# CHAPTER II

## LITERATURE REVIEW

Light-cured adhesives used with metal brackets are cured by scattered light inside the tooth because the opaque structure of stainless steel brackets blocks light transmission when direct irradiation is applied through the bracket.[4] Indirect irradiation from the mesial and distal sides, or from the incisal and cervical sides of the stainless steel brackets is necessary.[5] Enamel prisms are the most important components that scatter light through a tooth. They, then, influence the reflected light, which, in turn, influences the degree of cure of light-cured adhesives. The increased light intensity of curing units results in a high level of light reflectance at the enamel background, thus increasing the degree of cure.[5] Light paths are influenced by the translucency, opacity, light scattering and other properties of the teeth.[6] The degree of cure value derived from indirect irradiation method (from incisal and cervical edges of brackets for 10 seconds each) is significantly higher than that derived from the direct irradiation in stainless steel brackets, but the cure value is comparable to that of chemically-cured adhesives.[4,7]

Enamel trans-illumination allows light to reach the tooth/adhesive interface more easily than it can reach the bracket/adhesive interface. Inadequate polymerization of adhesives in the mesh bracket base results in reduced bond strength. Adequate polymerization of adhesives, including adhesives in the bracket mesh results in increased interlocking of composite in the bracket base. This leads to an increase in cohesive failure within adhesives, rather than adhesive failure at the tooth/adhesive or bracket/adhesive interface.[8]

The differences between a light-cured system and a self-cured (chemically-activated) system are only the initiators and activators. Adequate polymerization of a light-activated system produces physical and mechanical properties similar to those of a chemically-activated system.[9] To achieve optimal physical properties of adhesives, maximum conversion of monomer to polymer is required. Inadequate polymerization is associated with lowering the physical properties of materials and with bond failure. Adequate polymerization results in a strong bond between adhesives and brackets and/or teeth. The conversion of monomer to polymer and maximum curing depth depend on the composition of the composite materials, the intensity and wavelength of the light source, and exposure time.[10]

A light-cured or photo-activated system usually consists of two components, the photo-initiator and the accelerator. First, the photo-initiator or photo-sensitizer absorbs light of a specific wavelength. It captures photons, energy produced from the light sources or devices, which excite electrons. Second, the accelerator or photo-reducer, a tertiary amine, accepts excited electrons to form free radicals. Polymerization occurs when these free radicals react with the monomer, forming a co-polymer.[11]



Camphorquinone is the most common photo-initiator used in dental materials. It absorbs light in 400 to 500 nm (blue light in visible light spectrum), and has a maximum peak absorption of 465 nm.[12] When a specific wavelength initiates camphorquinone, the polymerization begins. However, camphorquinone has some limitations, such as its strong yellow color. Other photo-initiators are used in dental materials, such as 1-phenyl-1, 2-propanedione (PPD), with a peak absorption of 410 nm, bisacylphosphine oxide, or triacylphosphine oxide with a peak absorption of 320 to 390 nm.[13]

Light-cured adhesives need a polymerization time which lasts at least 20 seconds per side, for conventional quartz tungsten halogen lamp to reach adequate bond strength for bonding orthodontic brackets.[14] This causes a long working time for full arch bracket placement.

Curing time reduction improves the efficacy of bracket placement by reducing the risks of saliva contamination.[1] Several methods have been introduced to reduce bonding time, such as high-intensity light curing systems.

**Types of light curing unit**

Visible light curing units used in dentistry are divided into four types, based on light sources: 1) Quartz Tungsten Halogen (QTH), 2) Plasma Arc Curing (PAC), 3) Light Amplification by Stimulated Emission of Radiation (LASER), and 4) Light-Emitting Diode (LED).[11]

**1) The Quartz Tungsten Halogen lamp (QTH)** converts electric current to heat energy through thin tungsten filaments. Light occurs when high heat is generated at about 3,000 Kelvin.[12] Most of the energy put into the halogen system is changed into heat, but only a small portion of the energy is changed into light. The emitted light must be filtered to acquire the blue light spectrum needed for curing dental materials (Figure 1). One problem of the halogen light curing system is a degradation of instruments. High heat production causes degradation of bulb, filter, and reflector, leading to a decrease in blue light intensity, and consequently reduces the curing efficiency. A bulb has a limited life time of approximately 100 hours.[14-17] The halogen curing lamp needs to be cooled down from the heat generated, so a cooling fan is needed. The fan may disperse any bacterial aerosols present in the patient's mouth. In addition, the cooling fan makes the light curing unit big, noisy, and difficult to disinfect.[12]

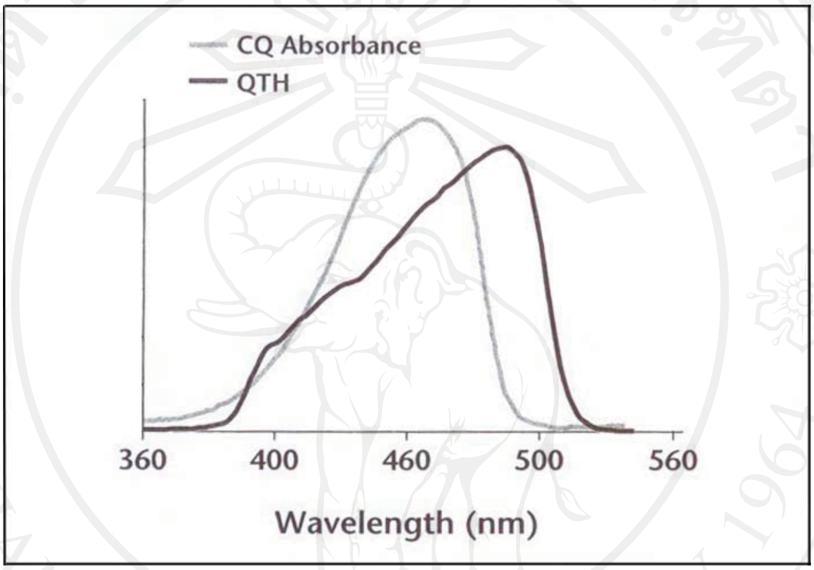


**Figure 1** Spectral emission of QTH lamp and camphorquinone absorbance.

(Adapted from Hammesfahr PD, O'Connor MT and Wang X 2002)

**2) The Plasma arc curing light (PAC)** was introduced to increase the power output and to reduce curing time. A high voltage between two electrodes results in the emission of a very intense beam of light, but the light spectrum produced is broad. So, filtration is needed to produce the blue light. The wavelength is generally the same as that of the quartz tungsten halogen lamp, 400 to 500 nm (Figure 2), but it includes intense peaks that do not coincide with the wavelength of camphorquinone absorption. Most of the light produced is not useful for camphorquinone initiation. A cooling system is also needed to cope with the high heat generated. The high intensity justifies a relatively short curing time, but the power of these devices declines with time and they are expensive to purchase and to maintain.[11]

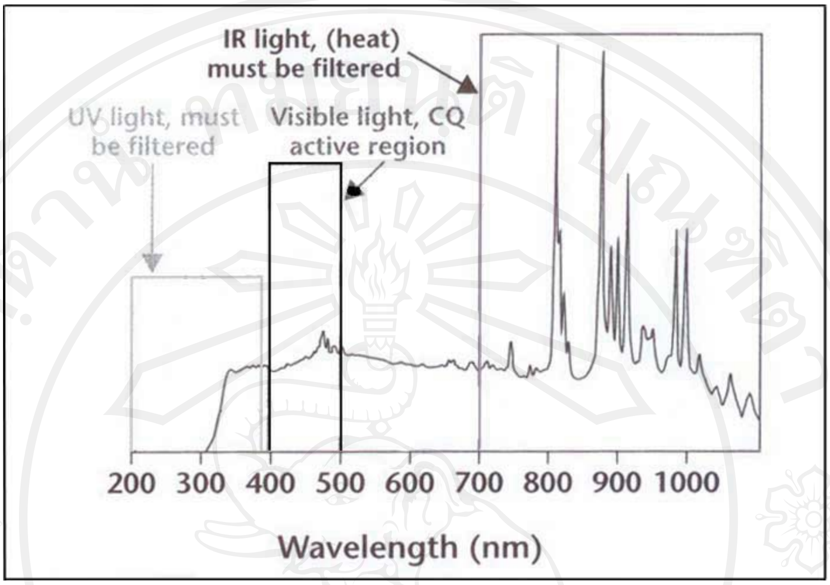


**Figure 2** Spectral emission of plasma arc light.
(Adapted from Hammesfahr PD, O'Connor MT and Wang X 2002)

**3) The argon laser**, when compared with other light sources used in dentistry, produces a highly concentrated, collimated beam and a narrow wavelength in the range of 457.5 to 514.5 nm,[18] with a peak wavelength after filtration of 488 nm[11] (Figure 3). This is close to the peak absorption of camphorquinone. For these reasons, the argon laser can provide adequate bracket bond strength with a 5- to 10-second curing time.[19] However, the disadvantages of the argon laser are: too narrow a spectral output, heat production (although slight) from the infrared light generated by the argon laser, and cost. So, this device is not widely used.[13]

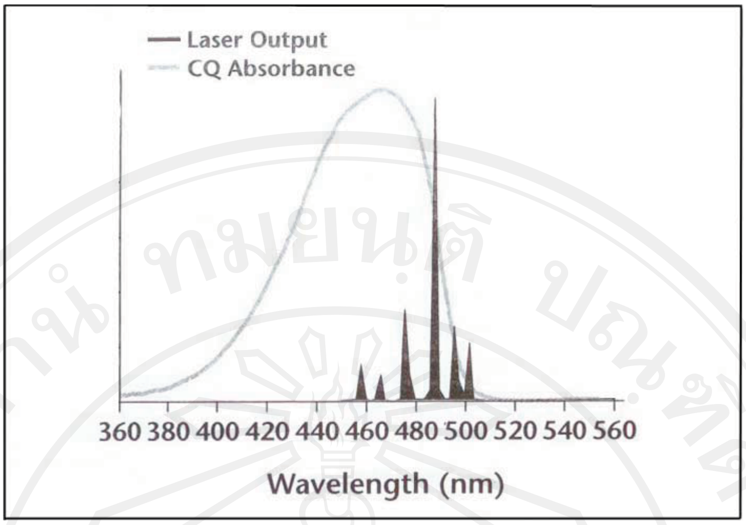


**Figure 3** Spectral emission of argon laser and camphorquinone absorbance.

(Adapted from Hammesfahr PD, O'Connor MT and Wang X 2002)

**4) The Light-Emitting Diode (LED)** is a semiconductor device that generates and emits light with a blue light wavelength, which can initiate photo-polymerization of dental adhesives without using a filter. It reaches a peak wavelength of 470 nm[12] (Figure 4), which is matched to the peak absorption wavelength of the camphorquinone initiator used in most visible-light-cured adhesives. The light-emitting diode can achieve the same effectiveness in polymerization as the halogen lamp at the same intensity level, but it consumes less energy.[15-17] This makes it possible to be used as a cordless handpiece.[14] Compared to the halogen lamp, the light-emitting diode gives a narrower spectrum, and has a longer lifetime (approximately 10,000 hours), because of little degradation and no heat generation.[2,12]

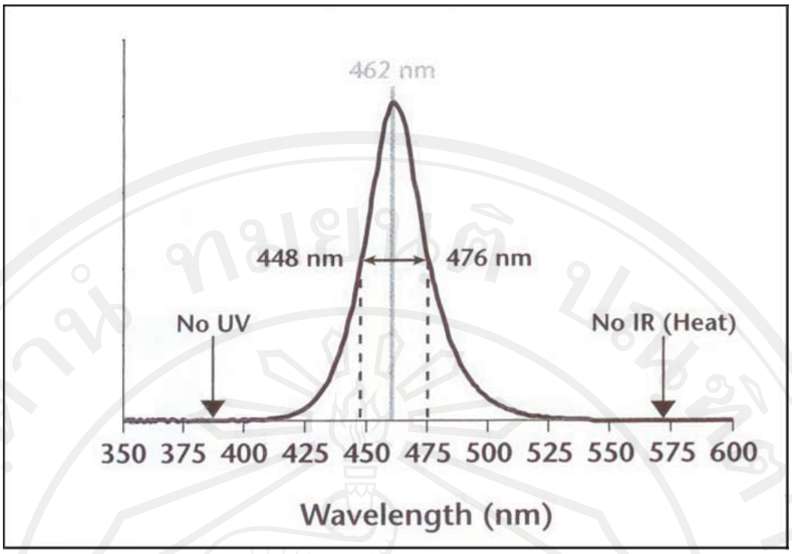


**Figure 4** Spectral emission of a blue light-emitting diode.

(Adapted from Hammesfahr PD, O'Connor MT and Wang X 2002)

**Factors affecting an efficiency of photo-polymerization**

From the total energy concept, the total light energy is equal to the light intensity multiplied by the curing time. This means that the efficiency of photo-polymerization depends on the light intensity and the curing time. The curing time can be reduced if a higher intensity is applied.[12,20] Conversely, if any factors reduce the light intensity, the adhesives will require a longer curing time for polymerization. The distance between the light tip and the surface of the material to be cured and the types of materials used also affect light intensity. The intensity of light from a light-emitting diode is inversely proportional to the square of the distance of the point of measurement from the light source. However, the light intensity would not significantly decrease if the distance from the light tip to the material to be cured is less than 1 cm.[21] In other words, the shear bond strengths of adhesives, for bonding orthodontic stainless steel brackets, cured at 1 or 10 mm from the tip of a light-emitting diode, are not significantly different.[8]

There are some material factors that affect light intensity. Material thickness: the thicker the material, the lower the light intensity.[22,23] Shade of materials: darker shades of materials, for examples A4 and C4, need longer polymerization time than lighter shades (A1). Composition of materials: for example, microfilled composite would decrease depth of cure, so it requires higher intensity to complete polymerization compared with hybrid and macrofilled composite.[24]

To reduce curing time, light sources with higher light intensity have been introduced. The high-power halogen lamp, with a light intensity of 3,000 $Mw/cm^2$ at a 6-second curing time, reduces working time without affecting shear bond strength for bonding stainless steel brackets compared with a conventional halogen light with an intensity of 1,000 $Mw/cm^2$ at a 40-second curing time. The 2-second curing time high-power halogen light produces significantly lower shear bond strength.[25]

According to ISO standards (ISO: 10650, 1999), a light intensity of 300 $Mw/cm^2$ is minimally required to achieve adequate polymerization of a 2 mm thickness of composite resin.[15] Even though the light-tip is 8 mm from the composite, the lowest depth of cure for the light from both the light-emitting diode and the halogen lamp is greater than 1 mm.[26] Since the thickness of orthodontic adhesives is less than 2 mm, shorter polymerization time for bonding brackets may be adequate.[27] However, it is important to check the light intensity of curing devices routinely. Built-in radiometers which come with curing devices are more accurate in measuring light intensity than non-built-in radiometers.[28]

Although light-emitting diode devices are battery powered, the power output from these devices will not decline with depleting batteries. The devices will provide the same intensity as at the beginning with no significant decrease in their power until the battery life reaches its end point.[29]

Another important factor is the wavelength of the light, which should match the maximum absorption of the photo-initiator to achieve efficient polymerization. The halogen lamp has a long wavelength of light output, with a peak wavelength outside the absorbance wavelength of camphorquinone. The light-emitting diode has a narrower spectrum, with most photons being emitted between 440 and 480 nm, and reaching a peak around 460 nm,[12] which is closer to the peak of maximum camphorquinone absorption, than that of the halogen light. This means that the number of photons emitted by the light-emitting diode is higher than that by the halogen lamp.[17]

Comparing a conventional halogen lamp, with an intensity of 600 $Mw/cm^2$ and a wavelength of 420 to 500 nm, and a light-emitting diode with the same intensity of 600 $Mw/cm^2$ but a narrower wavelength of 430 to 490 nm, the depth of cure from the light-emitting diode is significantly higher than that from the halogen lamp.[17] So, the wavelength of light is another affecting factor that should be considered.

Mavropoulos *et al.*[14] compared shear bond strength achieved by intensive light-emitting diode devices and by one high-power halogen lamp, and reported that the intensive light-emitting diode devices (intensity 800 to 1,000 $Mw/cm^2$) at a 10-second curing time achieved shear bond strength as great as that achieved by the high-power halogen lamp (intensity 900 Mw/ $cm^2$) at 40 seconds. However, a 5-second curing time with the intensive light-emitting diode devices produced significantly lower shear bond strength. They also concluded that high-power light-emitting diodes could reduce curing time to only 10 seconds.