radiation can interact only with the electrons of the atoms of the material because the much heavier nuclei are not able to follow the high frequencies of visible radiation. While core electrons have binding energies usually far higher than those provided by visible light and binding electrons interact only weakly with the electromagnetic wave below resonance, free electrons are accelerated after absorbed energy. This energy is then either re-emitted or transferred to the lattice (Kennedy, E. *et al.*, 2004).

1.9 Teeth fillings

Prevalence of dental caries ranges from 13% to 96% in different parts of the world in different age groups. Dental caries should be restored properly to prevent pulpal involvement and to restore the anatomy, function and aesthetics of the tooth structure.

Different tooth restorative materials are available to the dental practitioners. However depending upon tooth type, location and extent of dental caries, age and sex of the practitioner and the patient may affect the selection of filling material. There are two types of tooth restorations called direct and indirect.

Direct tooth restorations involve dental filling materials and usually require single sitting. Indirect tooth restorations involve inlays, on lays, crowns and bridges. Which usually require at least two sittings.

Composite and dental amalgam are most commonly used materials for direct tooth restorations. However, other materials such as glass ionomer, resin ionomer and miracle mix are also used for direct tooth restorations. These materials have their own advantages and disadvantages in relation to cavity preparations, strength, durability, aesthetics, secondary caries formation and cost, shows in table 1.1 (Poudel, K. R. *et.al.*, 2014).

Table 1.1. Advantages and disadvantages of different types of restorative materials.

Amalgam	**Composites**	**Glass ionomers**	**Resin ionomers**
Principal uses			
Dental fillings Heavily loaded posterior restorations	Aesthetic dental fillings Veneers	Small non-load fillings Cavity liners	Small non-load fillings Cavity liners

Leakage and recurrent decay			
Moderate leakage	Low leakage if properly bonded	Low leakage generally	Low leakage if properly bonded
Recurrent decay same as other materials	Recurrent decay depends on maintenance of tooth-material bond	Recurrent decay comparable to other materials	Recurrent decay comparable to other materials
Overall durability, fracture resistance and wear resistance			
Good to excellent durability in large load bearing restorations Brittle, subject to chipping on filling edges good bulk strength in large	Good durability in small to moderate restorations Moderate resistance to fracture in high load restorations	Moderate to good durability in non load-bearig restorations poor in load-bearig Low resistance to fracture	Moderate to good durability in non load-bearig restorations poor in load-bearig Low to moderate resistance to fracture

high-load restorations			
High resistance to wear	Moderate resistance to wear	High wear on chewing surfaces	High wear on chewing surfaces
Cavity preparation and clinical considerations			
Require removal of tooth structure	Adhesive bonding permits removal of less tooth structure	Adhesive bonding permits removal of less tooth structure	Adhesive bonding permits removal of less tooth structure
Tolerant to wide range of clinical conditions	Requires well-controlled field of operation	Requires well-controlled field of operation	Requires well-controlled field of operation
Moderately tolerant to moisture during placement	Very little tolerance to moisture during placement	Very little tolerance to moisture during placement	Very little

1.10 Commonly materials for direct tooth restorations

1.10.1 Composite (resin)

Composite is a mixture of acrylic resin and powdered glass-like particles. This kind of filling is well suited for visible areas in mouth. This type of materials hardened by exposure to blue light. These fillings have the same colour as the natural teeth (Anusavice, K. J., *et al.*, 2013).

Compostie materials may be defined as materials made up of two or more components and consisting of two or more phases. Such materials must be heterogeneous at least on a microscopic scale. composite materials may be divided into three general classes particulate filled materials consisting of a continuous matrix phase and a discontinuous filler phase made up of discrete particles, fiber filled composites and skeletal or interpenetrating network composites consisting of two continuous phases.

there are many reasons for using composite materials rather than the simpler homogeneous polymers. some of these reasons are

- Increased stiffness, strength, and dimensional stability
- Increased toughness or impact strength
- Increased heat distortion temperature
- Increased mechanical damping
- Reduced permeability to gases and liquids
- Modified electrical properties
- Reduced cost

Not all of these desirable features are found in any single composite. The advantages that composite materials have to offer must be balanced against their undesirable properties, which include complex rheological behavior and difficult fabrication techniques as well as reduction in some physical and mechanical properties.

The properties of composite materials are determined by the properties of the components, shape of the filler phase, morphology of the system , and the nature of inter face between the phases. Thus a great variety of properties can be obtained with composites just by alteration of one of these items e.g the morphological or interface properties. An important property of the interface that can greatly affect mechanical behavior is the strength of the adhesive bond between the phases (Landel, R. F. and Nielsen, L. E., 1993).

1.10.2 Amalgam

Dental amalgam has been used as a safe, durable, stable and cost effective restorative material for more than 150 years. Mercury is unique in its ability to form solid amalgams with other metals and dental amalgam comprises approximately 50% mercury, combined with silver and small amounts of copper, tin or zinc. There has always been a certain amount of controversy surrounding the use of dental amalgam as a restorative material. This has increased over the past 25 years and there has been much research into the health effects of amalgam over this time. Dental amalgams have commonly been called “silver fillings” because of their silver color when they are first placed. Today, amalgam is used most commonly in the back teeth. It is one of the oldest filling materials and has been used because it safe, stable and still used in many countries (Kao, R. T. *et al*., 2004).

1.11 The health effects of dental amalgam

In the mouth, mercury is amalgamated with other metals and is therefore rendered inert. Chewing can release some mercury vapour but this is very minimal. In the past, amalgam being associated with a variety of systemic conditions such as Alzheimer’s, Parkinson’s Disease and Multiple Sclerosis. However, several major studies have failed to reveal such effects. A recent epidemiological assessment found that evidence for the role of dental amalgam in multiple sclerosis, Parkinson's and Alzheimer's diseases was inconclusive. Evidence that dental amalgam can be a causative factor for effects on neuropsychological function, chronic fatigue syndrome and non-specific symptom complexes was also inconclusive.

It is perhaps worth noting that many studies of patients with alleged "amalgam illness" have shown that these patients often have a tendency towards psychosomatic disorders, anxiety and depression, panic disorder and the inability to perceive and understand threatening situations. The recent preliminary report by the Scientific Committee on Emerging and Newly Identified Health risks (SCENIHR) concluded that no increased risks of adverse systemic effects exist and they do not therefore consider that the current use of dental amalgam poses a risk of systemic disease (Cutler, A. H., 1999).

1.12 Restoration longevity

The longevity of different materials is not easily established because the data depends on a multitude of factors, where material selection is just one. Study design, cavity selection, operators, experience, non-standardized evaluation criteria and the cohorts play a role for the clinical outcome. However, several studies indicate that amalgam tend to last longer than other materials available, the longevity of glass-ionomers is lower than that of amalgam, however, these materials have frequently been assessed in primary teeth. In fillings subjected to low chewing forces, the composite materials perform better than a glass ionomer cement. The Atraumatic Restorative Treatment (ART) procedure appears to provide some positive results in primary teeth.

In general, dental amalgam out lasts resin composites with median ages of 10 to 15 years for amalgam, compared with composites ages of 5 to 8 years. Similarly, a study indicated that starting at 5 years after initial treatment, the need for additional restorative treatment was approximately 50% higher in the composite group. Annual failure rates of different restorative materials are given in Table

1-2, with glass ionomers having the highest failure rate of 7.6%. Espelid and colleagues compared the clinical behaviour of silver reinforced glass ionomers and resin modified glass ionomers. After 24 months, the resin modified glass ionomers have the best overall performance with respect to retention, marginal integrity and secondary caries (Petersen, P. E. *et al*., 2009).

Table 1.2. Annual failure rates of dental restorations.

Material	**Age at replacement**	**Annual failure rate**
Resin-based composites	8 years	2.3%
Poly-acid modified composites	7 years	3.5%
Resin-modified glass ionomers	2 years	3.1%
Glass ionomers	4 years	7.6%
Amalgam	10 years	2.2.%

1.13 Hardness testing

Hardness testing has found wide applications as a method for the classification of materials and for the comparative study of changes in their properties. The main purpose of the hardness test is to determine the suitability of a material, and also to obtimaize heat treatment of the material.

Many factors can influence the hardness measured and apart from the material itself, can be related to the equipment or the measurement. The most common methods of testing the hardness of restorative materials are Brinell, Rockwell, Knoop and Vickers test where, each of these tests differs slightly from the other (Horie, C. V., 2010).

Hardness is usually determined by abrasion tests, scratch tests or by indentation testing. The latter method, however, has found most extensive applications. The Brinell test, first described in 1900, is conducted by pressing a steel ball into the surface to be tested until a specified load is reached. The Brinell hardness is computed as the ratio of the load (3000 kg) to the contact area in square millimeters.

The Rockwell hardness testing method is essentially based on a similar principle. The range of applications of Brinell and Rockwell testing is limited by the fact that steel-ball indenters may be deformed when used on very hard materials. The Vicker's hardness is normally determined by using loads varying from 1 to 120 kg. The geometry of the Vicker type indentation is independent of the penetration and thus it would be expected that the hardness would be independent of the load. This relationship does not prevail with the Brinell method. The angle which the indentation makes with the surface of the test piece changes with the depth of penetration (Tabor, D., 2000).

1.14 Literature review

-In 2005 Weinmann, W., Thalacker, C. and Guggenberger, R et.al studied the hardening stresses in wall-to-wall bonded composites were measured and related to calculated values obtained from freely shrinking materials. Since the ultimate tensile strength of the materials contracting under restricted conditions was not lower than that of composites which were not hindered during the polymerization shrinkage, conclusion the contraction was drawn which compensated in flow instead of internal disruptions (Shaabin, M., 2009).

-In 2011 Nafie A. Almuslet et.al studied the effect of diode laser to enhance the hardness of human teeth filler material (Amalgam), in a short possible time via irradiation by low level laser. Hardening tests were carried out on different amalgam mixtures subjected to irradiation for two minutes by diode laser with wavelength of 675 nm and power of 15 mW. The samples were left for different time intervals and for each time interval hardening test was carried out using Brinell hardness test. Other samples were prepared for the same test with the same procedures but without irradiation, i.e. control group.

The irradiated samples showed a considerable increasing in their hardness compared to the samples without irradiation. The samples irradiated by laser need only 6 hours to reach the same value of hardness that the control group reached after 30 hours.

In conclusion, the irradiation of amalgam by this type of laser with the above parameters believed to be recrystalizing the material so it become harder with shorter time compared to the amalgam without irradiation (Almuslet, N., Elamin, H. J. and Elbashir, B. O., 2011).

-In 2014 Mubarak M. Ahmed et.al studied the effect of diode laser (810 nm), with various power (30, 200 and 500 mW) in hardness of the material used in the combinations of teeth (ceramics). Hardness was measured for dental ceramic samples in four groups, each group containing ten samples, tested before and after irradiation by diode laser for 2 and 10 minutes. The results showed that increasing the irradiation time from two minutes to ten minutes, as well as increasing power from 30 to 500 mW, does not have a significant effect in increasing the hardness of the ceramic material. This study found that the hardness of the samples was increased up to 18.28%, by irradiation of invisible diode laser 810 nm and power of 30 mW (Ahmed, M. M., Eldeen, E. M., Yagoub, S. O. and Abdelrahman, 2014).

-In 2014 Haydar H. J. Jamal Al-Deen studied the effect of copper content on mechanical properties of dental amalgam. For this purpose five alloys have been casted composed of constant percentage of tin 30% and the copper content is vary as follows 5, 10, 15, 20 and 25% and the rest was silver. The specimens were prepared and tested according to specification No. 1. Mechanical properties (compression strength, diametral tensile strength, creep, dimensional change and hardness) were investigated and found that all mechanical properties were enhanced by increasing copper content. The compression strength is increased by 37.4% at one day and 35.2% at 7 days of test. The diametral tensile strength is increased by 18.1% at one day and 13.5% at 7 days of test. Creep resistance is increased by 71.1%. Vickers microhardness increases by 29.4% at one day and 27.3% at 7 days of test. Increasing copper content stabilizes the dimensional change of dental amalgam. All as compared to low copper content amalgam (Al-Deen, H. H. J., Haleem, A. H. and Tuma, M. S., 2014).

Chapter Two

The Experimental Part

2.1 Introduction

Different equipments were used to increase and measure the amalgam hardness at different time intervals after the laser irradiation.

2.2 The diode laser

Diode lasers (continuous wave) with wavelength of 671 nm and output power of 100 mW, supplied from Roithner Laser Technik, (Austria) was used in this work to irradiate the samples for 30 seconds. Figure 2.1 shows a photo of the diode laser device.

Figure 2.1. The diode laser device.

2.3 Rockwell hardness tester

The hardness tester model TH 160, with dimensions of 268 × 86 × 50 mm, manufactured by Digiwork Instruments Company, Canada, was used to provide a wide range for non-distractive test of hardness.

Rockwell hardness numbers are the result of measuring the depth of indentation into the material. Therefore, the accuracy and resolution of this measurement is critical in obtaining good results. There are no mechanical linkages or sources of friction between this measuring device and the tested part. Figure 2.2 shows a photo of Rockwell tester.

Figure 2.2. Rockwell hardness tester model TH160.

2.4 Amalgam material

The dental amalgam used in this work is a capsule GK(Global Knowledge) manufactured by, AT&M Biomaterials Co., Ltd, China. It is produced by mixing liquid mercury with solid particles of an alloy of silver, tin and copper. This combination of solid metals is known as the Amalgam alloy produced by amalgamator. Figure 2.3 shows a photo of the amalgam package.

Figure 2.3. Amalgam capsules package.

2.5 Amalgamator

In the past, dentists mixed amalgam by hand which could expose them to mercury vapours. Today, manufacturers usually supply the materials to make the amalgam in a sealed capsule with two compartments. One side contains liquid mercury and the other side holds a mixture of alloy as a powder or tablet. The capsule can be placed in a machine called amalgamator that breaks the membrane between the two compartments and mixes the contents. The dentist collects the mixed amalgam, which at this stage has the consistency of a thick paste, and presses it firmly into the prepared tooth cavity (Saffir, J. A., 1939).

The amalgamator used in this work was model ST-D supplied from AT&M Biomaterials CO.LTD, American. Its specifications are listed in table 2.1.

Figure 2.4. Amalgam meter devise.

Table 2.1. The specifications of amalgamator model.

Type	Oral Therapy Equipments & Accessorie
Model Number	MID-MAM-I
Operating Temperature For consistency	5 to 4 C^0
Weight	3.5 Kg

2.6 The experimental procedures

The experimental procedures were done as follows:

-The amalgam capsule was prepared by amalgamator and the mixing time was 16 sec. The samples were formed in circular templates with diameter of 15 mm and thickness of 5 mm. Fifteen amalgam samples were formed in one template.

Figure 2.5. amalgam sample after preparation.

-Two samples had been formed for the experimental part.

-The first sample was prepared without irradiation process. The second was mixed, formed and irradiated for 30 secound by diode laser (671nm) with power of (100 mW).

-The samples were subjected to hardness testing.

-The hardness test was carried out for the two samples in different time intervals (2, 6, 12, 18 and 24 hours) after irradiation.

-The hardness was tested for samples three times and the average was taken. Their hardness were measured at the same time intervals in order to compare the hardness of the two samples. Figure 2.6 shows a diagram of the work steps, and Figure 2.7 shows the hardness test.

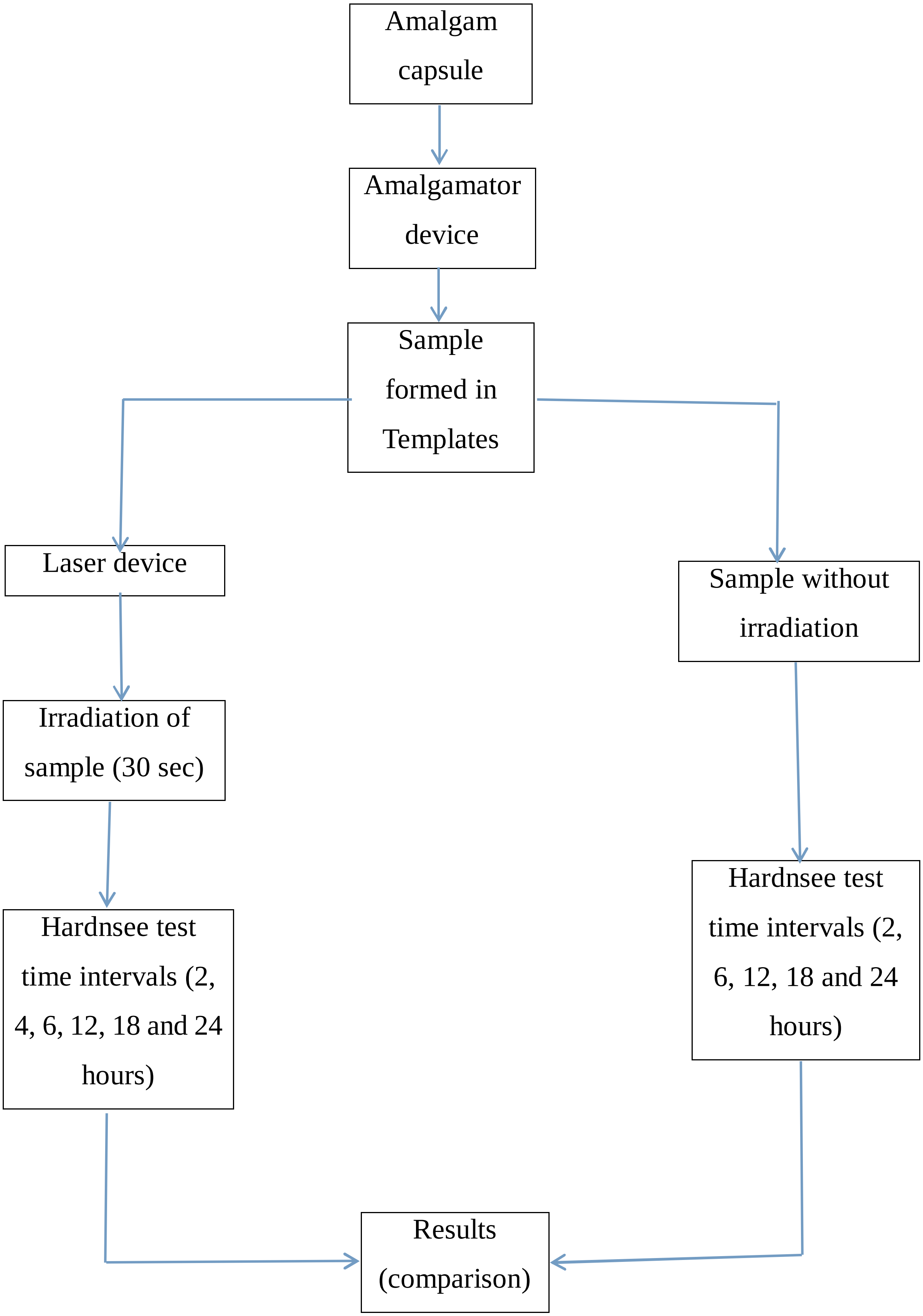

Figure 2.6. Block diagram of the steps followed in this work.

Figure 2.7. The hardness test for samples.

Chapter Three

Results and Discussion

3.1 Introduction

This chapter covers the results obtained from the experiments and discussion. The purpose of these experiments is to reduce the time required to gain suitable hardness and to increase the hardness of amalgam, irradiated by laser.

3.2 The Results

The results of the hardness test in (HRB) Hardness Rockwell Scale B, for different time intervals, of the filling amalgam without irradiation and with irradiation by diode laser (671 nm and power of 100 mW) are listed in table 3.1. The percentages for the hardness differences between the two groups in different time intervals are listed in table 3.2.

Table 3.1. Hardness values of amalgam without irradiation and after irradiation by diode laser measured at different times.

Time interval (hr)	**Hardness of amalgam without Irradiation (HRB)**	**Hardness of amalgam after Irradiation by diode laser (HRB)**	**Hardness difference between the two groups (ΔH)**
2	59.2	71.7	12.5
6	75.4	96.5	21.1
12	81.4	96.5	15.1
18	87.7	96.9	9.2
24	93.8	97.2	3.4

Table 3.2. The percentage of hardness differences between the two groups.

Time (hr)	**Percentage of hardness differences (HRB)%**
2	21.1
6	27.9
12	18.5
18	10.4
24	3.6

A comparison between the hardness of the control group and the irradiated group, at different time periods after samples irradiation, is shown in figure 3.1.

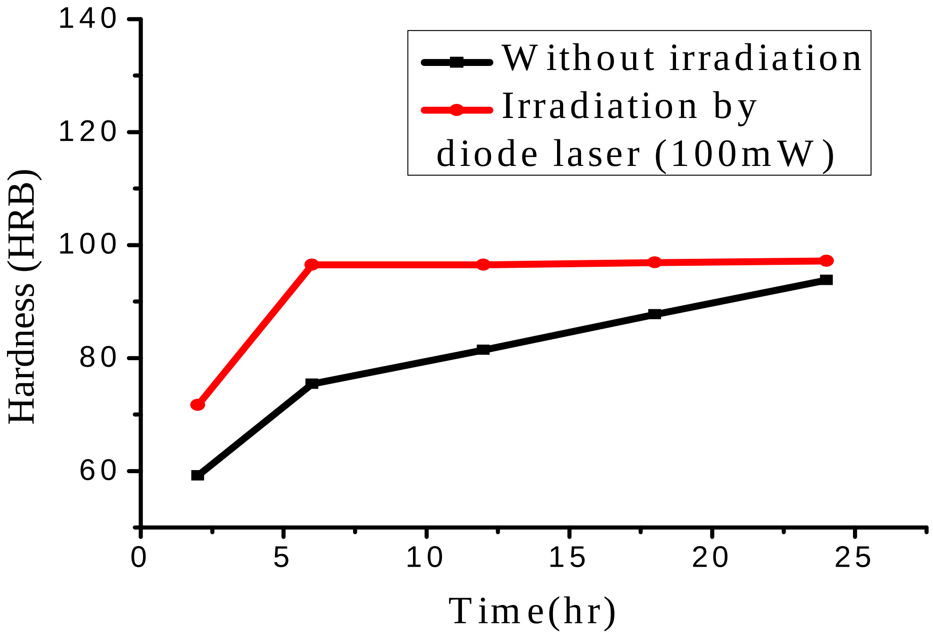

Figure 3.1. The hardness of samples with and without irradiation by diode laser after different time intervals.

As can be seen from figure 3.1, the hardness of the irradiated samples exceeds the hardness of the samples without irradiation by about 21% just two hours after amalgam preparation. The samples irradiated by diode laser took 6 hours only to achieve a hardness equal 96.5 HRB, while the samples without irradiation took 24 hours to reach its maximum hardness value of 93.8 HRB. After 6 hours the irradiated samples have hardness exceed that for nonirradiated samples by about 28%.

In a previous study the results of the hardness test of the filling amalgam without irradiation and with irradiation by diode laser 675 nm with power of 15 mW, showed that the hardness without irradiation (HRB) were 46.2, 47.6, 49.5, 52.5, 51.2 and 57.5 .The hardness after irradiation by diode laser 675 nm with power of 15 mW, (HRB) for two minutes were 56.8, 57, 58.6, 61.8, 64.5 and 77.6 the experiment was done at different time interval 2, 6, 10, 18, 24 and 30 hours (AHMED, H. J. A., 2006).

The comparison between the hardness of amalgam irradiated by diode laser 671 nm with power of 100 mW and diode laser 675 nm with power of 15 mW. In figure 3.2.

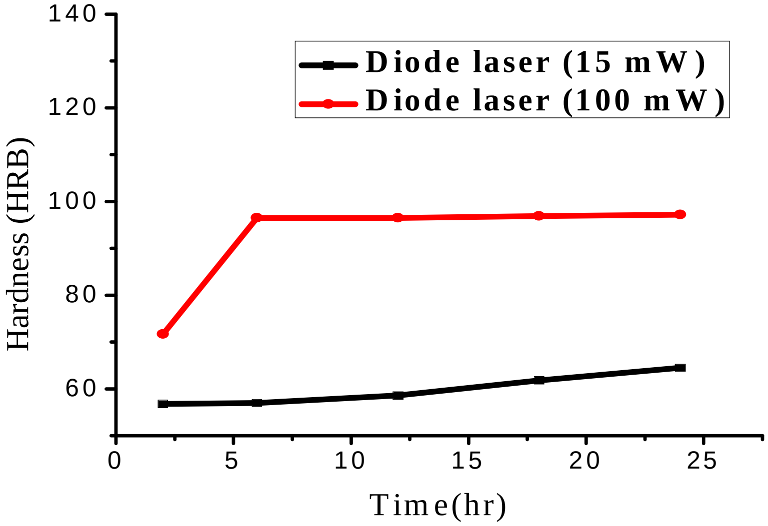

Figure 3.2. A comparison between effect of two lasers with different power on amalgam after the same time intervals.

When the hardness obtained from diode laser 671 nm with power of 100 mW, and the hardness obtained from diode laser 675nm with power of 15mW, the hardness increased by increasing the power and then the polymerization rate of the material will be higher.

3.3 The hardness enhancement by laser (Δ*H*)

Enhancement of the hardness of the samples irradiated by diode laser 671 nm with power of 100 mW after different time intervals is shown in figure 3.3.

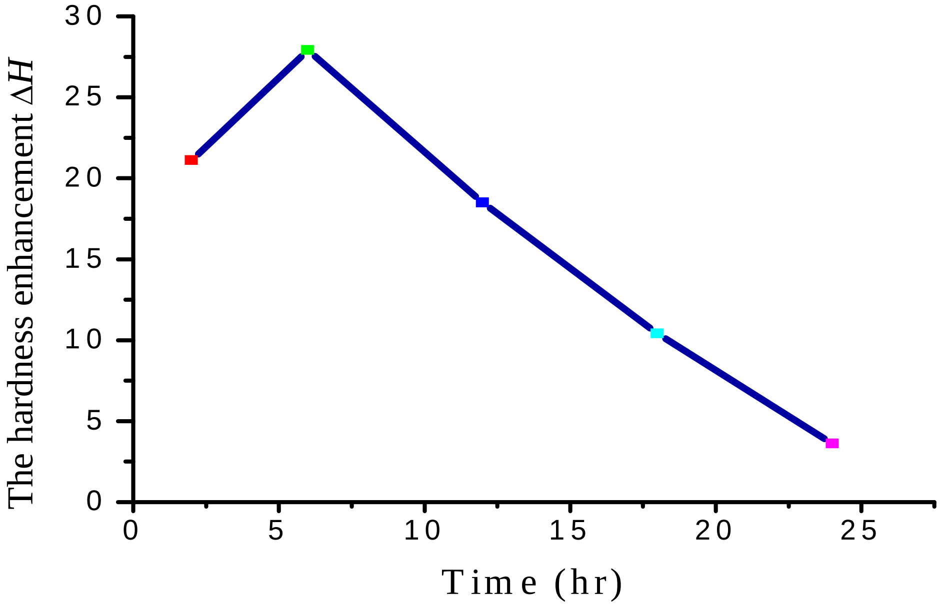

Figure 3.3. Enhancement of amalgam hardness irradiated by diode laser 671 nm and power of 100 mW.

3.4 Discussion

Considering the comparison of the results of hardness test between the samples subjected to irradiation by diode laser with wavelength of 671 nm and power of 100 mW, and hardness of the sample increased by 21% in the 2 hours. The sample irradiated by diode laser took 6 hours only to achieve hardness of 96.5 HRB. While, the sample without radiation took 24 hours to achieve the hardness value 93.8 HRB.

We believed that the hardness increased after irradiation due to the laser initiation which increases the polymerization rate of the amalgam (Kleverlaan, C. J. and

Feilzer, A. J., 2005), (Al-Assaf, S., *et al*., 2009).

Low power lasers can be used for Polymerization which denotes a chain reaction (chain polymerization), and consequently photopolymerization refers to the synthesis of polymers by chain reactions that are initiated upon the absorption of laser light by a polymerizable system. Notably, laser light serves only as an initiating tool. This is mainly due to the capability of laser to be tuned to a specific wavelength, therefore exciting a particular bond and hence the polymerization chain reaction starts.

The comparison between the hardness obtained from diode laser 671 nm with power of 100 mW, and the hardness obtained from diode laser 675 nm with power of 15 mW, showed that the hardness increased by increasing the power of the laser this is due to the faster polymerization which leads to enhance the hardness in shorter time.

The samples irradiated by diode laser with wavelength 671 nm and power of 100 mW irradiated for 30 secound (short time interval), took 24 hours to reach its maximum hardness value. But the samples irradiated by diode laser with wavelength 675nm and power of 15 mW irradiated for two minutes (long time interval) took 24 hours to reach its maximum hardness value. That means the enhancement in hardness increased with the increasing in laser power which reduced effectively the time of irradiation.

3.5 Conclusions

From the obtained results, one can concludes that:

- The irradiation by diode laser (671 nm) is effective in hardening enhancement of amalgam materials. The hardness of amalgam can be enhanced significantly (to about 28%) after just six hours from irradiation.
- The time required for the maximum hardening for amalgam irradiated by diode laser is much less than that for the maximum hardness of nonirradiated amalgam.

3.6 Recommendations

The following can be recommended as future work

- Using other diode laser with out put power more than 100 mW for the same purpose.
- Studing the enhancement for the hardness for the other filling materials, likes Composites, Glass ionomers and Resin ionomers.

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