REPUBLIC OF TURKEY

MARMARA UNIVERSITY

INSTITUTE OF HEALTH SCIENCES

COMPARISON OF SHEAR BOND STRENGTH OF BRACKETS CURED USING A NORMAL HALOGEN, NEW HIGH POWER HALOGEN AND LIGHT-EMITTING DIODE AT VARIOUS POLYMERIZATION TIMES

ERION ÇEREKJA

DOCTORATE THESIS

DEPARTMENT of ORTHODONTICS

SUPERVISOR

Associate Prof. Dr. Banu Çakırer

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DECLARATION

I declare that this thesis is a result of my own studies, from the beginning to the end at every stage and there is no non-ethical act. All the information in this thesis is acquired in the borders of academical and ethical rules. The information and the comments mentioned that are not a part of my own study are referred and all the references are have a part in the reference list. During the study and writing of this thesis I did not have any prohibiting act on patent and copyright laws.

01.12.2009

Erion Çerekja

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VI. Abbreviations and Symbols

1. cm : Centimeter
2. F : Force
3. gr : Gram
4. kg : Kilogram
5. mm : Millimeter
6. nm : Nanometer
7. N : Newton
8. Fig. : Figure
9. N : Number
10. SD : Standard deviation
11. P : Probability
12. X^2 : Chi Square
13. < : Less than
14. > : More than
15. N s :None-significant
16. ANOVA : Analysis of Covariance
17. Tukey : Tukey Multiple Comparison Test
18. ARI : Adhesive Remnant Index
19. S.B.S : Shear Bond Strength
20. MPa : Mega Pascal
21. % : percent
22. IR : Infrared
23. UV : Ultraviolet
24. CPQ : Camphorquinone
25. PPD : 1-Phenyl-1, 2-propanedione (PPD)
26. H_3PO_4 : Phosphoric Acid
27. A.P.F : Acidulated Phosphate Fluoride

28. C.P.P : Casein Phosphopeptide
29. sec : Second

1. SUMMARY

The aim of this study was to compare the effects of three different light sources used at different curing times on the shear bond strengths (SBS) of orthodontic brackets and evaluate the effect thermocycling has on SBS. 240 human premolar teeth were divided into 6 groups of 40.A premolar bracket (Gemini MBT, 3M/Unitek) was bonded to each tooth using a light-cured adhesive (Transbond XT, 3M/Unitek). Group 1 specimens were cured with a conventional halogen light (Hilux, Benlioglu) for 40 seconds. Group 2 and 3 were cured with a high intensity LED (Bluphase, Ivoclar) for 10 and 20 seconds respectively while Group 4, 5, 6 were cured with a high power halogen light (Swissmaster, EMS) for 2, 3 and 6 seconds respectively.Half of the samples were thermocycled in water between 5° and 55° for 7500 cycles.The specimens were stored at 37° in distilled water for 72 hours before SBS testing on a universal testing machine.

Statistically significant differences were found between the light sources when evaluating the SBS values. SBS of the Groups 4 and 5 were found significantly lower.

Statistically significant differences for SBS values were found for Group 4 between the non-thermocycled and the thermocycled samples.

Groups 4 and 5 showed statistically significant differences when assessing the failure sites leaving more adhesive on the tooth after debonding.

Thermocycling did not affect the failure site.

The recommended curing time for bonding stainless steel brackets is 6 seconds for the high power halogen and 10 seconds for the Blue Phase LED.

Key words: Shear bond strength, light sources, metal bracket, thermocycling, adhesive.

2. ÖZET

Farklı polimerizasyon zamanlarında, normal halojen, yeni yüksek güçlü halojen ve ışık saçan diyot kullanarak, yapıştırılmış braketlerin koparma ve sıyırma kuvvetinin karşılaştırılması.

Bu çalışmanın amacı, farklı ışınlanma sürelerinde uygulanan, 3 farklı ışın kaynağı kullanılarak yapıştırılan braketlerin, sıyırma kuvvetlerine olan dirençlerini ve ısı sirkülasyonun (thermocycling) bu direnç üzerine olan etkisinin, karşılaştırmalı olarak incelenmesidir. 240 adet daimi küçük azı diş 40 örneklik 6 gruba ayrılmıştır. Her dişe, aynı yapıştırma sistemi (Transbond XT, 3M/Unitek) kullanarak, küçük azı braketleri (Gemini MBT, 3M/Unitek) yapıştırılmıştır. Braketler, Grup 1 örnekleri üzerine, klasik halojen ışık (Hilux, Benlioglu) ile 40 sn ışınlanarak yapıştırılmıştır. Grup 2 ve 3 te hızlı LED (Bluphase, Ivoclar) ile sırasıyla 10 ve 20 sn ve Grup 4, 5 ve 6 da yüksek güçlü halojen (Swissmaster, EMS) ile sırasıyla 2,3 ve 6 sn ışınlanarak yapıştırılmıştır. Yapıştırmadan sonra numunelerin yarısı distile suda 5° ve 55° arasında 7500 kez sirküle edilmiştir. Tüm örnekler 72 saat distile su içinde bekletildikten sonra universal test cihazı ile sıyırma modunda test edilmiştir.

Sıyırma kuvvetlerine gösterilen dirençler değerlendirildiğinde, ışın kaynakları arasında anlamlı farklar bulunmuştur. Grup 4 ve 5 örneklemlerinin kopma direnci anlamlı derecede düşük bulunmuştur.

Isı Sirkülasyonu yapılmış ve yapılmamış gruplar karşılaştırıldığında diğer gruplar için anlamlı farklar bulunmazken Grup 4 örneklemlerinin kopma direnci anlamlı derecede düştüğü bulunmuştur.

Artık Yapışkan İndeksi (ARI) değerlendirildiğinde test edilen gruplar arasında anlamlı farklar bulunmuştur. Grup 4 ve Grup 5 örneklemlerinde kopma sonrası diş yüzeyinde daha fazla miktarda yapışkan kaldığı belirlenmiştir.

Isı Sirkülasyonun ARI degerlerini etkilemediği bulunmuştur.

Yapılan araştırma sonucunda yüksek güçlü halojen kullanıldığında 6 saniye ve hızlı LED kullanıldığında 10 saniye ışınlama süreleri önerilmektedir.

Anahtar sözcükler: Kopma direnci, ışık cihazı, metal braket, Isı Sirkülasyonu, yapıştırıcı

3. INTRODUCTION AND AIM

Orthodontic brackets are routinely bonded by using chemical or light-curing adhesive systems. With light-curing materials the clinician has sufficient time to position the brackets accurately and initiate polymerization when ready. Different light sources such as halogen, plasma, light-emitting diode (LED), and laser, have been developed to be able to decrease the necessary curing time for polymerization.

Conventional halogen lights have the disadvantage of having a long curing time required to cure each tooth, which wastes valuable clinical time. The curing efficiency of conventional halogen lights is limited, because 98% of their radiation does not contribute to polymerization but is lost as heat. In addition, only part of the halogen light spectrum is useful because the absorption spectrum of camphorquinone-the photo initiator-is comparatively narrow. To reduce curing time, light sources with higher power densities have been introduced (136).

The xenon plasma arc lamp has been around since 1950s. Xenon gas, a naturally occurring trace gas in the earth's atmosphere, is produced by the fractional distillation of liquid air. The xenon plasma arc light source is capable of producing light of a much greater intensity than that of the conventional tungsten-quartz halogen light, and the light can be filtered to a bandwidth concentration of 450 to 500 nm for peak absorption of the commonly used photo initiator systems. Conflicting information exists concerning curing time for xenon plasma lights. Ideal curing times suggested vary from 2 or 3 seconds to 6-9 seconds (139, 161). Some concerns have been expressed concerning the use of high-intensity lights. One of those concerns is the heat generated by the intense light and the effect of that heat on the dental pulp. Increases in pulpal temperature above 42.5°C have been reported to result in irreversible dental pulp tissue damage. Thus, any increase in pulpal temperature must not exceed 5°C to 6°C (128, 180).

Introduced in the late 1980s and early 1990s, argon lasers promised to dramatically reduce the curing time for dental composite resins. The argon laser produces a highly concentrated, coherent beam of light centered around the 480-nm wavelength which is the optimal wavelength for the photo activation of most of the dental resins on the market. Although conventional visible light curing units also emit energy centered on 480 nm, the energy is emitted over a much broader range. Recommendations of as few as 3 seconds of laser light exposure to the adhesive beneath brackets have been made. This is a dramatic reduction in the required exposure time, from 15 minutes to only 4. Nevertheless, the argon laser has several disadvantages. The laser units themselves are relatively large and expensive and in some jurisdictions in which lasers are considered to be instruments for cutting or removing hard or soft tissues, their use is limited to licensed dentists only (89). While not as expensive as a laser, the xenon light is more expensive than the conventional light (161).

Light emitting diodes (LEDs) were proposed as a polymerization source for light-cured composite resins in 1995 when breakthroughs in LED semiconductor technology led to higher luminous intensities. LEDs are solid-state light sources that have a potential lifetime of over 10,000 hours and can be subjected to mechanical shock and vibration with very low failure rates. They are manufactured by metal organic chemical vapor deposition of different semiconductor materials in films that are layered one on top of another. The latest blue LEDs use indium gallium nitride technology and can generate photons of a particular wavelength by varying the band gap. The narrow spectral emission of the LED encompasses the spectral absorption of camphoroquinone at 470 nm; this implies that the light unit is very efficient at polymerization. The efficient energy conversion of the LEDs has allowed the development of cordless light-curing units (LCUs) that operate silently and have a very long bulb life (46, 159). No information is available on the shear bond strength values of new generation high intensity LEDs (139).

Recently a new high–power halogen lamp which minimizes the curing times dramatically was introduced (139). Exposure to this high-power halogen lamp for 3-6 seconds was found to be sufficient to obtain bond strength (139).

Our aims were to:

1. Compare the shear bond strength of brackets bonded with the same light – cured adhesive system but cured with light sources that utilize different technologies for light protrusion. The first null hypothesis of the study was; there would be no difference in mean SBS values of the brackets bonded with the same light-cured adhesive system but cured with different light sources.
2. To compare the shear bond strength of brackets bonded by using the same light source at different curing times. The second null hypothesis of the study was; curing time would not cause any difference in mean SBS values of brackets when bonded by the same light source.
3. To evaluate the effect of thermocycling to bond strength. The third null hypothesis of the study was; there would be no effect of thermocycling on SBS values of brackets bonded by using different light sources and curing times.
4. To evaluate the bond failure site. The fourth null hypothesis of the study was; there would be no difference in the distribution of ARI scores with different light curing systems, with different curing times and with and without thermocycling.

4. LITERATURE REVIEW

4.1 Direct Bonding

Experiments on bonding of acrylic resins to enamel and dentine began in the early 1950s in England with Dr. Oskar Hagger who developed a monomer based on glycerophosphoric acid dimethacrylate that was chemically cured with sulphinic acid (63). His work led to the development of Sevitron, an early commercial adhesive (86, 98). In the U.S in 1955, Dr. Michael Buonocore made the second, and more important, advancement in adhesive dentistry, by demonstrating that acid etching of enamel led to improved resin–enamel bonds by using Sevitron-like resin formulations (30). He observed that little adhesion was obtained on unetched enamel, which he correctly surmised lacked microscopic porosities for resin infiltration. He knew that concentrated (85%) phosphoric acid was used in industry to pre-treat metal surfaces prior to painting or resin coating; thus, it was logical for him to use 85% phosphoric acid for 30 sec to etch enamel, followed by water rinsing. The results of his work were very controversial at the time. Many researchers regarded Dr. Buonocore's approach as unconventional and reckless because he advocated the use of dangerous, industrial-strength acids in the oral cavity. Over the next 10 years, many investigators like Newman in 1965 (106), RL Bowen in 1962 (142), Nobuo Nakabayashi in 1982(142), Takao Fusayama in 1979 (142) and J Kanca in 1992 (24,142) confirmed the utility of acid etching enamel to increase resin–enamel bond strengths and developed the system. The concentration of the phosphoric acid was subsequently reduced to 50% (133), and more recently to 32–37%. With the recognition that primary tooth enamel surfaces were largely aprismatic, etching times of 120 sec were commonly used for bonding procedures for primary teeth (99). Those etching times have been reduced to 60 sec (146) and, more recently, 20–30 sec (48, 76) for aprismatic enamel for bonding of pit and fissure sealants and orthodontic brackets. Both a reduction in the acid concentration as well as etching time (23,163) had

been proposed. Despite the availability of alternative enamel etchants such as pyruvic, citric, oxalic, nitric or maleic, phosphoric acid still remains the etchant of choice, with the contemporary adoption of a reduced etching time to 15 sec for both prismatic and aprismatic enamel. The solutions used to etch enamel were also made into gels to permit better control of these acids (122).

The direct technique is the most popular method among clinicians because of its simplicity and reliability. There is no need for separation phase required to place the bands and decalcification occurs less than with bands. The levels of the brackets can be easily modified and brackets can easily be placed on unerupted teeth. It requires less instrumentation, is more esthetic (181, 118), more hygienic with lesser irritation and can be more easily accepted by the patients (20, 24, 130). On the other hand direct bonding is less retentive than bands, enamel cracks and fractures can occur during bracket removal and when removing the remaining adhesive from the tooth the enamel layer which is rich in fluoride is also removed (181, 118).

A lot of research has been done in-vivo and in-vitro either to measure the resistance against shear or tensile bond strength of attachments bonded, or to evaluate the effect of blood and saliva contamination on bonding (119, 138, and 165).

4.2 Composite Structure and Characteristics

All composites consist of a mixture of resin and filler. Matrix is composed of monomers and co-monomer. Two most commonly used monomers are Bis GMA and urethane dimethacrylate. A diluent is added to control the viscosity of the final product. Often as a co-monomer, Triethylene glycol dimethacrylate (TEGMA) is used to control the viscosity of the unmixed materials. The monomer and co-monomer molecules are difunctional methacrylate. Bis GMA was developed by Dr Rafel Bowen (24) and it is a difunctional methacrylate which is normally formed by a reaction between bisphenol A and glycidyl-methacrylate. It is an oligomer, formed by many monomers. Resin- based composite restorative materials have the following major components:

- An organic resin matrix
- An inorganic filler
- A coupling agent
- Initiator –accelerator system
- Pigments

The composites are divided into two groups according to their polymerization type as self cured and light cured materials.

4.2.1 Self cured materials

No mix adhesives set when one paste under light pressure is brought together with a primer fluid on the etched enamel and bracket backing or when another paste on the tooth is to be bonded. Generally the primers are composites with low amount of fillings (118). Thus one adhesive component is applied to the bracket base while another is applied to the dried etched tooth and pressed firmly together in place for 30 to 60 seconds (181).

4.2.2 Light cured materials

The light cured resins have the advantage of extended, though not indefinite, working time. Light-cured resins used with metal brackets are usually dual-cure resins incorporating light initiators and a chemical catalyst. Ultraviolet light was firstly used for curing the resins (181). Watts and Tavas in 1979 were the first to use visible light to cure resins (79, 118). The light cured material have an increased working time for the

orthodontist, maximum curing depth, less porosity and allows the clinician to clean the composite around the base of the bracket decreasing the demineralization of the enamel through plaque accumulation (53, 79, 118)

4.3 Photo Polymerization

Understanding photo-polymerization begins with an understanding of light itself. Since the time of Isaac Newton, the wave and particle models of light were in competition until the Quantum revolution of the early twentieth century, when these models were combined in the quantum synthesis. The idea of duality is rooted in a debate over the nature of light and matter dating back to the 1600s, when competing theories of light were proposed by Christiaan Huygens and Isaac Newton: light was thought either to consist of waves (Huygens) or of particle (Newton). Through the work of Albert Einstein, Louis de Broglie, and many others, current scientific theory holds that all particles also have a wave nature (and vice versa) (171). This phenomenon has been verified not only for elementary particles, but also for compound particles like atoms and even molecules. In fact, according to traditional formulations of non-relativistic quantum mechanics, wave–particle duality applies to all objects, even macroscopic ones; we can't detect wave properties of macroscopic objects due to their small wavelengths (131).

A photon is an elementary particle, the quantum of the electromagnetic field and the basic "unit" of light and all other forms of electromagnetic radiation. It is also the force carrier for the electromagnetic force. Knowledge of the photon characteristics as energy, momentum, irradiance, spin and entanglement are important for the understanding of light.

The energy of a photon of frequency n is given by $E=hn$, where h is Planck's constant. Because the energy of photons is directly proportional to their frequency, low energy photons have low frequencies, while high-energy photons have high frequencies. Low-energy photons are called radio waves or microwaves, medium-energy photons are

called light (or light waves, or visible light), high-energy photons are called X-rays, and those having even higher energy are called gamma rays.

The momentum of a photon is given by dividing the energy by the speed of light.

Irradiance is a term that can legitimately be used for light output from a source and also for light input onto a defined surface area; thus, there are two possible conditions. The flux can be arriving at the surface, in which case the radiant flux density or optical power received per unit area on the surface may also be referred to uniquely as radiant incidence. The flux can arrive from any direction above the surface, as indicated by the rays. Irradiance in this case is defined as: M = dF/dA (foto) where d*F* is the radiant flux arriving at the point and *dA* is the differential area surrounding the point

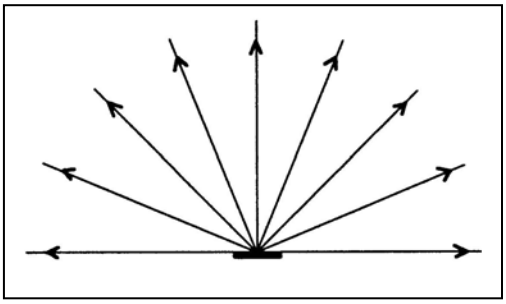


Figure 4.1 Radiant incidence

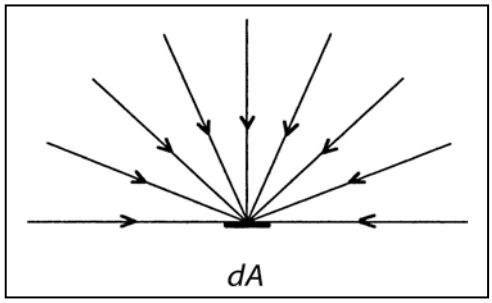


Figure 4.2 Radiant exitance

In quantum mechanics, spin is an intrinsic angular momentum associated with particles. Photons should be observed in three spin projections (–1, 0 and 1); however, the zero projection would require a frame where the photon is at rest, but, since photons travel at the speed of light, such a frame does not exist according to the theory of relativity, and so photons only have two spin projections.

Photon entanglement is a quantum phenomenon that occurs when two or more photons share unique properties but remain physically separated (56**).** Photo-polymerization is now a widely accepted initiation mode for the clinical hardening processes required with a wide range of biomaterials including dental adhesives and restoratives. The process is started by a photo-initiator chemical. These photo-initiators absorb the wavelength of light according to their absorption properties and start the reaction (65). The organic monomer phase usually includes low concentrations of

inhibitors and stabilizers together with the chemicals required for activation and initiation of monomer polymerization or “cure”. The initiation process has a significant effect on the kinetics of polymerization and the polymer structure; thus, it can affect several properties, such as rheology and long-term performance, of the network. Rheology is the study of the flow of matter: mainly liquids but also soft solids or solids under conditions in which they flow rather than deform elastically. The structure of radicals and their effect on the rate of reaction is critical to the development of an understanding of polymerization (65, 105).

4.3.1 Photo polymerization by ultraviolet (UV) light

UV Light contains photons between 10nm-400nm in wavelength. These photons are highly loaded in energy and can sometimes break the ties of the electrons within a chemical bond (60). Thus UV photons can participate in many chemical reactions but, due to their high energy level, they are uncontrollable and can create side effects like shrinkage and breaking of the chemical bond (60). Benzoic Alkyl Ether was the first photo-initiator used in dental composites cured with UV light (40). Human eye can be damaged if exposed for long periods to UV Light, thus medical and dental practitioners should be careful when using UV devices.

4.3.2 Photo polymerization by visible light (VL)

The disadvantages of UV Light gave way to research for photo–initiators activated within the 400-500nm wavelength of the VL (11). Visible Light Cured (VLC) dental composites are supplied as single-component formulations. Resin composites formulated as dual-component types undergo either self-cure upon mixing, or dual cure upon mixing and application of visible light. Dual- cure systems incorporate both self-cure and VLC activator/initiator chemicals.

4.4 Photo-Initiators

The VLC resin-composite materials usually employ photo-sensitized free-radical initiators, commonly, an *a*-1,2 diketone, such as benzyl or camphorquinone, and an amine-reducing agent such as dimethylaminoethyl methacrylate (DMAEMA) or dimethyl p-toluidine (DMPTI) (42, 160).

4.4.1 Camphorquinone (CQ)

The CQ/amine photo-initiator system for generating radicals is widely used for the polymerization of dental restorative materials. Light is absorbed by CQ (Figure 4.3) in the blue region, between 375nm-500nm reaching peak absorption at 470nm (109), and leads to the transition of the dicarbonyl group (156). The nonbonding electrons can be promoted to a proton antibonding orbital. This excited state has a half-life of approximately 0.05msec. The excited proton transition interacts with an amine molecule and forms an exciplex, which is an excited short-lived state. Within this exciplex, CQ accepts an electron from amine and from the radical ion pair, and abstracts a hydrogen atom from the tertiary amine which results in the primary radical. This latter radical then attacks the carbon double bonds of the monomers. The former CQ radical may retard polymerization through termination reactions. The concentration of CQ photo-sensitizer is in the range 0.17–1.03 mass percent of the resin phase and that of DMAEMA reducing agent is 0.86–1.39 mass percent (160). The combined photo-sensitizer/ reducing-agent complex has an extended absorption band within the VL spectrum.

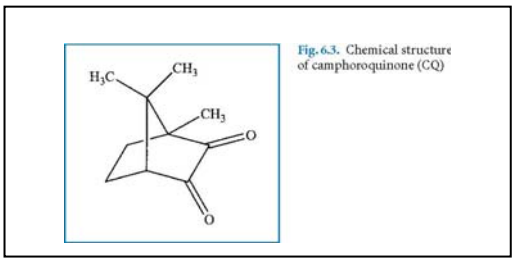


Fig. 6.3. Chemical structure of camphoroquinone (CQ)

Figure 4.3 Camphoroquinone (CQ)

4.4.2 1-Phenyl-1, 2-propanedione (PPD)

Camphorquinone is inherently yellow, which causes problems in color matching. This, in turn, places practical limits on the concentration of CQ and, consequently, limits the degree of polymerization and depth of cure that can be attained; therefore, alternative photo-sensitizers have been considered. Diacetyl (2, 3- butanedione) and propanal have been studied by Peutzfeldt and Asmussen (125, 126). A prominent initiator is 1-phenyl-1, 2 -propanedione (PPD) which has an aromatic group on one side of the dicarbonyl and a methyl group on the other (Figure 4.4) and *l*max[a]410 nm. Recent experiments showed that PPD would be an efficient visible light photo-sensitizer, comparable with camphorquinone, for the initiation of the dental resin polymerization (37, 120), and that resins initiated with PPD showed better mechanical properties than those initiated with CQ (158). Furthermore, PPD can act synergistically with CQ to increase the monomer conversion to polymer and/or reduce the photo-sensitizer concentration (and, hence, color). This blend of photo sensitizers may produce a better balance between surface cure and bulk cure (111,121). The combination will also contribute to a reduction in chroma (from deep yellow to a pale yellow) when the total photo-sensitizer (PPD+CQ) concentration is held constant since the PPD wavelength (*l*max[a]410 nm) will shift the hue to a less yellow shade(shorter dominant wavelength).

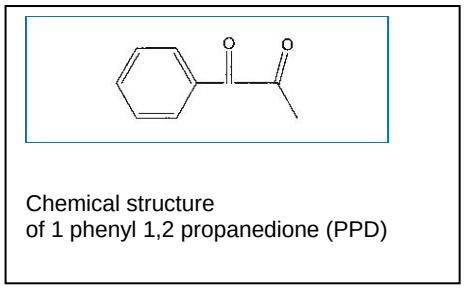


Figure 4.4 phenyl 1,2 propanedione (PPD)

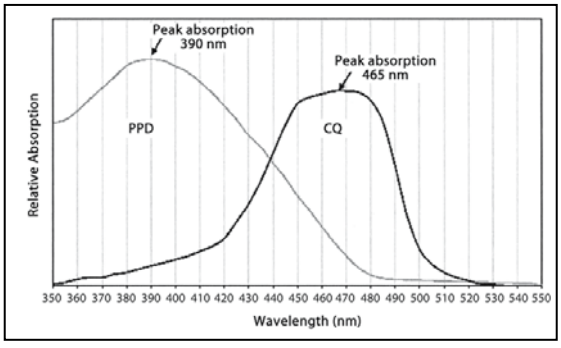


Figure 4.5 Absorption spectra for CQ&PPD

4.5 Light Sources

Photons may be produced by several different types of light sources. These sources include; quartz–tungsten–halogen (QTH), plasma arc, laser, and light-emitting diode (LED).

4.5.1 Quartz–tungsten–halogen sources (QTH)

A quartz–tungsten–halogen light source consists of a halogen bulb with a filament. When a current passes through the filament, the wire heats up, and as a result, electromagnetic radiation is emitted from the filament (4). The traditional standard irradiance of the QTH sources has been approximately 500mW/cm2, which is close to the absorption values of Camphorquinone (CQ) and can adequately cure most orthodontic composite resins in 20 seconds and light-cured resin-modified glass ionomers in 40 seconds per bracket. The absorption curve of 1-Phenyl-1, 2-propanedione (PPD) does not coincide with the emission curve of QTH, but still light between 400-450 wavelengths is enough to start polymerization of PPD photo-initiators. The spectrum of QTH radiation is continuous over the visible range, with radiation intensity increasing considerably towards the red end of the spectrum. Most of this radiation does not contribute to polymerization and must be filtered (70). The QTH sources require filters to select blue-light wavelengths between approximately 400 and 500 nm.

QTH sources have several disadvantages (155):

- The light power output is less than %1 of the consumed electric power
- The halogen bulbs have a limited lifetime of about 100 hours
- Prolonged curing time
- Loss in power of the bulb can cause improper polymerization unless the power is periodically checked by a radiometer

- Heat may cause damage to the filters exposing the patient and doctor to unwanted wavelengths of light (104)

Attempts have been made to enhance the speed of the light curing process by increasing the intensity output or by using turbo tips that focus the light into a smaller area by reducing the curing time to half (181).

4.5.2 Plasma arc curing sources

Plasma arc curing (PAC) sources contain xenon plasma lamps. The light is emitted from glowing plasma, which is composed of a gaseous mixture of ionized molecules and electrons. The lamp filled with high-pressure xenon gas emits high-intensity light by an electric discharge. They are characterized by a very high output in a narrow range of wavelengths around 470 nm (127). The peak energy level is 900mW for plasma arc while it is around 300mW for conventional halogen light. Their claim is that the higher the light intensity, the higher penetration depth is achieved in a short time by these systems (88). However, this raises the question of whether the high irradiance delivered in short time would lead to an adequate polymerization. Another issue of concern is the rate of polymerization. Curing by PAC sources occurs very fast and there is the risk of high polymerization shrinkage. Plasma arc lights are too expensive. The wavelengths filtered are between 400-500nm like in QTH lights transferring too much heat to the tooth which might harm the pulp tissue.

4.5.3 Laser sources

Laser sources produce light at a few distinct frequencies within the desired region around 480 nm, thus completely eliminating the need for filtering undesired wavelengths (38). Introduced in the late 1980s and early 1990s, argon lasers promised to dramatically reduce the curing time for dental composite resins. The argon laser produces a highly concentrated, coherent beam of light centered on the 480-nm

wavelength. This is the optimal wavelength for the photo activation of most of the dental resins on the market. The photo initiator system such as camphoroquinone is very sensitive to light in the blue region of the visible light spectrum, with the peak of activity centered around 480 nanometers (nm). The argon laser is monochromatic and emits light over a narrow band of wavelengths in the blue green spectrum (457.9 to 514.5 nm), making it ideally suited to polymerize composite resins.

Although conventional visible light curing units also emit energy centered on 480 nm, the energy is emitted over a much broader range. Accu-Cure-3000 is a commercially developed Laser-LCU (Light curing unit) whose output spectrum falls entirely within the absorption spectrum of CQ.

A study by Blankenau has shown that the AccuCure-3000 produced post cure physical characteristics that are much improved over those attained by an Argon-Ion laser and QTH light sources (22). Recommendations of as few as 3 seconds of laser light exposure to the adhesive beneath brackets have been made. This is a dramatic reduction in the required exposure time, from 15 minutes to only 4. Nevertheless, lasers are not widely used in orthodontics because of high cost, poor portability. Care should be taken when using Lasers because of risk of damaging the tissues and eyes (38). In addition, in some jurisdictions in which lasers are considered to be instruments for cutting or removing hard or soft tissues, their use is limited to licensed dentists only (89).

4.5.4 Light-Emitting-Diode sources (LED)

Light-emitting-diode sources are semi-conductor devices of an n–p type, constructed from two layers of semi-conducting materials, one doped with electrons (n-doped), the other doped with “holes” (p-type). The ends of the crystals are cleaved and polished to give a laser resonant cavity (the ends rarely necessitate reflective coatings).When a small voltage is applied to the terminal; electrons are injected from the n-region into the p-region (and the holes from p- to n-region). The holes and electrons rejoin emitting photons of identical wavelengths to cure the composite resins (102, 178).

This recombinant radiation forms the basis for the LED and explains the narrow bandwidth of the light emitted (12). The wavelength of the emitted light is not only dependent on the crystal structure – in the case of the blue diode it is gallium nitride (GaN) – but also on the length and refractive index of the semi-conductor crystal (154). GaN LEDs were first proposed for activation of dental light-cured composites by Mills (103) in a letter to the editor of the "British Dental Journal".

Individual LEDs have a relatively low light irradiance output compared with a QTH bulb; therefore, multiple diodes are often arranged into an array, the combined output of which, when appropriately channeled through a light guide, can approach that of QTH values (74). LEDs have a lifetime of more than 10.000 hours and undergo little degradation of output over this time. It requires no filters to produce blue light, resist shock and vibration and need little power to operate. LEDs are the most efficient device to convert %10 of the electric energy to proper wavelength (102). Most LEDs cannot cure materials using PPD initiators because of their narrow wavelength.

4.6 Factors Affecting In-Vitro Bond Strength

4.6.1 Difference among teeth

Older permanent human teeth tend to produce slightly higher bond strength than younger permanent teeth (142).When deciduous bovine, permanent bovine and human enamel were compared it was found that the bond strength to bovine enamel was 21% to 44% weaker than to human enamel, and the bond strength to deciduous bovine enamel was significantly greater than to permanent bovine enamel (110). Hobson *et al.* (69) and Mattick *et al.* (96) investigated the acid etch pattern and bond strength to etched enamel on different types of human teeth. They found that there were significant differences in the acid etch pattern achieved on different tooth types and that in the upper arch bond strength was greater on the anterior teeth than posterior teeth. Weatherell (174) suggested that the premolar teeth differed from the rest of the permanent dentition in the

quality of enamel present. There is a higher percentage of aprismatic enamel, which causes the bond strengths of brackets in the premolar region to be among of the lowest.

4.6.2 Effects of fluoride

Teeth with a higher concentration of fluoride are generally considered more resistant to acid etching than normal teeth resulting to reduction of up to 40% in bond strength so they may require an extended etching time to reach the bond strength required (24,130,142). Hirce et al (68) found that etching enamel for 4 minutes with 50% phosphoric acid containing 2% sodium fluoride significantly weakened the bond strength compared to etching teeth with 50% phosphoric acid alone for 1 minute. However, in other studies where pumice and fluoridated prophylaxis pastes (182) or fluoride solutions were used following acid etching (19), shear bond strength was not significantly affected. The conflicting findings may be the result of a number of factors, including variation in the fluoride concentrations used by different researchers and improvements in the properties of the bonding agents and / or the bracket- retention mechanism.

4.6.3 Casein

A milk protein derivative, casein phosphopeptide– amorphous calcium phosphate (CPP-ACP) complex, has been introduced for caries prevention and enamel remineralization The proposed mechanism of action of CPP-ACP is related to its localization at the tooth surface, where it buffers free calcium and phosphate ion activities, maintaining a state of supersaturation with respect to tooth enamel, thereby preventing demineralization and facilitating remineralization. Studies have shown that use of CPP-ACP as a prophylactic agent in orthodontics does not compromise the

bracket bond and can give higher bond strengths than in cases when no pre treatment is performed (80).

4.6.4 Acid etching

Several studies have been published on the effect of acid etching on SBS (23, 24, 48, 76, 99, 106, 122, 129, 133, 142, and 163). Some factors that influence acid etching of enamel for orthodontic bonding include the type and concentration of the acid and the duration of etching. The highest bond strengths are achieved with the use of 10 percent or 37 percent phosphoric acid etching and a bonding agent (28 MPa). The use of 10 percent maleic acid for etching results in lower bond strength (18 MPa). No drastic differences are seen in the bond strengths between 15 seconds and 60 seconds etching with 37 percent phosphoric acid. If etching time is less than 10 seconds bond strength reduces significantly (129, 142).

4.6.5 Chlorhexidine

Bond strength is reduced if the chlorhexidine is applied on the etched enamel or the sealant before the adhesive is applied. But the bond strength is not affected if the chlorhexidine is applied after bonding has been completed or as a prophylactic paste on enamel before etching (24,142).

4.6.6 Bleaching

Bond strength of resin composite to carbamide-peroxide-bleached teeth treated with fifth-generation bonding agents is reduced, although this reduction apparently can be reversed using sodium ascorbate. Bleaching produces oxygen, which inhibits free radical polymerization of resin composites (24,142).

4.6.7 Air thinning

Air thinning can reduce the bond strength of a sixth-generation bonding agent (self-etching bonding agent) to enamel (141).

4.6.8 Air abrasion

Air abrasion, also referred to as micro-etching, is a technique in which particles of aluminum oxide are propelled against the surface of enamel or other substrate by high air pressure, causing abrasion of the surface. Some manufacturers of commercial units have suggested that air abrasion could eliminate acid etching; however, bond strengths to air-abraded enamel are only approximately 50% of those to acid-etched enamel for resin composites (134) and hybrid ionomers (13).

4.6.9 Acidic primers and adhesives

An alternative to etching enamel with phosphoric acid is to use self-etching bonding agents, often referred to as sixth- or seventh-generation bonding agents. The sixth-generation bonding agents include the self-etching primer and adhesive (apply primer, then apply adhesive) and the self-etching adhesive (mix components), By reducing the number of steps during bonding orthodontic brackets to the teeth, clinicians are able to save time as well as reduce the potential for error and contamination during the bonding procedure. Although these primers are expensive, comparable bond strengths to those obtained when enamel was conditioned with either phosophoric or maleic acids are found (142). Many of the tested self-etching primer and adhesive systems produced bond strength values much lower than conventional system. Clinically, these products might not be suitable for orthodontic bracket bonding in terms of the shear bond strength achieved after thermal cycling and water storage (36). A one-step adhesive system has the potential to be successfully used in bonding orthodontic brackets if its shear bond strength can be increased (15).

4.6.10 Laser etching

The application of laser energy to enamel surface causes localized melting and ablation. Etching results mainly from the micro-explosion of entrapped water in enamel and there may also be some melting of the hydroxyapatite crystals. Laser etching produces lower bond strengths than acid etching and is more expensive (142).

4.7 Studies Comparing Shear Bond Strengths (SBS) of Brackets Bonded with Different Light Sources

Dunn et al (46) in 2002 compared the SBS of orthodontic brackets bonded to teeth with conventional halogen-based light-curing units and commercially available LED curing units. Two LED light-curing units (LumaCure, LumaLite, Spring Valley, Calif. and VersaLux, Centrix, Shelton, Conn.) and 2 halogen-based light-curing units (Optilux 501, Demetron, Danbury, Conn. and ProLite, Dentsply) were tested. One hundred standard metal orthodontic brackets were bonded to extracted human third molars with a light-cured adhesive system. The specimens were divided into 4 groups with 25 teeth in each. All brackets were cured for 40 seconds with a different light-curing unit. The specimens were stored in water at 37°C for 24 hours and then tested for SBS with an Instron universal testing machine at a crosshead speed of 1 mm/min until the brackets were debonded. One-way analysis of variance detected no differences in bond strength between the 4 groups. Chi-square analysis detected no difference in the adhesive remnant index scores of the 4 groups. The LED light-curing units bonded brackets to etched tooth enamel as well as the halogen-based light-curing units and no difference was found between the two.

Wendl et al (177) in 2004 compared the SBS of a light-cured resin Enlight (Ormco Corp.) and of a light-cured glass ionomer cement GIC (Fuji Ortho LC) using various polymerization lamps (halogen, high performance halogen, xenon, and diode) for the direct bonding of brackets. The polymerization lamps used in the study were a normal halogen light (Optilux 401, Kerr Corp, Orange ,USA), a high performance halogen light (Optilux 501, Kerr Corp, Orange, USA), plasma (Apollo 95 E, DMD, USA) and LED (GCE Light, GC Europe, Belgium). The samples were divided in 2 groups. The first group of samples was tested 1 hour and the second 24 hours after polymerization. The self-curing resin Concise (3M Unitek) was used as the control. All polymerization lamps achieved the minimum bond strength of 5–8 MPa. With Enlight LV, bond strength was dependent on curing time .The halogen lamp achieved the highest bond strength of 10.0 MPa, $P < 0.001$, with a curing time of 40 seconds. The other lamps showed similar results. Fuji Ortho LC, on the other hand, was independent of the duration of light curing and the type of lamp used. The bond strengths of the resin-modified glass ionomer cement (RMGIC) were similar to or somewhat higher than those achieved with light-cured composite resin when lamps with short polymerization times were used, but were significantly lower when compared with the self curing composite adhesive. After 24 hours, the bond strengths of all adhesives showed a significant increase: Enlight 19 per cent, Fuji Ortho LC 6.6 per cent, Concise 16 per cent. Bond failure occurred for Enlight at the bracket–composite resin adhesive interface in 90 per cent and with Concise in 57 per cent. However, Fuji Ortho LC showed far more cohesive and mixed failures, indicating an improved bond between bracket and cement.

Üşümez et al (168) in 2004 evaluated the effect of light-emitting diode (LED) light curing on the SBS of orthodontic brackets bonded to teeth. Light exposure of 40 seconds from a conventional halogen-based light-curing unit was used as a control. Eighty human premolars were divided into four groups of 20 each. Brackets were bonded to acid-etched teeth with Transbond XT light-cured adhesive. In the first group, the adhesive was light cured for 40 seconds with a conventional halogen unit (XL3000, 3M). In the other three groups, adhesive was cured with a commercial LED unit (Elipar

FreeLight, 3M ESPE) for 10, 20, or 40 seconds. SBS was measured on a universal testing machine and recorded in megapascals. Adhesive remnant index (ARI) scores were determined after failure of brackets. Data were analyzed using analysis of variance and chi-square tests. No statistically significant differences were found among the SBS values of halogen-based light-cured and 20- and 40-second LED-cured specimens. However, 10 seconds of LED curing yielded significantly lower SBS. No statistically significant differences were found between the ARI scores among groups.

Ip et al (71) in 2004 compared the effectiveness of three curing lights of different types. Adhesive pre-coated orthodontic brackets were bonded to135 extracted premolars stored in distilled water which were divided in 9 groups and the adhesive (Prime and Bond TM resin) was cured using three different curing lights (Apollo 95E plasma light, DMDS, UK; Optilux 501 high intensity halogen light, Kerr, UK; XL 3000 halogen light 3M Unitek, UK), each at three different times. The curing times recommended by the manufacturers were 2 seconds for the plasma light, 10 seconds for the high intensity quartz halogen light and 20 seconds for the standard one. Bond strength was tested using a shear/peel method. Analysis of variance using the General Linear Model program in Minitab Version 13.1 suggested that the effect of both light type and curing time on debond stress was statistically significant. Further analysis of the differences between the light sources without the curing time variable revealed that there were no differences between the debond stresses with respect to the three lights, although curing time was a significant variable. The interactions between the 3 light units and curing time were not significant according to ANOVA .Mean debond stresses with these cure times were 9.36 MPa for plasma, 11.77 MPa for QHL and 12.00 MPa for the standard light. Increasing the plasma light cure to 4 seconds increased the mean debond stress to 11.19 MPa, similar to that for the other lights. As a result the use of plasma light confers worthwhile time savings when bonding orthodontic brackets, producing bonds of equivalent strength to those found with quartz halogen lights.

Staudt et al (157) in 2005 investigated the minimum time necessary to bond brackets with a new, relatively low-priced, high-power halogen light. Five groups of 15

deciduous bovine incisors were bonded with stainless steel brackets (Mini Diamond Twin, Ormco, Orange, Calif) by using different lamps and curing times. Three of the groups were bonded by using a high-power halogen light (Swiss Master Light, Electro Medical Systems, Nyon, Switzerland) for 2, 3, and 6 seconds, respectively. The fourth group, bonded with a fast halogen light (Optilux 501, Sybron Dental Specialties, Danbury, Conn) for 40 seconds, served as the positive control group. The fifth group, the comparison group, was bonded with plasma light (Remecure, Remedent, Deurle, Belgium) for 4 seconds. After storage for 24 hours in the dark at 37°C in water, shear bond strength was measured with a universal testing machine. For the statistical evaluation, SPSS software (version 11.5, SPSS, Chicago, Ill) was used. The level of significance was set at *P* 0.05. Because the distribution of the shear bond strength values was normal, parametric tests were applied. The mean, standard deviation, and 95% confidence interval of the mean were estimated for each group. Comparisons of shear bond strength between lights and curing times were performed by analysis of variance (ANOVA). If a statistically significant difference was found, the post-hoc Tukey test was used to identify which groups were different. Additionally, the groups were classified into Tukey homogeneous subsets. The Weibull survival analysis was also applied to compare the performance of each sample by calculating survival probability at given values of shear stress. The nonparametric Kruskal-Wallis test was used to test for significant differences between groups regarding the ARI. A curing time of 2 seconds with the high-power halogen light negatively affected the bond strength and the probability of bond survival. It was also reported that an exposure time of 3 sec should be used with caution because the 3 sec group was not significantly different from the 2 sec group, therefore, 6 sec is recommended. The adhesive remnant index scores were not significantly different among the groups. Most failures, about 60%, occurred at the bracket base/adhesive interface. The high-power halogen light seems to be a cost-effective solution to reducing curing time. The recommended curing times to bond stainless steel brackets are 6 seconds and, with caution, even 3 seconds.

Cacciafesta et al (34) in 2005 evaluated the effect of light-tip distance on the shear bond strength and failure site of brackets cured with three different light curing

units: a high-intensity halogen (Astralis 10, Ivoclar-Vivadent, Schaan, Liechtenstein), 10-second curing, a light-emitting diode (LED, e-Light, GC Europe, Leuven, Belgium), six-second curing, and a plasma arc (PAC System, (PAC System, American Dental Technologies, Corpus Christi, Tex). four-second curing. One hundred and thirty-five bovine permanent mandibular incisors were randomly allocated to nine groups of 15 specimens each. Stainless steel brackets were bonded with a composite resin to the teeth, and each curing light was tested at zero, three, and six mm from the bracket. After bonding, all samples were stored in distilled water at room temperature for 24 hours and subsequently tested for shear bond strength. When the three light curing units were compared at a light-tip distance of zero mm, the three lights showed no significantly different shear bond strengths. At light-tip distances of three and six mm, no significant differences were found between the halogen and plasma arc lights, but both lights showed significantly higher shear bond strengths than the LED light. When evaluating the effect of the light-tip distance on each light curing unit, the halogen light showed no significant differences between the three distances. However, the LED light produced significantly lower shear bond strengths at a greater light-tip distance, and the plasma arc lamp showed significantly higher shear bond strengths at a greater light-tip distance. In hard-to-reach areas, the use of PAC system is suggested, whereas the LED evaluated in this study is not recommended.

Swanson et al (159) in 2005 evaluated the relationship between the shear bond strength of orthodontic brackets bonded to enamel and the duration of photo polymerization with LEDs and conventional quartz-tungsten-halogen light-curing units. Three LED light-curing units (GC e-light, GC America, Alsip, Ill; Elipar FreeLight, 3M ESPE Dental Products, St Paul, Minn; and UltraLume LED 2, Ultradent Products, South Jordan, Utah) and 1 halogen-based light-curing unit (Ortholux XT, 3M Unitek, Monrovia, Calif) were evaluated. Two hundred forty metal orthodontic brackets were bonded to extracted molars. Specimens were divided into 12 groups of 20 teeth each. Each group was cured with a different light-curing unit for 40, 20, or 10 seconds. The specimens were stored in water at 37 °C for 24 hours and then subjected to a shear force with a universal testing machine until bracket failure. Two-way ANOVA detected

significantly weaker mean shear bond strength with the GC e-light at 10 and 40 seconds (P<.001) and higher mean shear bond strength for the UltraLume LED 2 at 40 seconds (P<.001). All experimental groups had laboratory mean shear bond strengths greater than 8 MPa, even with a 10-second cure.

Thind et al (162) in 2005 investigated whether there were differences between the debond stress and adhesive remnant index (ARI) of an adhesive cured with three different orthodontic light sources. Sixty sound premolar teeth were divided into three groups of 20. A standard pre-adjusted edgewise premolar bracket (Victory Series ™) was bonded to each tooth using a light-cured orthodontic adhesive, Transbond XT ™. Group 1 (control) specimens were cured with an Ortholux XT ™ (tungsten-quartz-halogen bulb) light for 20 seconds, group 2 with an Ortho lite ™ (plasma arc) for 6 seconds and group 3 with an Ortholux LED ™ light-emitting diode for 10 seconds. The specimens were debonded 24 hours later using a universal mechanical testing machine, operating at a crosshead speed of 0.5mm per minute. The Weibull modulus and a Logrank test showed no statistically significant differences between the three groups for debond stress. The ARI was assessed at ×10 magnification. The ARI scores for group 2 were significantly different from those of groups 1 and 3 (between which there was no significant difference). For group 2 there was a greater tendency for failure to occur at the adhesive/tooth interface than for the other two groups. There appears to be no reason why any of the three types of light sources cannot be used in orthodontics. Polymerization, as effective as that produced by conventional bulb light sources, was obtained with the short exposure times recommended for the plasma arc or light-emitting diode sources.

Silta et al (144) in 2005 evaluated the ability of the latest generation of QTH and LED light-curing units (LCUs) to bond orthodontic brackets to teeth at decreased polymerization times. Two LED light curing units (Ortholux LED, 3M Unitek, Monrovia, Calif; UltraLume LED 5, Ultradent Products, South Jordan, Utah) and a QTH LCU (Optilux 501, Demetron, Danbury, Conn) were evaluated. One hundred eighty metal orthodontic brackets were bonded to extracted human molars. The specimens were

divided into 9 groups (3 lights and 3 curing times) of 20 teeth each. Each group was cured with 1 of the 3 lights for 20, 10, or 6 seconds. Thirty minutes after polymerization, the specimens were subjected to shear force on a universal testing machine until bracket failure. They found out that brackets bonded by all light types had lower bond strengths with the 6-second cure than the 20-second cure. The highest bond strengths were obtained with the Optilux 501 QTH and the UltraLume LED 5 at the longest cure time of 20 seconds. It is recommended that orthodontic brackets be photo polymerized for at least 20 seconds with the QTH or the LED LCU before the arch wires are engaged.

Signorelli et al (143) in 2006 evaluated the in-vitro shear bond strength and in-vivo survival rate of orthodontic brackets bonded with either a halogen or a plasma arc light. Ninety extracted premolars were divided into 6 groups of 15. Stainless steel brackets were bonded to the teeth by using either a halogen light with a 20-second curing time or a plasma arc light with a 2-, 6-, or 10-second curing time. Brackets were debonded either within 30 minutes of bonding or after thermocycling for 24 hours. No significant differences in bond strengths were found 30 minutes after bonding between the halogen light and the plasma arc light with 2, 6, or 10-second curing times. Similar bond strengths were also found between the halogen light with a 20-second curing time and plasma arc light with 6 seconds of curing time after 24 hours of thermocycling. For the in-vivo study, no significant difference was found in bracket failure rates between the 2 light sources (4.9% in both groups). No significant differences were found between ARI scores for the halogen light and the plasma arc light at either 30 minutes or 24 hours after debonding. These results indicate that the plasma arc light with a 6-second curing time can produce similar bond strength and bracket-failure rates as the halogen light that requires a longer curing time.

Owens et al (117) in 2007 they evaluated the quality of irradiance, in terms of power density (intensity) and spectral distribution (peak wavelength), emitted from LED and quartz-tungsten halogen (QTH) light curing units in vitro. The battery expenditure of these LED units was also tested. The intensity and spectral distribution from four third generation LED (Smartlite PS, Coltolux LED, radii Plus, Diopower) and one QTH

(Schein Visible Cure) light sources were measured using six different dental curing light meters (Coltolux, Cure Right, Demetron 100, Demetron LED., Hilux, and Light Meter-200) and a visible-ultraviolet light spectrophotometer (Hitachi Elmer-Perkins). The battery life was also plotted for each light source following a 1500 second duration period. The data obtained from radiometric and spectro-photometric analysis was compared to manufacturer specifications. Radiometric evaluation revealed LED light units tested did not satisfy manufacturer claims for minimum intensities. Spectral emissions from the LED light sources did meet manufacturer requirements. No clinically appreciable battery drain was evidenced from testing all re-chargeable LED units. Despite limitations LED technology appears to be an effective alternative for curing of light activated esthetic restorative materials. Additional advantages associated with LED curing lights include ergonomic handling capabilities, negative heat generation, and minimal maintenance concerns.

Rego et al (132) in 2007 compared the shear bond strength of orthodontic metallic brackets photo-activated with two different light-curing sources at different exposure times: halogen light (XL 1500, 3M ESPE) and LED light (Ortholux, 3M Unitek). Sixty bovine permanent lower incisors were inserted into PVC tubes containing plaster. The buccal surfaces were cleaned with pumice and water, and then etched with 37% phosphoric acid gel. The XT Primer bonding agent (3M Unitek) was applied to the enamel surfaces and the metallic pre-coated brackets (Transbond APC II system, 3M Unitek) were attached to upper central incisors. The teeth were randomly divided into four groups (n=15). In Group I (Control), halogen light was used for 40 seconds, while in Groups II, III, and IV were light-cured with LED light unit for 40, 10, and 5 seconds, respectively. The teeth were stored in distilled water at 37 degrees C for 24 hours. The brackets were submitted to shear bond strength test in universal testing machine (Instron) at a crosshead speed of 0.5 mm/minute. Shear bond strength means (MPa) were 4.87 for Group I; 5.89 for Group II; 4.83 for Group III, and 4.39 for Group IV. Tukey's test detected no statistically significant differences among the groups regarding the shear bond strength ($p>0.05$). Neither of the types of light-curing sources or exposure times influenced the shear bond strength of metallic brackets.

Erhardt et al (50) in 2008 sought to evaluate the long-term bond strength of etch-and-rinse and self-etch adhesive systems to dentin after one year of water storage. Crown fragments from the buccal surface of extracted bovine incisors were ground flat to expose dentin surfaces. Four etch-and-rinse and two self-etch bonding agents were used according to manufacturers' instructions. Bonded specimens were stored in water for either 24 hours or one year at 37 delete C. After elapsed storage times, specimens were tested for shear bond strength (SBS) at 0.5 mm/min. Data were analyzed by ANOVA and Tukey's tests ($p < 0.05$). Both evaluated factors (adhesive system and storage time) and their interactions were statistically significant. Single Bond produced the highest SBS regardless of the water degradation period. One-year water storage reduced the SBS of Prime & Bond NT and One-Up Bond F significantly; the other adhesives performed similarly. Long-term bond strengths of etch-and-rinse and self-etch adhesive systems are susceptible to hygroscopic and hydrolytic effects to varying extents, depending on their chemistry and structure. The presence of monomers with different properties might induce preferential degradation of specific adhesive polymer systems.

Penido et al (124) in 2009 evaluated the shear bond strength in vivo and in vitro of metallic brackets bonded to human teeth with light-curing bonding materials, using two types of light-curing units. Sixty human premolars were divided into six groups. In the GI and GII groups, the brackets were directly bonded to volunteers' maxillary and mandibular second premolars on the right and left sides, respectively, of their mouths. In the other groups, the brackets were bonded to extracted first premolars. The polymerization was performed in GI, GIII, and GV with an LED (light-emitting diode) device, while in GII, GIV, and GVI, a halogen light was used. In GI and GII, shear strength tests were conducted using a portable digital dynamometer placed directly in the patients' mouths. The teeth from GIII, GIV, GV, and GVI were stored in distilled water at 37 degrees C for 24 hours. Afterward, they were thermocycled between 5 degrees and 55 degrees C. Then, in GIII and GIV, a Universal Testing Machine was used; in GV and GVI, mechanical tests were performed with a digital dynamometer. The

bracket/adhesive failure modes were evaluated with the Adhesive Remnant Index (ARI). RESULTS: The average values of the shear strengths in MPa were: GI = 3.65; GII = 4.39; GIII = 6.45; GIV = 7.11; GV = 4.67; and GVI = 4.21. The type of light-curing unit did not interfere with the results of the mechanical tests in vivo or in vitro. The tests performed with a portable digital device obtained average values that were significantly lower than those performed with the Universal Testing Machine.

5. MATERIAL AND METHOD

5.1 Bond Strength Testing Materials

5.1.1 Teeth

240 extracted human premolar teeth were collected and stored in distilled water at room temperature. The water was changed weekly, to prevent the growth of bacteria and fungi. The criteria for tooth selection included;

1. Intact buccal enamel with no cracks caused by the pressure of the extraction forceps
2. No caries or gross irregularities of the enamel structure
3. Buccal enamel surfaces which had not been treated with hydrogen peroxide (H2O2), formalin, alcohol, or other chemical agents after extraction.

5.1.2 Brackets

All brackets used for the test and control groups were foil-mesh-based stainless steel (upper premolar) Gemini MBT brackets (3M /Unitek, USA). The bracket dimension was measured with a digital caliper to be 3.45 mm in wide and 3 mm in height. The area was calculated and converted to a metric surface area of 10.35 mm square for stress calculation in megapascals (MPa). (Picture 5.1)

5.1.3 Adhesives

A no-mix composite resin made for the bonding of orthodontic bracket (Transbond XT, 3M Unitek) was used for the test. The adhesives were applied to the enamel surface according to the manufacturer's instructions. (Picture 5.1)

Transbond XT composite resin: 3M Unitek company, no-mix light activated composite, contains 14% Bis GMA, %9 Bis EMA and %77 quartz and sub –micron silica particles (45)

Transbond XT Primer: 3M Unitek company, light activated and containing % 45-55 Bis EMA,%45-%55 Triethylen-GMA (107)

5.1.4 Light-curing units

Light curing units used in this study were:

Normal Halogen (Hilux, Benlioğlu, Istanbul, Turkey) (Figure 5.3)

LED (Bluephase, Ivoclar Vivadent) (Figure 5.5)

High Power Halogen (Swismaster Light, no M 00042, Electromedical systems, SA, Nyon, Switzerland) (Figure 5.4)

Technical characteristics of the light curing units investigated in this study were summarized in Table 5.1

Table 5.1 Technical characteristics of the light curing units

Curing Units	Type	Light intensity (mW/cm2)	Wavelength (nm)	Curing Time (sec)
Hilux	Conventional Low power Halogen	800	400-500	40
Swissmaster	High power Halogen	3000	390-530	2, 3, 6
Blue Phase	LED	1200∓10%	380-515	10, 20

5.1.5 Bond strength testing

In this study, shear bond strength tests were carried out using a Universal Testing machine in the Faculty of Technical Education in Marmara University (Picture 5.8). To create accurate shear –type forces, the samples were placed centered on the direction of the force applied. The machine was activated with a crosshead speed of 1 mm\minute until failure was noticed. The peak force levels, automatically recorded on the testing machine, were converted to stress per unit area (MPa) by dividing the force (N) by the mean unit area of the base of the brackets (Z).

5.1.6 Examination of failure area

After bracket failure, the enamel surface was examined under a light microscope at x50 magnification(Picture 5.18), and the amount of adhesive remaining on the tooth was recorded with the use of the adhesive remnant index (ARI).The ARI score in our

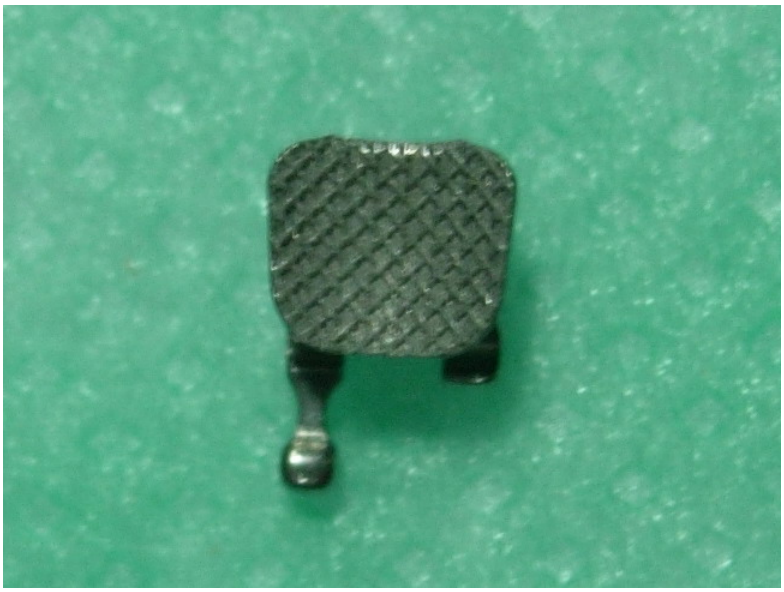
study is the same as the one used by Artun and Bergland (9). The criteria for scoring are as follows: 0, no adhesive on the tooth (Picture 5.17); 1, less than half of the adhesive on the tooth (Picture 5.16); 2, more than half of the adhesive on the tooth (Picture 5.15); and 3, all of the adhesive on the tooth (Picture 5.14).

5.1.7 Radiometer

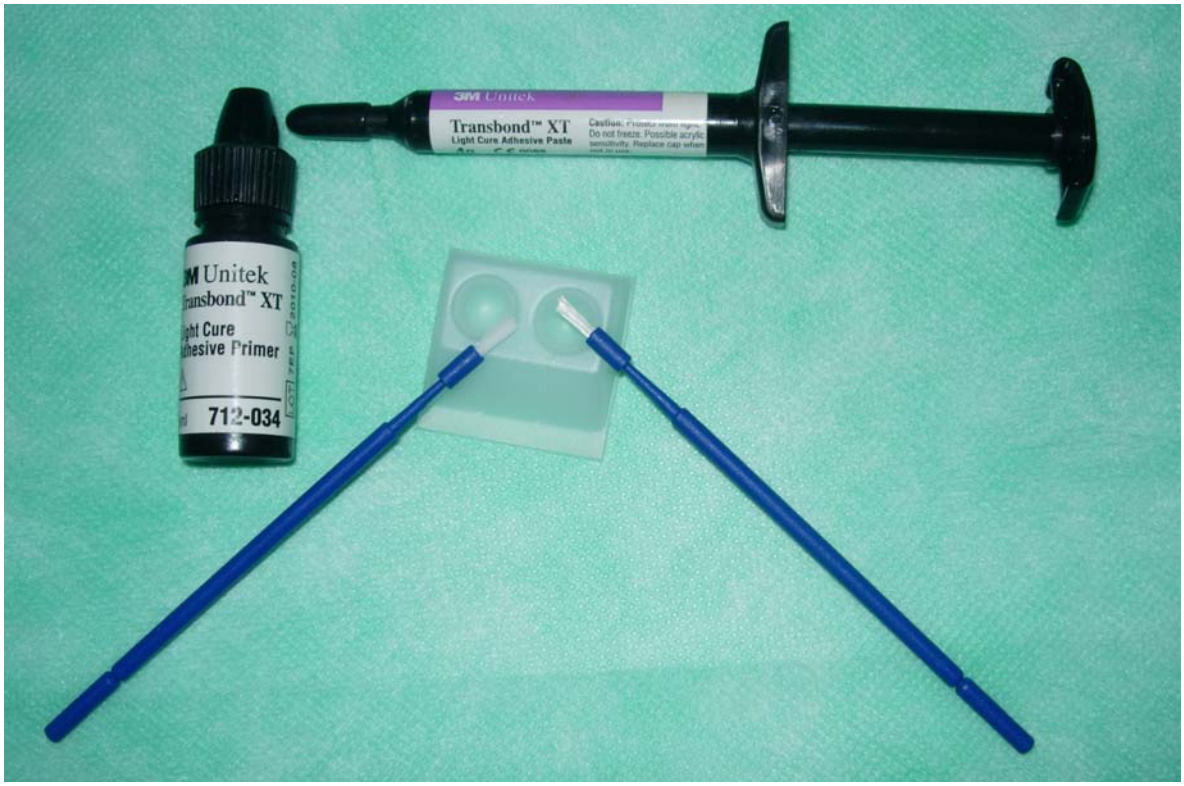
The light intensity of the light sources was measured with a digital radiometer (Benlioglu, Turkey) (Picture 5.6). The EMS device was measured with its own radiometer which is mounted on the device.

5.1.8 Thermo-cycling

Intraoral temperatures have been recorded as low as 0°C and as high as 67°C. Thermo cycling is believed to simulate oral conditions in vitro (142). While simulating the introduction of hot and cold extremes in the oral cavity it also shows the relationship of the linear coefficient of thermal expansion between tooth and restorative material (49). Half of the samples cured with the 3 light systems at different periods were thermocycled using a thermo-cycling apparatus (Marmara University, Faculty of Dentistry, Department of Restorative Dentistry) in water baths held at 5°C and 55°C with a dwell time of 30 seconds and a transfer time between dwells of 4 seconds (7, 80) for 7.500 cycles to stimulate accelerated aging by thermally induced stresses (Picture 5.7).

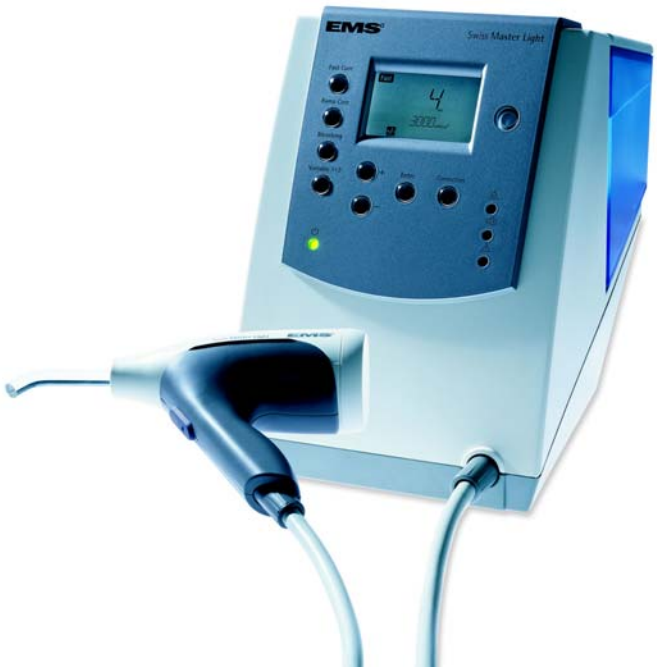


Picture 5.1 Gemini MBT Bracket



Picture 5.2 Transbond XT

Picture 5.3 Normal halogen light source



Picture 5.4 Swissmaster high power halogen light source

Picture 5.5 Blue phase light source

Picture 5.6 Radiomete

Picture 5.7 Thermocycling device

5.2 Bond Strength Testing Method

5.2.1 Preparation of the teeth

The extracted teeth were cleansed of soft tissue and then polished with no fluoridated pumice and rubber prophylactic cups at low speed for 10 seconds and immersed in distilled water in a sealed container for one to three months until testing. The water was changed weekly, to prevent the growth of bacteria and fungi. Before the bonding procedure, the labial surface of each tooth was polished for 1 minute with a combination of a polishing agent and a brush at a low speed (3000 rpm) using a micro-motor. The teeth have been distributed into 6 experimental groups, each containing 20 teeth.

5.2.2 Bonding of the brackets

A 37 % orthophosphoric acid gel was used for the acid etching of the teeth for 30 seconds. The teeth were then rinsed with water for 30 seconds and dried with oil-free air for 10 seconds, followed by application of the primer and of the composite applied to the bracket base (stainless steel Gemini MBT brackets, 3M /Unitek, USA).The bracket was firmly placed on the flattest area of the crown with respect to the occluso- gingival distance. Excess composite was carefully removed using a probe. Light curing was performed as follows. The control group was cured with a conventional low power halogen curing light for 40 seconds. The other groups were cured for 2, 3, 6 seconds respectively with a high–power halogen light (Swiss Master Light) and with 3rd generation Led light for 10, 20 seconds respectively .The distance of the light guiding tip was held standard for all specimen and the direction was 90 degrees to the bracket to have the same angle on each case. For each device half of the curing time was used mesially and half distally.

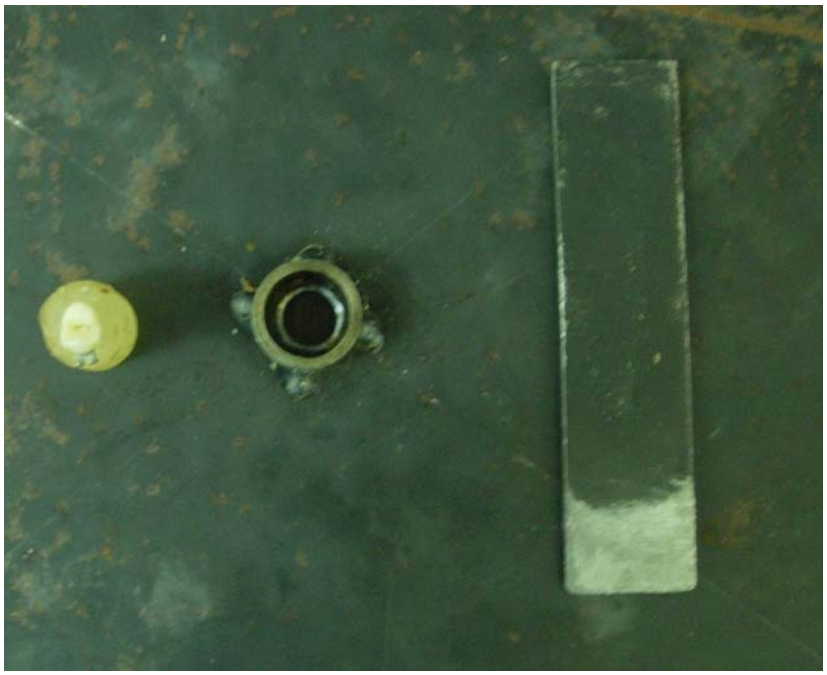
5.2.3 Preparation of the acrylic blocks

After bonding the brackets to the teeth the metal paralleling device was used to position the tooth in the acrylic so that the base of the bracket is parallel to the shear force vector. The teeth were mounted in a 2 cm diameter circle mould using chemically cured acrylic (Panacryl) using the special constructed device (Picture 5.10, Picture 5.11). The device is made so that the metal arm is 90 to the basement. The tip of the metal arm gets through the bracket slot putting the bracket and tooth in a parallel position to the shear vector applied by the Zwick/Z010 universal testing machine (Picture 5.8) so the force on the bracket top is applied at 90 degrees(Picture 5.9- 5.12-5.13).

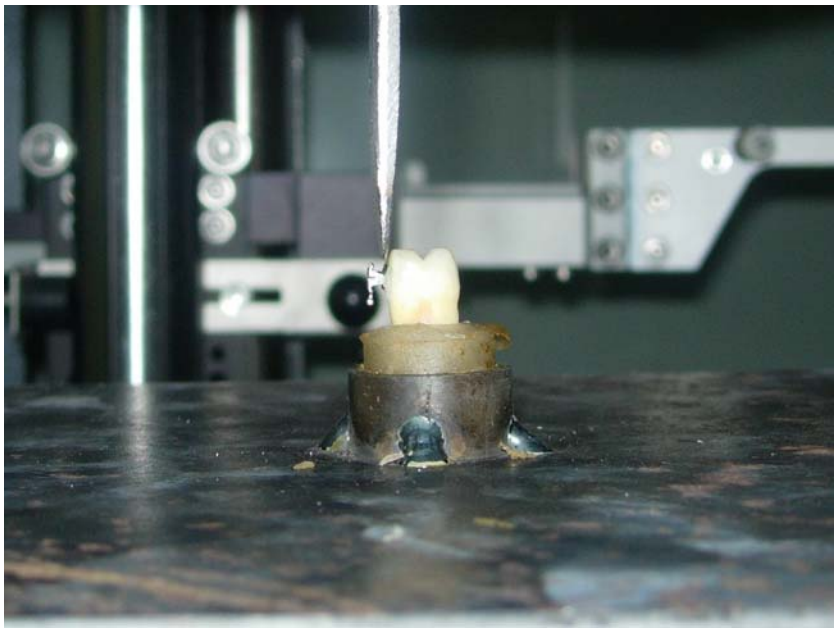
Picture 5.8 Zwick/Z010 universal testing machine

Picture 5.9 mounting the adaptor to the Universal testing machine

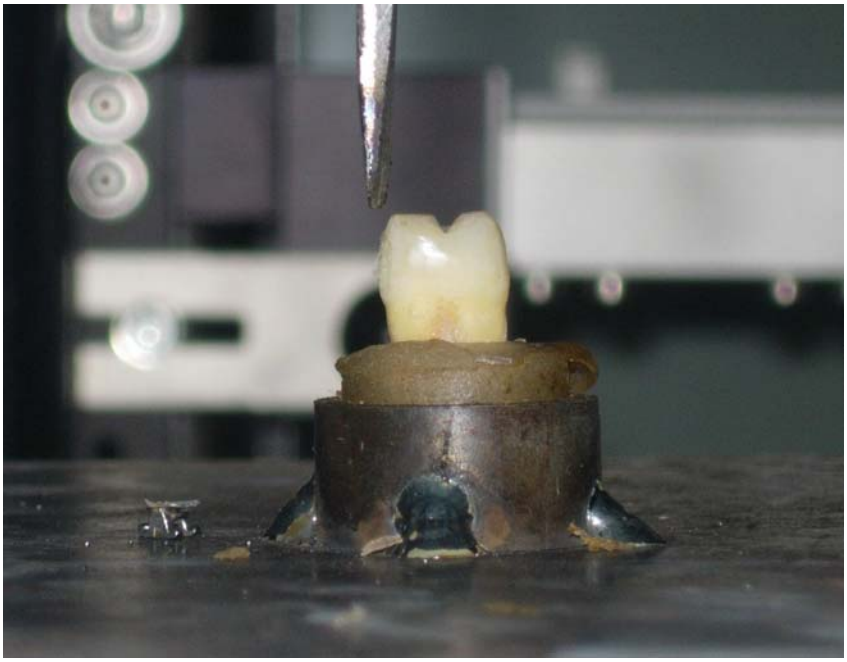
Picture 5.10 Special constructed parallel device



Picture 5.11 Transfer adaptor



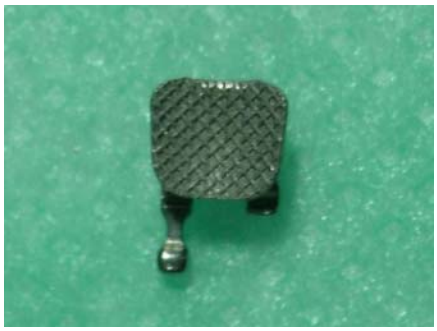
Picture 5.12 Sample testing



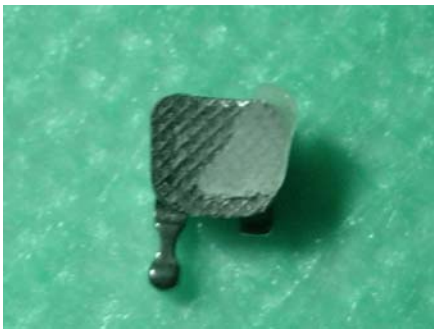
Picture 5.13 Bracket failure

5.2.4 Scoring of the samples after the test

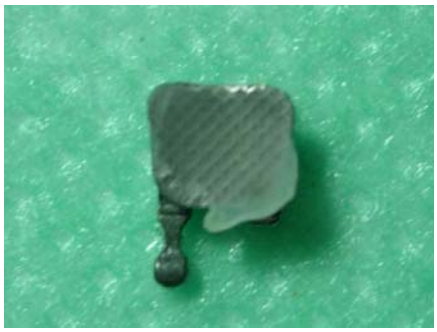
After bracket failure, the enamel surface was examined under a light microscope at 50 x magnification, and the amount of adhesive remaining on the tooth was recorded with the use of the adhesive remnant index (ARI). The criteria for scoring were as follows: 0, no adhesive on the tooth (Picture 5.17); 1, less than half of the adhesive on the tooth (Picture 5.16); 2, more than half of the adhesive on the tooth (Picture 5.15); and 3, all of the adhesive on the tooth. (Picture 7.14)



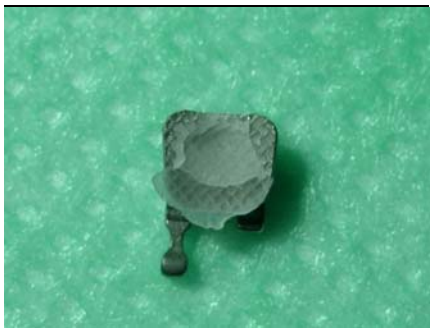
Picture 5.14 ARI Score 3



Picture 5.15 ARI Score 2



Picture 5.17 ARI Score 0



Picture 5.16 ARI Score 1

Picture 5.18 Light stereomicroscope

5.3 Thermocycling

Half of the samples from each of the 6 groups were thermocycled in water between 5° and 55° for 7500 cycles. During thermocycling, the dwelling time for the specimens in each well was 30 seconds, and the transfer time between the wells was 4 seconds. The specimens were stored at 37° in distilled water for 72 hours to provide baseline data for comperative purposes before shear bond testing. The purpose of the cycle time was to measure the effects on bond strength of accelerated aging by thermally induced stresses.

5.4 Statistical Analysis

NCSS 2007 packet program was used for the statistic analyzing of the data. The mean, standard deviation as well as the difference between the groups was compared with 1-way ANOVA. If a statistically significant difference was found, the Tukey multiple comparison test was used to identify which groups were different. To compare the groups in two the unpaired t-test and to compare the unequal values the chi-square test was used. The level of significance was set at P <0, 05.

6. RESULTS

6.1 Intragroup and Intergroup Comparisons of SBS values between Thermocyled and Non-Thermocycled Subgroups

Table 6.1.1 Unpaired t- test comparing the Non-thermocycled and Thermocycled subgroups values

	Non-thermocycled	**Thermocyled**	**t**	**P**
Hilux 40 sec (Group 1)	17,33±3,83	15,82±6,37	0,91	0,369
Blue phase 10 sec (Group 2)	14,48±4,76	12,35±2,79	1,73	0,093
Blue phase 20 sec (Group 3)	15,1±3,57	13,9±2,41	1,24	0,222
EMS 2 sec (Group 4)	11,1±2,75	8,19±5,46	2,13	**0,04**
EMS 3 sec (Group 5)	11,5±3,68	10,75±6,32	0,45	0,652
EMS 6 sec (Group 6)	15,74±2,81	15,72±3,53	0,02	0,984

The shear bond strength values of the groups that were thermocycled showed lower values than the groups that were not thermocycled However, the only group that showed statistically significant lower values was Group 4 (p= 0, 04). (Table 6.1.1)

Table 6.1.2 Unpaired t-test comparing SBS values with and without thermocycling, for Blue phase (LED) 10 seconds and 20 seconds

	Non-thermocycled	Thermocyled
Blue phase 10 sec (Group 2)	14,48±4,76	12,35±2,79
Blue phase 20sec (Group 3)	15,1±3,57	13,9±2,41
T	-0,46	-1,84
P	0,652	0,081

The shear bond strength(SBS) values for the samples in Group 2 showed lower SBS compared to Group 3 for both thermocycled and non-thermocycled subgroups, however, the differences were not statistically significant (non- thermocycled group, p=0,652; thermocycled group, p=0,0.081). (Table 6.1.2)

Table 6.1.3 One-way Anova comparing the SBS values with and without thermocycling for EMS at 2, 3, 6 seconds

	No thermocycle	Thermocyle
EMS 2 sec (Group 4)	11,1±2,75	8,19±5,46
EMS 3 sec (Group 5)	11,5±3,68	10,75±6,32
EMS 6 sec (Group 6)	15,74±2,81	15,72±3,53
F	13,81	14,21
P	**0,0001**	**0,0001**

The shear bond strength values for the samples in Groups 4, 5, and 6 showed statistically significant differences for both thermocycled and non-thermocycled subgroups (p=0, 0001) (Table 6.1.3).

Table 6.1.4 Tukey multiple comparison test among EMS groups

Tukey Multiple comparison test	Non-thermocycled	Thermocyled
EMS 2 sec / EMS 3 sec (Group 4)/ (Group 5)	0,714	0,079
EMS 2 sec / EMS 6 sec (Group 4)/ (Group 6)	**0,0001**	**0,0001**
EMS 3 sec / EMS 6 sec (Group 5)/ (Group 6)	**0,0001**	**0,005**

Group 6 showed significantly higher shear bond strength values compared to Group 4 and Group 5 (p=0.001), while SBS values were not significantly different between Group 4 and Group 5 (p=0,714) for both thermocycled and non-thermocycled subgroups. (Table 6.1.4)

6.2 Comparison of SBS Values between Non-Thermocycled Subgroups

Table 6.2.1 One-way Anova test was used to compare the SBS values of Group1, Group2 and Group4 non-thermocycled subgroups

	Hilux 40 sec (Group 1)	Blue phase 10 sec (Group 2)	EMS 2 sec (Group 4)	F	P
Non-thermocycled	17,33±3,83	14,48±4,76	11,1±2,75	13,2	**0,0001**

The SBS values for Group 1, Group 2 and Group 4 non-thermocycled subgroups showed statistically significant difference (p=0, 0001). (Table 6.2.1)

Table 6.2.2 Tukey multiple comparison test was used to compare SBS values among Groups 1, 2, and 4 non-thermocycled subgroups

Tukey Multiple Comparison test	Non-thermocycled
Group 1 /Group 2	0,059
Group 1 / Group 4	**0,0001**
Group 2/ Group 4	**0,021**

Group 4 non-thermocycled subgroup showed significantly lower SBS values than Group 1 (p=0, 0001) and Group 2 (p=0,021) non-thermocycled subgroups while no difference was found between Group 1 and Group 2 non-thermocycled subgroups (p=0,059). (Table 6.2.2)

Table 6.2.3 One-way Anova test was used to compare the SBS values among the non thermocycled subgroups of Groups 1, 2, and 5.

	Hilux 40 sec (Group 1)	**Blue phase 10 sec (Group 2)**	**EMS 3 sec (Group 5)**	**F**	**P**
Non-thermocycled	17,33±3,83	14,48±4,76	11,5±3,68	10,05	**0,0001**

The SBS values for the samples in Group 1, Group 2 and Group 5 non-thermocycled subgroups showed statistically significant difference (p=0,0001). (Table 6.2.3)

Table 6.2.4 Tukey multiple comparison test was used to detect which group/groups were responsible for the statistically significant difference among the non thermocycled subgroups for Groups 1, 2, and 5.

Tukey Multiple comparison test	**Non thermocycled**
Group 1 / Group 2	0,081
Group 1 / Group 5	**0,0001**
Group 2/ Group 5	0,065

Group 5 non-thermocycled subgroup showed significantly lower SBS values than Group 1 non-thermocycled subgroup (p=0,0001) while the SBS values of Group 5 non-thermocycled subgroup were not significantly different than SBS values of Group 2 non-thermocycled subgroup (p=0,065). (Table 6.2.4)

Table 6.2.5 One-way Anova test was used to compare the SBS values among the non thermocycled subgroups of Group 1, Group 2 and Group 6

	Hilux 40 sec (Group 1)	Blue phase 10 sec (Group 2)	EMS 6 sec (Group 6)	F	P
Non thermocycled	17,33±3,83	14,48±4,76	15,74±2,81	2,73	0,075

The SBS values among the non thermocycled subgroups of Group 1, Group 2 and Group 6 did not show any statistically significant differences (p=0,075). (Table 6.2.5)

Table 6.2.6 One-way Anova test was used to compare the SBS values among the non thermocycled subgroups of Group 1, Group 3 and Group 4

	Hilux 40 sec (Group 1)	Blue phase 20 sec (Group 3)	EMS 2 sec (Group 4)	F	P
Non-thermocycled	17,33±3,83	15,1±3,57	11,1±2,75	17,13	**0,0001**

The SBS values of the samples in non-thermocycled subgroups of Group 1, Group 3 and Group 4 showed statistically significant difference (p=0,0001). (Table 6.2.6)

Table 6.2.7 Tukey multiple comparison test was used to detect which group/groups were responsible for the statistically significant difference among the non thermocycled subgroups of Groups 1, 3, and 4.

Tukey Multiple Comparison Test	Non-thermocycled
Group 1 /Group 3	0,104
Group 1 / Group 4	**0,0001**
Group 3/ Group 4	**0,001**

Group 4 non-thermocycled subgroup showed significantly lower SBS values than Group 1 (p=0, 0001) and Group 3 (p=0,001) non-thermocycled subgroups while no statistically

significant difference was detected between Groups 1 and 3 non-thermocycled subgroups (p=0,104). (Table 6.2.7)

Table 6.2.8 One-way Anova test was used to compare the SBS values among the non thermocycled subgroups of Group 1, Group 3 and Group 5

	Hilux 40 sec (Group 1)	**Blue phase 20 sec (Group 3)**	**EMS 3 sec (Group 5)**	**F**	**P**
Non thermocycled	17,33±3,83	15,1±3,57	11,5±3,68	12,71	**0,0001**

The SBS values of the samples in non-thermocycled subgroups of Group1, Group3 and Group5 showed statistically significant difference (p=0, 0001). (Table 6.2.8)

Table 6.2.9 Tukey multiple comparison test was used to detect which group/groups were responsible for the statistically significant difference among the non thermocycled subgroups of Groups 1, 3, and 5

Tukey Multiple Comparison Test	**Non thermocycled**
Group 1 / Group 3	0,143
Group 1 / Group 5	**0,0001**
Group 3/ Group 5	**0,009**

Group 5 non-thermocycled subgroup showed significantly lower SBS values than Group 1 (p=0, 0001) and Group 3 non-thermocycled subgroups (p=0,009) while no statistically significant difference was detected between Group 1 and Group 3 non-thermocycled subgroups (p=0,143). (Table 6.2.9)

Table 6.2.10 One-way Anova test was used to compare the SBS values among the non thermocycled subgroups of Group 1, Group 3 and Group 6

	Hilux 40 sec (Group 1)	Blue phase 20 sec (Group 3)	EMS 6 sec (Group 6)	F	P
No thermocycle	17,33±3,83	15,1±3,57	15,74±2,81	2,25	0,114

The SBS values of the samples in non thermocyled subgroups of Group 1, Group 3 and Group 6 did not show any statistically significant differences (p=0,114). (Table 6.2.10)

6.3 Comparison of SBS Values between Thermocycled Subgroups

Table 6.3.1 One-way Anova test was used to compare the SBS values among the thermocycled subgroups of Group 1, Group 2 and Group 4

	Hilux 40 sec (Group 1)	Blue phase 10 sec (Group 2)	EMS 2 sec (Group 4)	F	p
Thermocyled	15,82±6,37	12,35±2,79	8,19±5,46	11,2	**0,0001**

The SBS values for the thermocycled samples in Group 1, Group 2 and Group 4 showed statistically significant difference (p=0, 0001). (Table 6.3.1)

Table 6.3.2 Tukey multiple comparison test was used to detect which group/groups were responsible for the statistically significant difference among the thermocycled subgroups of Groups 1, 2, and 4.

Tukey Multiple Comparison Test	Thermocyled
Group 1 / Group 2	0,089
Group 1 / Group 4	**0,0001**
Group 2/ Group 4	**0,021**

Group 4 thermocycled subgroup showed significantly lower SBS values than Group 1 (p=0,0001) and Group 2 (p=0,021) thermocycled subgroups while no difference was found among Group 1 and Group 2 thermocycled subgroups (p=0,089). (Table 6.3.2)

Table 6.3.3 One-way Anova test was used to compare the SBS values among the thermocycled subgroups of Group 1, Group 2 and Group 5

	Hilux 40 sec (Group 1)	**Blue phase 10 sec (Group 2)**	**EMS 3 sec (Group 5)**	**F**	**P**
Thermocyle	15,82±6,37	12,35±2,79	10,75±6,32	4,55	**0,015**

The SBS values for the thermocycled samples in Group 1, Group 2 and 5.Group showed statistically significant difference (p=0,015). (Table 6.3.3)

Table 6.3.4 Tukey multiple comparison test was used to detect which group/groups were responsible for the statistically significant difference among the thermocycled subgroups of Groups 1, 2, and 5.

Tukey Multiple Comparison Test	**Thermocyled**
Group 1 /Group 2	0,116
Group 1 / Group 5	**0,012**
Group 2/ Group 5	0,622

Group 5 thermocycled subgroup showed significantly lower values than Group 1 thermocycled subgroup (p=0,012) (Table 6.3.4)

Table 6.3.5 One-way Anova test was used to compare the SBS values among the thermocycled subgroups of Group 1, Group 2 and Group 6

	Hilux 40 sec (Group 1)	**Blue phase 10 sec (Group 2)**	**EMS 6 sec (Group 6)**	**F**	**P**
Thermocyled	15,82±6,37	12,35±2,79	15,72±3,53	3,84	**0,027**

The SBS values for the thermocycled samples in Group 1, Group 2 and Group 6 showed statistically significant difference (p=0,027). (Table 6.3.5)

Table 6.3.6 Tukey multiple comparison test was used to detect which group/groups were responsible for the statistically significant difference among the thermocycled subgroups of Groups 1, 2, and 6.

Tukey Multiple Comparison Test	Thermocyled
Group 1 / Group 2	**0,047**
Group 1 / Group 6	0,997
Group 2/ Group 6	0,055

Group 6 thermocycled subgroup showed no significant difference than Group 1 (p=0,997) and Group 2 thermocycled subgroups (p=0,055) while Group 2 thermocycled subgroup showed significantly SBS values than Group 1 thermocycled subgroup (p=0.047). (Table 6.3.6)

Table 6.3.7 One-way Anova test was used to compare the SBS values among the thermocycled subgroups of Group 1, Group 3 and Group 4

	Hilux 40 sec (Group 1)	Blue phase 20 sec (Group 3)	EMS 2 sec (Group 4)	F	P
Thermocyled	15,82±6,37	13,9±2,41	8,19±5,46	12,4	**0,0001**

The SBS values for the thermocycled samples in Group 1, Group 3 and Group 4 showed statistically significant difference (p=0, 0001). (Table 6.3.7)

Table 6.3.8 Tukey multiple comparison test was used to detect which group/groups were responsible for the statistically significant difference among the thermocycled subgroups of Groups 1, 3, and 4.

Tukey Multiple Comparison Test	Thermocyled
Group 1 / Group 3	0,456
Group 1 / Group 4	**0,0001**
Group 3/ Group 4	**0,01**

Group 4 thermocycled subgroup showed significantly lower SBS values than Group 1 (p=0,0001) and Group 3 (p=0,001) thermocycled subgroups while no difference was found among Group 1 and Group 3 thermocycled subgroups (p=0,456). (Table 6.3.8)

Table 6.3.9 One-way Anova test was used to compare the SBS values among the thermocycled subgroups of Group 1, Group 3 and Group 5

	Hilux 40 sec (Group 1)	**Blue phase 20 sec (Group 3)**	**EMS 3 sec (Group 5)**	**F**	**P**
Thermocyled	15,82±6,37	13,9±2,41	10,75±6,32	4,54	**0,015**

The SBS values for the thermocycled samples in Group 1, Group 3 and Group 5 showed statistically significant difference (p=0,015). (Table 6.3.9)

Table 6.3.10 Tukey multiple comparison test was used to detect which group/groups were responsible for the statistically significant difference among the thermocycled subgroups of Groups 1, 3, and 5.

Tukey Multiple Comparison Test	**Thermocyle**
Group 1 / Group 3	0,499
Group 1 / Group 5	**0,011**
Group 3/ Group 5	0,161

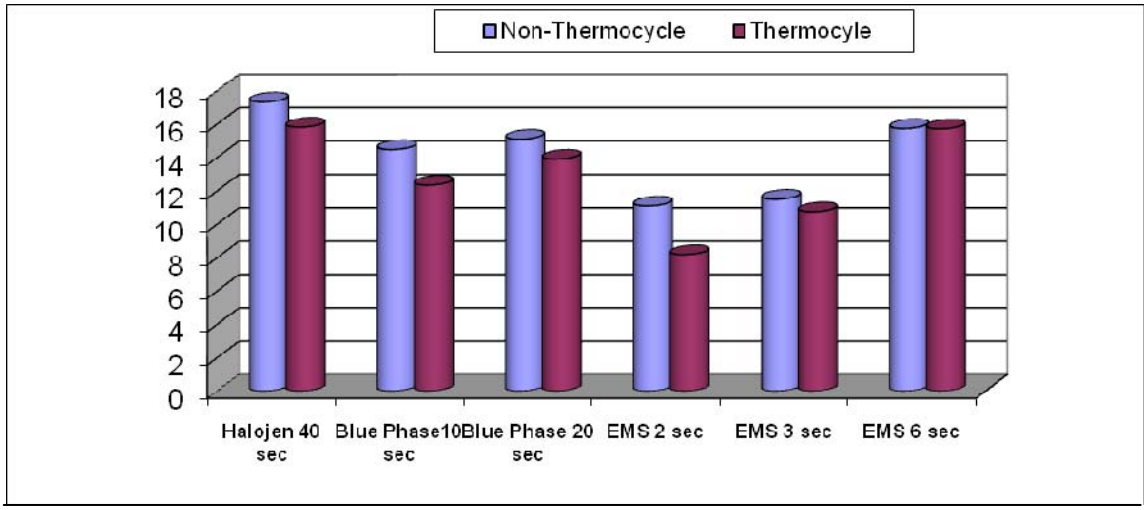
Group 5 thermocycled subgroup showed significantly lower SBS values than Group 1 (p=0,011) and no difference than Group 3 (p=0,161) thermocycled subgroups. (Table 6.3.10)

Table 6.3.11 One-way Anova test was used to compare the SBS values among the thermocycled subgroups of Group 1, Group 3 and Group 6

	Hilux 40 sec (Group 1)	Blue phase 20 sec (Group 3)	EMS 6 sec (Group 6)	F	P
Thermocyled	15,82±6,37	13,9±2,41	15,72±3,53	1,18	0,312

The SBS values for the thermocycled samples in Group 1, Group 3 and Group 6 showed no statistically significant difference (p=0,312). (Table 6.3.11)

Table 6.3.12 Graphic showing the shear bond strength for non-thermocycled and thermocycled subgroups.



6.4 Adhesive Remnant Index Results

Table 6.4.1 ARI Score Distribution for Non thermocycled subgroups

ARI (Non thermocycle)	Hilux 40 sec (1.Group)		Blue Phase10 sec (2.Group)		Blue Phase 20 sec (3.Group)		EMS 2 sec (4.Group)		EMS 3 sec (5.Group)		EMS 6 sec (6.Group)	
0	5	%25	7	%35	8	%40	2	%10	2	%10	5	%25
1	5	%25	6	%30	8	%40	7	%35	4	%20	6	%30
2	10	%50	7	%35	4	%20	8	%40	9	%45	6	%30
3	0	%0	0	%0	0	%0	3	%15	5	%25	3	%15

Table 6.4.2 Chi square test was used to evaluate the difference in ARI scores between non-thermocycled subgroups

ARI (Non thermocycle)					
Hilux 40 sec	Hilux 40 sec	Hilux 40 sec	Hilux 40 sec	Hilux 40 sec	Hilux 40 sec
Blue Phase 10sec	Blue Phase 10sec	Blue Phase 10sec	Blue Phase 20sec	Blue Phase 20sec	Blue Phase 20sec
EMS 2 sec	EMS 3 sec	EMS 6 sec	EMS 2 sec	EMS 3 sec	EMS 6 sec
p=0,142	**p=0,033**	p=0,259	**p=0,045**	**p=0,006**	p=0,103

Statistically significant differences were found between the Group 1- Group 3-Group 4, Group 1-Group 3-Group 5 and Group 1-Group 2-Group 5 regarding the ARI.(Table 6.4.2) Group 4 and 5 were found to be responsible for the difference. For non-thermocycled subgroups of Groups 4 and 5, the ARI scores were mostly 2 or 3 which showed that after debonding more adhesive were left on the teeth surfaces. (Table 6.4.2)

Table 6.4.3 ARI Score Distribution for Thermocycled groups

ARI (Thermocyle)	Hilux 40 sec (Group 1)	Blue Phase10 sec (Group 2)	Blue Phase 20 sec (Group 3)	EMS2 sec (Group4)	EMS3 sec (Group 5)	EMS6 sec (Group 6)
0	8 %40	8 %40	2 %60	1 %5	1 %5	12 %60
1	8 %40	8 %40	5 %25	6 %30	4 %20	4 %20
2	4 %20	4 %20	3 %15	5 %25	8 %40	4 %20
3	0 %0	0 %0	0 %0	8 %40	7 %35	0 %0

Table 6.4.4 Chi square test was used to evaluate the difference in ARI scores between the Thermocycled subgroups

ARI (Thermocyle)					
Hilux 40 sec Blue Phase 10sec	Hilux 40 sec Blue Phase 10sec	Hilux 40 sec Blue Phase 10sec	Hilux 40 sec Blue Phase 20sec	Hilux 40 sec Blue Phase 20sec	Hilux 40 sec Blue Phase 20sec
EMS 2 sec	EMS 3 sec	EMS 6 sec	EMS 2 sec	EMS 3 sec	EMS 6 sec
p=0,001	**p=0,007**	p=0,602	**p=0,0002**	**p=0,0001**	p=0,607

Statistically significant differences were found between the thermocyced samples of Group 1- Group 2-Group 4, Group 1- Group 2-Group 5, Group 1- Group 3-Group 4 and Group 1- Group 3-Group 5 regarding the ARI scores(Table 6.4.4). Group 4 and Group 5 were found to be responsible. For thermocycled subgroups of Groups 4 and 5, the ARI scores were mostly 2 or 3 which showed that after debonding more adhesive were left on the teeth surfaces. (Table 6.4.4)

Table 6.4.5 Comparison of the ARI Scores for the Non thermocycled and Thermocycled groups

ARI Score	Non thermocycled/ Thermocyled
Hilux 40 sec (Group 1)	p=0,138
Blue phase 10 sec (Group 2)	p=0,556
Blue phase 20 sec (Group 3)	p=0,442
EMS 2 sec (Group 4)	p=0,337
EMS 3 sec (Group 5)	p=0,867
EMS 6 sec (Group 6)	p=0,082

No statistically significant differences were found between the non thermocycled and thermocycled groups regarding the ARI scores (Table 6.4.5)

Table 6.4.6 Graphic ARI Score distribution for the Non thermocycled subgroups

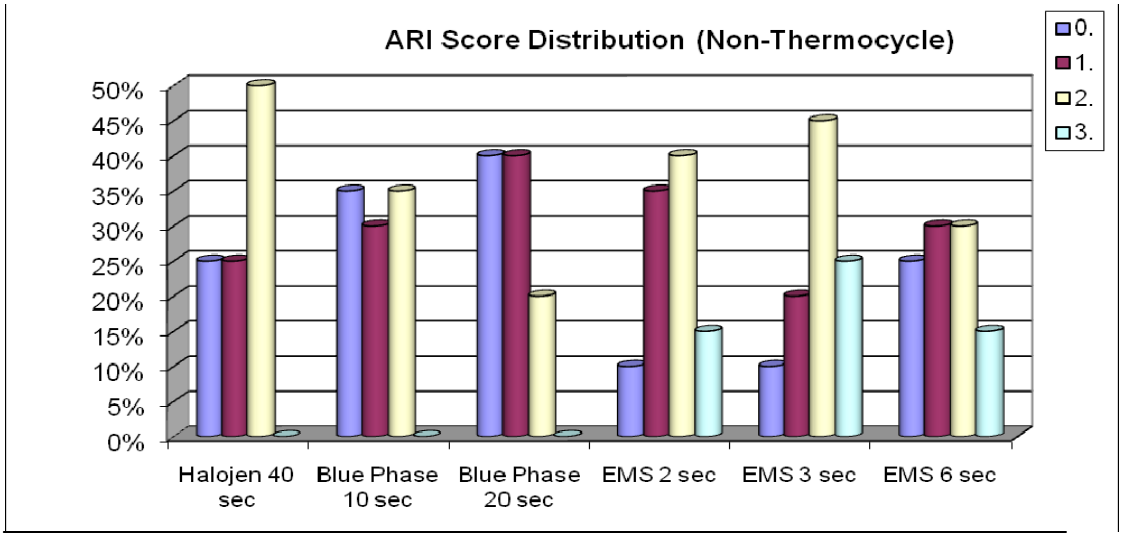


Table 6.4.7 Graphic with ARI Score distribution for the Thermocycled subgroups

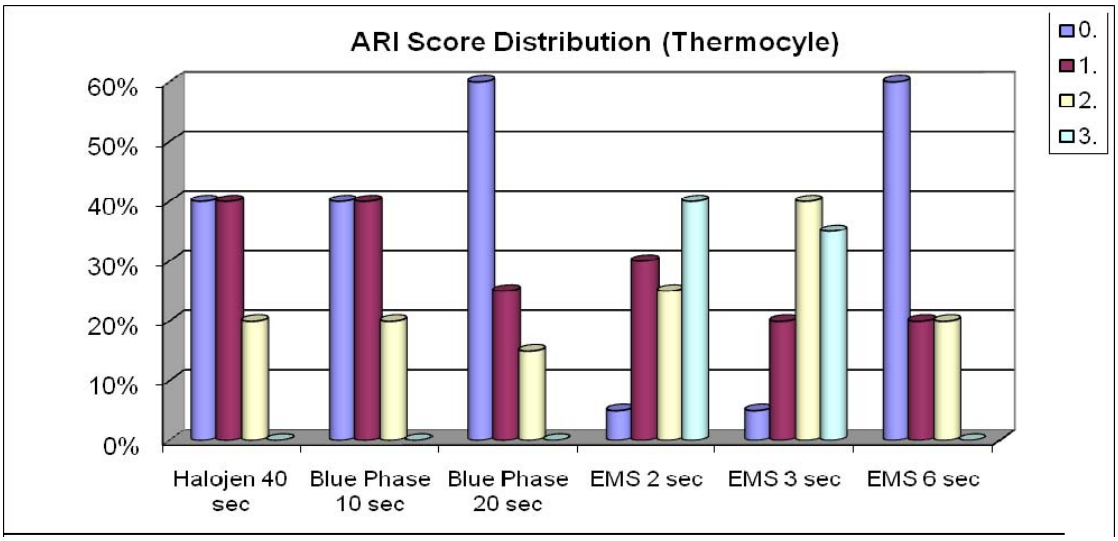
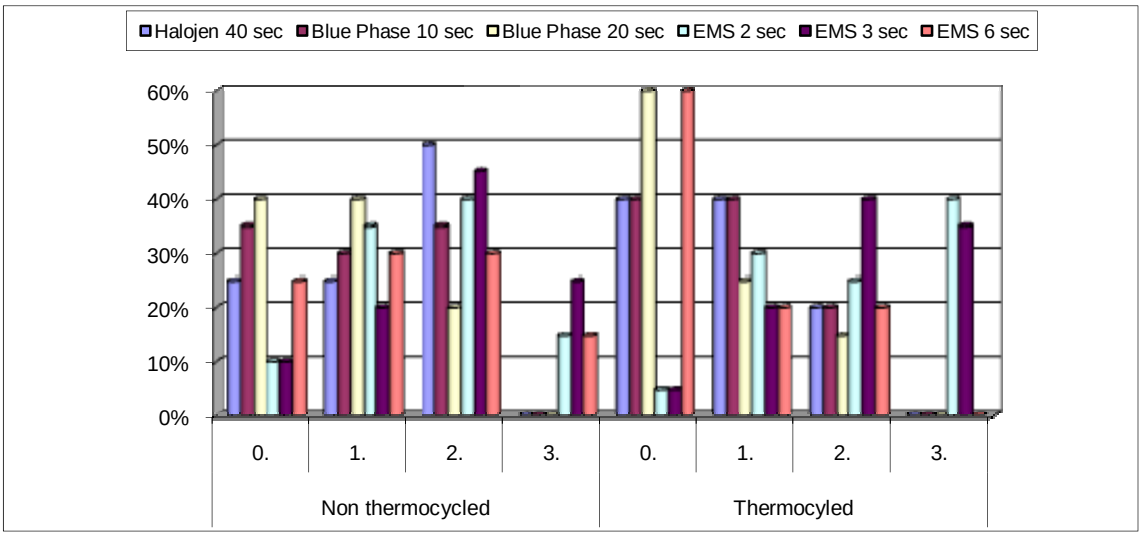


Table 6.4.8 Graphic showing the ARI Score distribution for Non thermocycled and Thermocycled subgroups



7. DISCUSSION

7.1 Discussion of study materials and method

The light sources used in our study are a conventional halogen light (Benlioglu, Turkey), high power halogen (Swissmaster, EMS) and a high intensity LED (Bluphase, Ivoclar). The light sources were selected due to their high performances which were reported in previous studies (71, 73, 83, 136, 137, 139, 144, and 168). Many late studies have compared in vitro, different light sources, using different combinations of adhesives and forces (32, 34, 46, 136, 137, 140, 159, 162, and 139). None of these studies have performed a combination of the light sources and duration of curing times and thermal aging process available in the present study.

The present study was conducted on extracted human premolar teeth like some other in-vitro studies in the literature (73, 83, and 144). In most of the studies because of their similarities to the human teeth, their flat surfaces and for being easy to collect, bovine teeth have been used (110). More recently, Osterle *et al.* (110) found that the bond strength of bovine enamel was 21% to 44% weaker than human enamel, however, the bond strength of deciduous bovine enamel was found to be significantly greater than permanent bovine enamel. The SBS values found in our study were consistent to those of Osterle et al. (110). However, SBS values in our study were not as high as described in Oesterle et al. (110) study when compared to the values reported in the study of Staudt et al. (157) where deciduous bovine incisors were used. The reason Oesterle et al.(110) found higher difference, between the SBS values of human and bovine teeth, is that human incisor teeth were used in their study while, human premolar teeth were used in the current study. Hobson *et al.* (69) and Mattick *et al.* (96) investigated the acid etch pattern and bond strength to etched enamel on different types of human teeth. They found that there were significant differences in the acid etch pattern achieved on

different tooth types and that in the upper arch bond strength was greater on the anterior teeth than posterior teeth. Weatherell (174) suggested that the premolar teeth differed from the rest of the permanent dentition in the quality of enamel present. There is a higher percentage of aprismatic enamel, which causes the bond strengths of brackets in the premolar region to be among of the lowest.

In our study in order to conserve the organic structure of the enamel the teeth were stored at room temperature in distilled water like it has been suggested in the previously published literature (16, 39, and 97). Other researchers have used thymol (2, 112, 113, and 114), 70% alcohol concentration (26, 66), formaldehyde (52), and human serum (92, 101, and 169). However, a study performed by Ozbilgen et al (118) showed that, the conditions the teeth were stored in, did not affect the bond strength.

In the present study the extracted teeth were cleansed of soft tissue and then polished with no fluoridated pumice and rubber prophylactic cups at low speed for 10 seconds and immersed in distilled water in a sealed container for one to three months until testing. The water was changed weekly, to prevent the growth of bacteria and fungi. Before the bonding procedure, the labial surface of each tooth was polished for 1 minute with a combination of a polishing agent and a brush at a low speed (3000 rpm) using a micro-motor as recommended (31). In other studies, a combination of fluoride free pumice and water (16, 52, 93, 94), or silicon carbide discs at different thickness to flatten the surface of the tooth for better adaptation of the bracket base to the tooth, have been used (26, 92).

A 37 % orthophosphoric acid gel was used for the acid etching of the teeth for 30 seconds. Several studies have been published related with the effect of acid etching on SBS (23, 24, 48, 76, 99, 106, 122, 129, 133, 142, and 163). Some acid-etching related factors that influence orthodontic bonding include the type and concentration of the acid and the duration of etching (6). No drastic differences were found in the bond strengths when 37 % phosphoric acid was used between 15 second and 60 second for etching (129). If etching time was less than 10 seconds bond strength was found to be reduced significantly (129, 142). Many recent studies have used the latest self–etch primers due to their resistance to moist and saliva (5, 9, 10, 16, 17, 18, 28, 52, 61, 93, 94, 115, 119,

138, 152, 165, 166, 170). Many of the tested self-etching primer and adhesive systems produced bond strength values much lower than conventional system. Clinically, these products might not be suitable for orthodontic bracket bonding in terms of the shear bond strength achieved after thermal cycling and water storage (36). A one-step adhesive system was found to have the potential to be successfully used in bonding orthodontic brackets if its shear bond strength could have been increased (15).

In the present study the brackets used for the test and control groups were foil-mesh-based stainless steel (upper premolar) Gemini MBT brackets (3M /Unitek, USA). Studies have shown that foil-mesh-based and integral based brackets bond better than perforated ones (104, 172). Wang et al (172) reported that the size and design of a bracket base can affect bond strength. The Tomy bracket, with its circular concave base, produced greater bond strength than did the mesh-based brackets and that among the brackets with mesh-type bases, when the mesh spacing was larger; the bond strength was found to be greater (172).

After bonding the brackets half of the samples were thermocycled in water between 5° and 55° for 7500 cycles (7, 25, 61, 80, 82, and 165) to stimulate accelerated aging by thermally induced stresses. All specimens in our study were stored at 37° in distilled water (25, 26, 28, 31, 38, 45, 47, 78, 82, 93, 94, 104) for 72 hours to provide baseline data for comparative purposes before shear bond testing on a universal testing machine. Some studies used different storing procedure of the samples after bonding of the brackets such as water (16, 62), artificial saliva (45, 81, 107), and normal saline (79). Intraoral temperatures have been recorded as low as 0°C and as high as 67°C. Thermocycling is believed to simulate oral conditions in vitro (142). While simulating the introduction of hot and cold extremes in the oral cavity it also shows the relationship of the linear coefficient of thermal expansion between tooth and restorative material (49). Godfrey et al (82) found no difference between thermocycled samples and samples stored in 37 °C. Other studies in restorative dentistry have shown that thermocycling of samples can decrease the bond strength by 20% to 70% (44, 108). In our study the shear bond strength values of the groups that were thermocycled showed lower values than the groups that were not thermocycled but the differences were

statistically not significant for most of the groups. The only group that showed statistically significant lower values was Group 4 (p= 0,04) (Table 6.1.1). That might have happened due to insufficient polymerization of the composite with 2 seconds of curing time with the high power halogen light. Similar low results were found by Wendl et al (177) for the xenon lamp at 2 sec curing time.

In our study the bracket was first bonded to the tooth than through a special constructed device the teeth were mounted in a 2 cm diameter circle mould using chemically cured acrylic. Many studies have used similar techniques by first bonding the brackets to the tooth than placing the teeth in moulds and using transferring jig to the testing machine (100, 113, 114, 116). However, in some studies a transferring jig was not used by placing the samples directly to the device (38, 101). This caused lack of standardization and recalibration was required when testing each sample. In other studies the teeth were placed in the moulds so that their vestibular side could be parallel to the ground before bonding the brackets (39, 60, 65, 97, 113, 120,), this would exert force parallel to the outer contour of the tooth but not to the base of the bracket so it might have caused forces to act in wrong directions producing wrong results (52, 100).

Shear bond strength of the samples was evaluated in our study. In most of the studies either shear bond strength (6, 16, 27, 52, 97, 102, and 176) or tensile bond strength (51, 101, 150, and 173) was evaluated. Very few studies have evaluated both bonding strengths in the same experimental design (47, 118).

After bracket failure, the enamel surface was examined under a light microscope at x50 magnification, and the amount of adhesive remaining on the tooth was recorded with the use of the adhesive remnant index (ARI).The ARI score in our study was the same as the one used by Artun and Bergland (9). Some studies have used a modification of the ARI index used by Artun and Bergland (16, 148), some others only evaluated if the bracket failure has taken place between adhesive and bracket or adhesive and enamel (25, 66). After the bracket failure enamel surface evaluation has been performed by a stereo light microscope (6, 11, 28, 33, 41, 52, 67, 87, 102, 138, 147), or by a SEM to be able to evaluate in more details (28, 52, 67, 82, 92, 104, 107, 118).

7.2 Discussion of the null hypothesis

1-The first null hypothesis of the study was rejected

The halogen light source showed the highest SBS values. There was no statistifically significant difference between the conventional halogen (Group 1) and the LED light source (Group 2 and 3) SBS values before and after thermocycling. SBS scores for Group 4 and 5 showed significant lower values than the other groups. Our results were consistent with those of Staudt et al (157) concerning the low SBS values for 2 sec and 3 sec exposures with the high power halogen, although deciduous bovine teeth have been used in their study (157). Silta et al (144) evaluated the ability of the latest generation of QTH (Optilux 501, Demetron, Danbury, Conn) and two LED light-curing units (Ortholux LED, 3M Unitek, Monrovia, Calif; UltraLume LED 5, Ultradent Products, South Jordan, Utah) to bond orthodontic brackets to teeth at decreased polymerization times. Their SBS values were lower than the ones in our study and they have reported that 10 seconds curing time was not enough when LED curing units were used. Unlike our study, Silta et.al. (144) have used self etching primer as adhesive and pre-coated brackets. Üşümez et al (168) evaluated the effect of light-emitting diode (LED) (Elipar FreeLight, 3M ESPE) for 10, 20, or 40 seconds curing times on shear bond strength (SBS) of orthodontic brackets bonded to human premolar teeth. Their results were consistent with ours regarding the conventional halogen and LED light source with 20 seconds of curing time, but were reported to be lower when LED curing unit was applied for 10 seconds. The Blue Phase LED light used in our study had a power density of 1200 mW/cm2 which is higher than the 400 mW/cm2 of the LED used in their study. This can explain the reason why 10 seconds of curing time produced SBS values similar to the SBS values produced by conventional halogen and the LED with 20 seconds of curing time in our study. Thind et al (162) bonded brackets on sound premolar teeth by using Transbond XT as adhesive and compared Ortholux XT ™ (tungsten-quartz-halogen bulb) for 20 seconds of curing time, Ortho lite ™ (plasma arc)

for 6 seconds of curing time and Ortholux LED ™ light-emitting diode for 10 seconds of curing time. They did not find any significant differences between the light sources. Their results were consistent with ours when conventional halogen, Bluephase light for 10 sec and high power halogen EMS light for 6 seconds were used.

2- The second null hypothesis of the study was rejected

Statistically significant differences were found in our study for one of the light sources when the shear bond strengths were evaluated at different curing times. SBS values of the groups where high intensity halogen was used (EMS) for 2 sec (Group 4) and 3 sec (Group 5), were found to be significantly lower when compared to the high power halogen (EMS) applied for 6 sec (Group 6). No statistically significant differences were found for Bluephase 10 sec (Group 2) and 20 sec (Group 3). Our results were consistent with those of Staudt et al (157) concerning the high power halogen values.

3- The third null hypothesis of the study was rejected

ARI scores did not show any statistically significant differences when non-thermocycled and thermocycled subgroups were compared (Table 6.4.5). However intergroup comparisons for both thermocycled and non-thermocycled subgroups showed statistically significant differences in the ARI scores. For the groups where high power halogen (EMS) was used for 2 sec and 3 sec, more 2 and 3 ARI scores were recorded which showed that more adhesive was left on the tooth after debonding for these groups (Group 4 and 5). Our results were similar to those of Signorelli et al (143). Signorelli et al (143) also used Transbond XT as adhesive and compared normal halogen light with plasma light and reported that more adhesive remained on the bracket base when normal halogen light was used. Oesterle et al (89) also showed that more adhesive remained on the bracket base when a normal halogen light for 40 seconds and plasma light for 6

seconds were used. Their results were consistent with ours when normal halogen was used for 40 sec and high power halogen was used for 6 sec. Sfondrini et al (137), compared the conventional halogen and plasma, and reported that the samples cured with the conventional halogen, had more adhesive left on the tooth surface. In our study the conventional halogen light had less adhesive left on the tooth surface. The reason for the difference was thought to be the difference in curing times used for the conventional halogen light which in our study was twice (20x2) that of their study. Increasing the curing time increases the polymerization of the adhesive under the bracket and its retention (27). Staudt et al (157) in their study using plasma light, quick halogen and high power halogen light sources on deciduous bovine teeth found out that more adhesive remained on the tooth surface than on the bracket base. Our results were consistent with their study for the ARI score values of the groups cured with the high power halogen for 2 and 3 seconds which produced more 2 and 3 ARI scores, but different for the other groups.

4-The fourth null hypothesis of the study was rejected

When thermocycled and non-thermocycled subgroups were compared statistically significant differences were found for the high intensity halogen (EMS) group treated for 2 seconds (p=0,04); while other groups did not show any significant differences. Our results were consistent with the results of Godfrey et al (82) for all the groups except for group 4. Three possibilities could be discussed related with the difference in Group 4. First thermocycling might have directly degraded the adhesion at the resin-metal interface, thus promoting an interfacial adhesive failure. Secondly the thermocycling of resin based cements might have caused degradation of the resin itself with consequent promotion of cohesive failure due to improper polymerization. Finally it might have been a combination of both of these factors.

The results of this study supported the use of the high-power halogen light and blue phase. They both are cost-effective solution to reduce light-curing time. The

recommended curing time for bonding stainless steel brackets was 6 seconds for the high power halogen and 10 seconds for the Blue Phase LED. For ceramic brackets, the curing time could be less because the light polymerizes the composite through transillumination of the bracket as well (157). Curing time is reportedly not influenced by the bandwidth of the emission spectrum of different lights as long as it corresponds approximately to the absorption spectrum of camphorquinone. It is shown that the double bond conversion rate of resin composites is not influenced by the emission spectrum, if the irradiated light energy is the same. Therefore, the parameter that allowed relevant reduction in curing time in our study seemed to be the increase in power density which was 3000 mW/cm2 for the high-power halogen light , 1200 mW/cm2 for the Blue phase Led and 800 mW/cm2 for the Hilux.

8. CONCLUSIONS

1- The Blue Phase LED produced SBS values similar to conventional halogen for both 10 sec and 20 sec curing times and was not affected by thermocycling. The recommended curing time for bonding stainless steel brackets with Blue Phase LED was 10 seconds.

2-The High Power Halogen produced SBS values similar to conventional halogen when 3 seconds and 6 seconds curing times were used but failed to produce similar values for curing time of 2 seconds, which dramatically decreased SBS values with and without thermocycling. The recommended curing time for bonding stainless steel brackets with EMS high power halogen light was 6 seconds or even 3 second with caution.

3- ARI scores evaluation showed that when EMS applied for 2 seconds and 3 seconds more adhesive was left on the tooth surface after debonding. For the other groups less 2 and 3 scores were recorded, which showed that most of the adhesive was removed from the tooth surface during debonding. ARI scores were not affected by thermocycling

4- Thermocycling caused lower SBS values to be recorded however, the differences between thermocycled and non-thermocycled subgroups were not statistically significant except for group 4. The clinicians must be careful since the conditions in the mouth might affect greatly the bonding strength when short curing times are used with the light sources.

5- Our results were based on in-vitro laboratory conditions, and the clinical relevance of our findings should also be confirmed with in vivo studies.

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1.	Research Assistant	Ankara University Institute of Health Sciences	2002-2003
2.	Research Assistant	Marmara University Institute of Health Sciences	2003-2009

Yabancı Dilleri	**Okuduğunu Anlama***	**Konuşma***	**Yazma***
Turkish	Very good	Very good	Very good
English	Very good	Very good	Very good
French	Very good	Very good	Very good
Italian	Very good	Very good	Very good
German	Very good	Good	Good

Yabancı Dil Sınav Notu #								
KPDS	ÜDS	IELTS	TOEFL IBT	TOEFL PBT	TOEFL CBT	FCE	CAE	CPE
				623				

	Sayısal	**Eşit Ağırlık**	**Sözel**
LES Puanı			
(Diğer) Puanı			

Bilgisayar Bilgisi

Program	**Kullanma becerisi**
Microsoft Office	Very good
Adobe Photoshop	Very good
Quick Basic	Very good

*****Çok iyi, iyi, orta, zayıf olarak değerlendirin