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“Effect of heat transmission through different materials of varying thickness with multiple different curing lights”

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Effect of heat transmission through different materials of varying thickness with multiple
different curing lights

A Thesis

Presented to the Faculty of the Advanced Education in General Dentistry, Two-Year Program,
United States Army Dental Activity, Fort Hood, Texas
And the Uniformed Services University of the Health Sciences – Post Graduate Dental College
In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Oral Biology

By

James W Stirland, CPT, USA, DC

April 2017

Effect of heat transmission through different materials of varying thickness with multiple
different curing lights

A REPORT ON

Research project investigating the amount of heat transmitted through different composites and
different thicknesses.

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ABSTRACT

Purpose: The purpose of this study is to determine the amount of heat transmitted with three higher intensity LED curing units (FlashMax P3, Ultradent Valo, Coltene SPEC 3) and one conventional LED curing unit (3M Paradigm) through different thicknesses of two different composite materials (3M Paradigm Nano Hybrid Universal Composite A2, Kerr SonicFill 2 A2) and different distances from standardized thickness of composite commonly used in dentistry.

Methods: Two different composite materials (3M Paradigm Nano Hybrid Universal Composite A2, Kerr SonicFill 2 A2) were used. Eight groups were tested with two subgroups; different thickness of each composite (subgroup A) and distance from standardized thickness of composite (subgroup B). The group testing thickness had three samples of each thickness (1mm, 2mm, 3mm). This was performed for all four curing lights (FlashMax P3, Ultradent Valo, Coltene SPEC 3, 3M Paradigm) for a total of 72 composite discs that were polymerized. The group testing distance had three samples of the same standard thickness (2mm) with four different curing distances from the composite (0mm, 1mm, 2mm, 3mm). This was performed for all four curing units (FlashMax P3, Ultradent Valo, Coltene SPEC 3, 3M Paradigm) for a total of 96 composite discs that were polymerized. Each composite/light combination had a control of air at different distances from the sensor to the curing light. Each sample was made using different thicknesses of acrylic washers where the measurements were 1mm (h) x 4 mm (d), with the inner diameter being 2mm. The samples were measured and recorded using a K-type thermal sensor attached to a glass slab. The thermal sensor was connected to an automatic data logger (Extech SDL200 4-Channel Datalogging Thermometer with SD Card Memory) where logging was initiated prior to curing was and continued logging until temperature returned to normal temperature every second. Data was analyzed with Microsoft Excel.

Results: A significant ($p \leq 0.001$) change in temperature was found between the different subgroups of curing through air alone, distance from the curing unit, and the different thickness of composite for both the 3M Paradigm Nano Hybrid Universal Restorative and Kerr Sonicfill 2 bulk fill resin material.

Conclusions: From this study one can conclude that there is a difference in the heat that is transmitted through different resin materials in regards to thickness and distance. There is a potential for pulpal damage from LED curing lights when the light is activated along with the heat from the polymerization reaction from the composite.

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INTRODUCTION

Composite fillings have become a major focus in restorative dentistry for many reasons. The ability to restore esthetically has increased research in resin filled restorative materials. Also the ability to bond to natural tooth structure is another benefit to this type of filling material. New advances in resin technology and composition aids in better wear, more favorable esthetics, and long lasting resilience.

Typical composites are composed of 1) an organic resin matrix, 2) an inorganic filler content, 3) a siline coupling agent, and 4) photoinitiators. The resin matrix is composed mainly of bis-GMA but can also have other monomers that aid in different properties. TEGDMA and PEGDMA aid in decreasing the viscosity of the resin. The filler content is usually made of quartz, or glass that aid in preventing shrinkage of the composite. They also aid in the stability of the composite along with the different properties such as wear, polishability, esthetics and handling. Radioopaque markers are associated with the fillers, which help in visualization of the resin restoration radiographically. The coupling agent is crucial to bond the organic resin matrix and the inorganic filler content of the composite. Resin polymerization is essential to the process of utilization as a restorative material. The process is accomplished by the initiation, propagation and termination, which result in an amount of the resin to be polymerized (Figure 1, Figure 2). One way the initiation can be accomplished is by a photo initiator, which catalyzes the reaction. A common photoinitiator is camphorquinone, which Ausmussen et al discovered its reaction to be in range from 370 to 500 nm, with a peak at 468 nm.¹ Once there are free radicals formed, then propagation continues by the free radicals breaking the double bonds on the monomers and

combining with the monomer. This new complex is still active and will continue to combine with other monomers until termination occurs where two free radicals form. Once the curing unit is removed from the resin, there is still polymerization occurring until there is a stable termination. This means that there is still continued energy being generated from just the reaction alone. Normally manufactures state that it takes a certain amount of time for this process to be optimal (40sec).

Figure 1 (Anusavice, Kenneth J. *Phillips' Science of Dental Materials, 12th Edition*. W.B. Saunders Company, 2013.

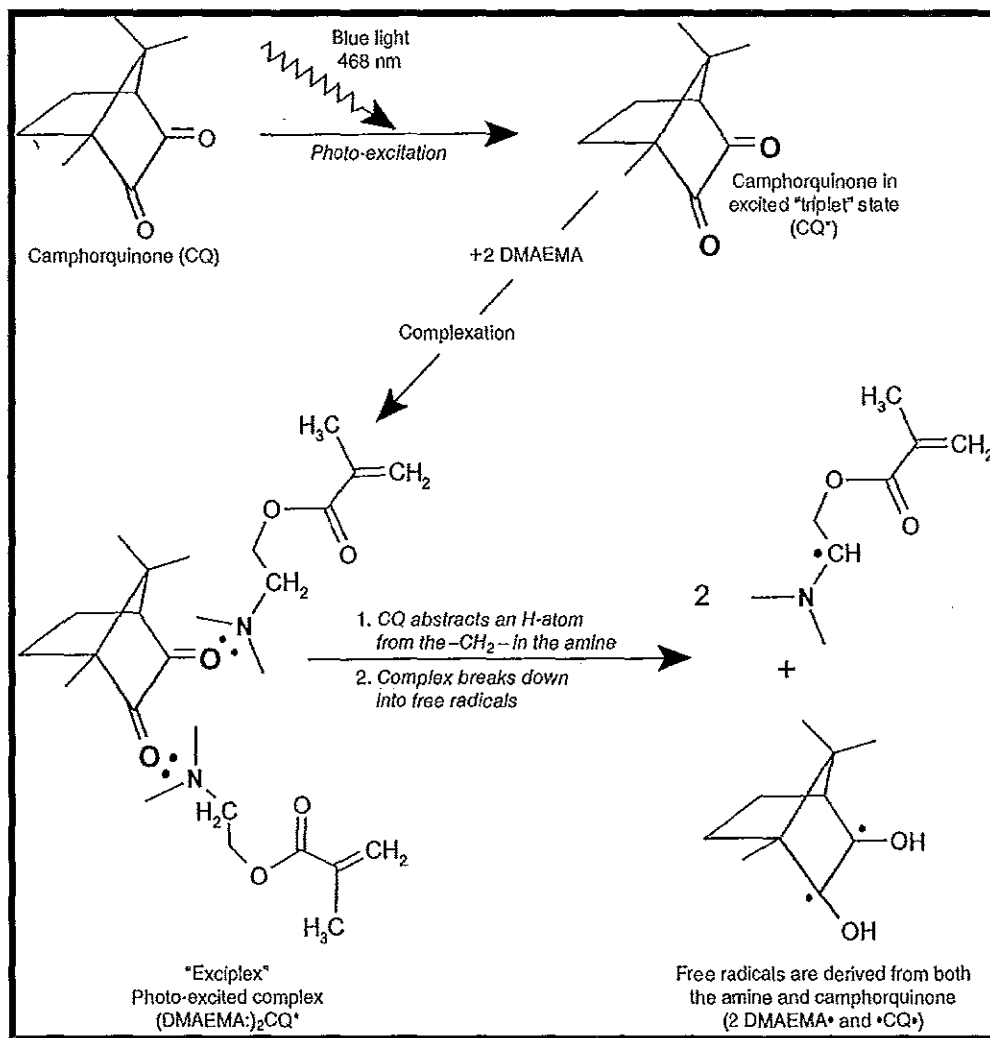
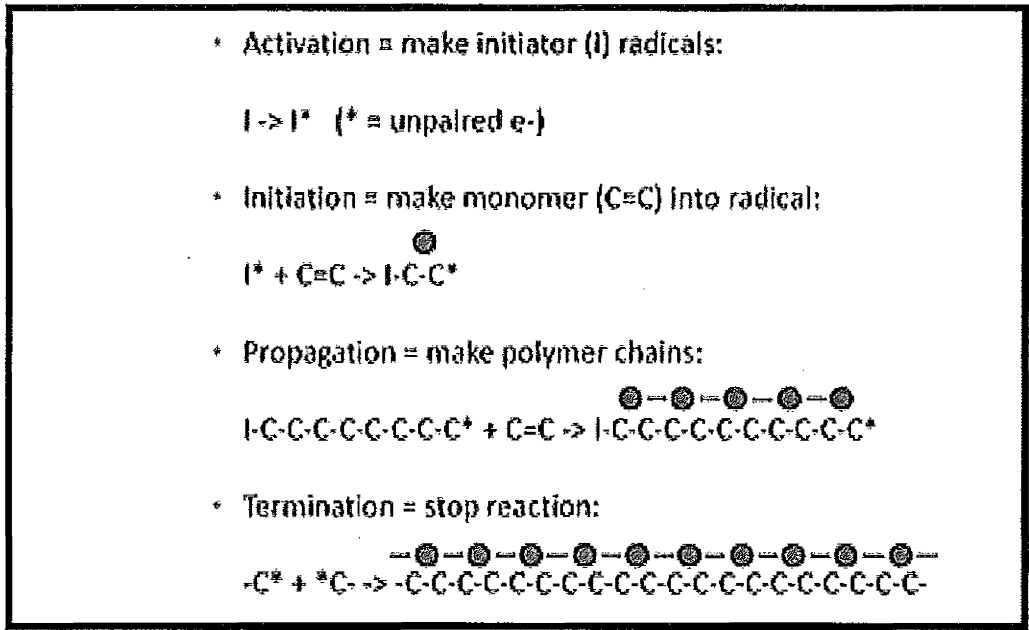


Figure 2 (Hilton, Thomas J. *Summitt's Fundamentals of Operative Dentistry: A Contemporary Approach, 4th Edition*. Quintessence, 10/2013)



Newer light curing units state that this initial cure can be done in a shorter amount of time. Higher-powered LED-curing lights will also increase the temperature at which the curing takes place. With a few studies showing that certain temperature increases can cause pulpal damage, it is important that the proper use of the new generation of LED curing lights are correctly used in order to prevent irreversible harm to the patient. Along with the light curing unit there is also an additional increase in temperature from the curing of the composite material that could be additive.^{2,3,4,5,6} Multiple studies have indicated that this exothermic reaction could actually increase temperature up to 20 degrees Celsius within the composite.^{1,2,3,7} Lloyd et al. along with Yap et al. indicate that the main factor that determines the intrapulpal temperature rise

is the energy taken in during curing,^{2,8} whereas Matsutani et al. say that the exothermic reaction of the resin play a greater role in temperature increase.³

The additional heat from the polymerization reaction along with heat generated from high intensity LED curing lights can possibly have a negative effect to the vitality of the pulp. In 1965 Zach et al. indicated that an increase of 5.5 and 11.1 degrees Celsius could cause irreversible pulpitis in 15% to 60% of cases. They also indicated in that study regardless of the cause of the pulpal temperature change, a minor rise had evidence of pulpitis.⁹ Another study by Pohto and Scheinin found that irreversible damage occurs at 42-42.5 degrees Celsius.¹⁰ Eriksson et al concur with the critical temperature of 42 degrees Celsius when the duration is at least for one minute.¹¹ Studies have shown that normal temperature of the pulp is around 34-35 degrees Celsius.^{12,13} Besides the thermal changes that can occur from other routine dental care, polymerization of resin restorative material also can play a role in thermal rise to the pulp and ultimately irreversible pulpitis. The polymerization along with the light activation can be additive and can increase the temperature even further.¹⁴ Further along this point Yap et al. indicate that the main involvement to the increase in thermal rise is the light source¹⁵, or type of light source.¹⁶ Newer LED units have the ability to produce higher power density (mW/cm²) compared to earlier generation of LED curing lights. Specifically the Ultradent Valo LED curing light has three different power modes and can also emit a broader spectrum for curing different wavelengths used by different composite systems.¹⁷ The highest power setting reports to have the ability to reach 3200mW/cm² which is called Xtra power. This study also tests two other high power LED curing lights and one regular LED curing light.

This study focuses on two different composite resins: 3M Paradigm Nano Hybrid Universal Restorative and Kerr Sonicfill 2 bulk fill resin material.

3M Paradigm Nano Hybrid Universal Restorative is a nanohybrid type resin material. Nanohybrids are a newer type of composite technology where there are nano-sized particles along with larger sized filler particles within whole complex. Mahmoud et al indicated that compared to microhybrid resin composites, nanohybrids showed adequate clinical results after two years of wear.¹⁸ 3M Paradigm Nano Hybrid Universal Restorative uses many different resins within the resin matrix (Table 1, Figure 3). The bis-GMA (bisphenol-A-glycidyl methacrylate) and UDMA- urethane dimethacrylate are main components in most resin composite systems that have good mechanical properties. The other resins in 3M Paradigm Nano Hybrid Universal Restorative: TEGDMA (triethyleneglycoldimethacrylate) which aids in lowering the viscosity of the resin, bis-EMA (ethoxylated bisphenol-A-glycol dimethacrylate) which aids in decreasing volumetric shrinkage¹⁹, and PEGDMA (poly ethylene glycol dimethacrylate) which also aids in decreasing shrinkage help make up the resin matrix. The filler system of this composite uses a combination of surface modified zirconia/silica particles and 20 nm surface modified silica particles. 3M indicate to use this product in both anterior and posterior restorations along with core build-ups, splinting, and indirect restorations.

Kerr Sonicfill 2 bulk fill composite is a restorative material utilized for single fill placement. The manufacture claims that up to 5 mm can be cured at the same time. The components of Sonicfill 2 are listed in table 1.²⁰

Table 1

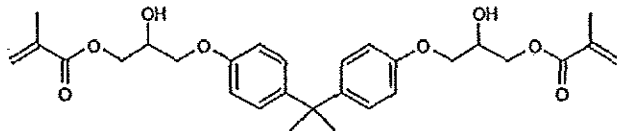
Material	Manufacturer	Type	Filler	Resin Matrix
Paradigm Nano Hybrid Universal Restorative	3M ESPE	Nanohybrid	<ul style="list-style-type: none"> Surface modified zirconia/silica with median particle size of approximately 3 microns or less 	<ul style="list-style-type: none"> bis-GMA- bisphenol A glycidyl methacrylate UDMA- urethane dimethacrylate TEGDMA-

			<ul style="list-style-type: none"> • Non-agglomerated/non-aggregated 20 nanometer surface modified silica particles • 82% by weight (68% by volume) 	triethyleneglycoldimethacrylate <ul style="list-style-type: none"> • bis-EMA- ethoxylated bisphenol A glycol dimethacrylate • PEGDMA- poly (ethylene glycol) dimethacrylate
Sonicfill 2	Kerr	Bulkfill	<ul style="list-style-type: none"> • SiO₂, Glass, oxide, 	<ul style="list-style-type: none"> • EBPDMA- Ethoxylated bisphenol-A- dimethacrylate • Bis-GMA- bis-GMA- bisphenol A glycidyl methacrylate • TEGDMA - Triethyleneglycoldimethacrylate

Figure 3 (Hilton, Thomas J. *Summitt's Fundamentals of Operative Dentistry: A Contemporary Approach, 4th Edition*. Quintessence, 10/2013)

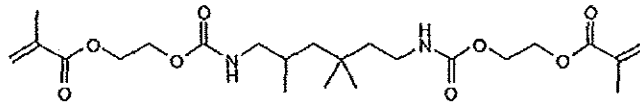
Bis-GMA

bisphenol A glycerolate dimethacrylate or 2,2-bis (p-2'-hydroxy-3'-methacryloxypropoxyphenyl)-propane



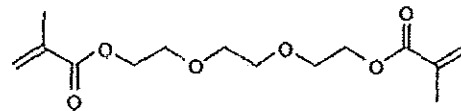
UDMA

urethane dimethacrylate or 1,6-di(methacryloyloxyethylcarbamoyl)-3,3,5-trimethylhexane

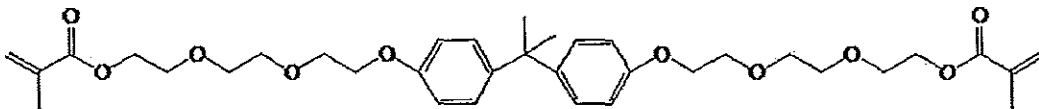


TEGDMA

triethyleneglycol dimethacrylate

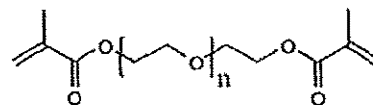


Structure of Bis-EMA6.



PEGDMA

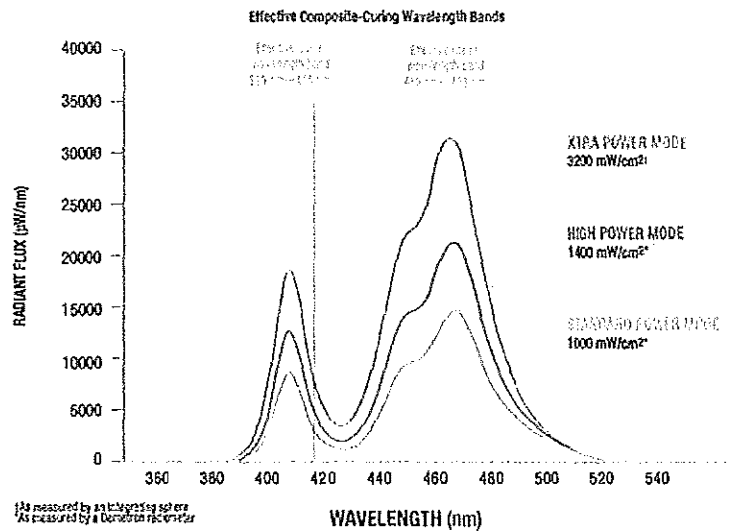
polyethylene glycol dimethacrylate



Four different light-emitting diode (LED) curing lights were utilized in this study to determine heat transmission. Valo, Ultradent LED curing light, S.P.E.C. 3 LED curing light, FlashMax P3 460 4W curing light, Paradigm LED 3M ESPE curing light. The first three lights are marketed at high irradiance curing lights that have significant higher ranges of irradiance compared to the standard LED curing lights.

The Valo, Ultradent is an LED curing light that utilizes a broad-spectrum multi wavelength at 395-480 nm, which allows for a broader range of curing different resin materials that are initiated by camphorquinone and other proprietary photoinitiators. Also the Valo LED curing light has three different irradiance (mW/cm^2); Standard Power $1000 \text{ mW}/\text{cm}^2$, High Power $1400 \text{ mW}/\text{cm}^2$, and Xtra Power $3200 \text{ mW}/\text{cm}^2$. (Figure 4) This enables the clinician to determine the level for the desired effects. Another benefit to the VALO LED curing light is the low-profile design, which enables better curing in limited spaces.

Figure 4 (Ultradent Valo brochure)



The S.P.E.C. 3 LED which stands for Special Plasma Emulated Curing 3 modes of curing is a LED curing light that can be utilized for many different clinical situations. It has three different curing modes (3K Mode, Standard Mode, and Ortho Mode). The manufacture states that wavelength range is 430 nm-490 nm. During the 3K Mode/Ortho Mode the irradiance is measured to 3000-3500 mW/cm². In the standard mode the irradiance is 1600 mW/cm².

The FlashMax P3 460 4W has the highest irradiance with range of 5000-6000 mW/cm². The wavelength range for the curing light is 440 nm-480 nm with a peak at 460 nm. The FlashMax P3 has three different curing modes based off of color; green, orange, and red. The green curing mode is normal manual use with a 1 or 3 sec curing cycle. The orange curing mode is semi-automatic with a set of 3 sec or 1 sec bursts. The red mode is fully automatic with either 3 sec or 1 sec curing cycles until the operator terminates by pressing the curing unit again.

The Paradigm LED 3M ESPE curing light is a standard curing light that has the irradiance levels measured at 1200 mW/cm². The wavelength range is 430-480 nm. The Paradigm LED curing light has different timer settings (5, 10, 15, 20 seconds, continuous mode) along with a tack cure mode.

The Extech SDL200 4-Channel Datalogging Thermometer with SD Card Memory was utilized for a thermosensor and data logger with a K-type thermocouple. The range for the K-type thermocouple is -100 to 1300°C. The logger has the option of measuring changes to temperature every second where they are stored on the SD card and can be transferred to a computer in an Excel format.

The utilization of LED light curing units is used in many dental procedures. Using the most efficient materials and methods would increase the effectiveness of our providers who provide care to our soldiers. The more efficient our providers are in providing care, the more our wellness and readiness will be increased throughout the military. Specifically as dental providers it is important to not cause any undue damage to those in our care. If there are curing lights that will enable faster polymerization along with not compromising the health of the pulp then this would allow for more efficient care in all military environments. Testing these four different curing lights, Valo, Ultradent LED curing light, S.P.E.C. 3 LED curing light, FlashMax P3 460 4W curing light, Paradigm LED 3M ESPE curing light, will allow the Army to focus on a specific LED unit that is superior in curing and low in thermal transmission.

PURPOSE

The purpose of this study is to determine the amount of heat transmitted with three higher intensity LED curing units (FlashMax P3, Ultradent Valo, Coltene SPEC 3) and one conventional LED curing unit (3M Paradigm) through different thicknesses of two different composite materials (3M Paradigm Nano Hybrid Universal Composite A2, Kerr SonicFill 2 A2) and different distances from standardized thickness of composite commonly used in dentistry.

HYPOTHESIS

Research questions: Will there be a significant change in heat transmitted through different thicknesses of resin composite material? Will the type of resin composite material affect the heat transmitted? Will the type of curing light effect how much heat is transmitted? Will there be an increase in temperature that could potentially cause pulpal damage? Will the distance from which the curing light is suspended from the uncured resin affect the amount of heat that is transmitted?

Null hypothesis #1: There is no difference in the heat that is transmitted through different resin materials.

Null hypothesis #2: There is no difference in the heat that is transmitted through resin materials regardless of the distance at which the resin is cured.

Null hypothesis #3: There is no difference in the heat that is transmitted through resin materials regardless of thickness.

Alternative hypothesis: There is a difference in the heat that is transmitted through different resin materials in regards to thickness and distance.

MATERIALS AND METHODS

Samples of both composites, 3M Paradigm Nano Hybrid Universal Restorative and Kerr Sonicfill2, were fabricated using pre-made acrylic washers in three different dimensions. The washer dimensions varied in thickness ranging from 1mm, 2mm, and 3mm. (Picture 6,7) The outer diameter of the three different washers were the same at 4mm. The inner diameter of the three different washers were the same at 2mm. The two different resin composites were still within clinical usage at the time of testing in regards to expiration dates. The four different curing lights, Valo, Ultradent LED curing light, S.P.E.C. 3 LED curing light, FlashMax P3 460 4W curing light, Paradigm LED 3M ESPE curing light were used according to the manufactures. (Picture 8-14) The groups and subgroups being assessed in this study are:

Group 1: FlashMax P3 460 W LED curing light and 3M Paradigm Nano Hybrid Universal Restorative

Subgroup A: Air (control)

Subgroup B: Thickness of composite material

Subgroup C: Distance from curing unit to resin

Group 2: Valo, Ultradent LED curing light and 3M Paradigm Nano Hybrid Universal Restorative

Subgroup A: Air (control)

Subgroup B: Thickness of composite material

Subgroup C: Distance from curing unit to resin

Group 3: S.P.E.C. 3 LED curing light and 3M Paradigm Nano Hybrid Universal Restorative

Subgroup A: Air (control)

Subgroup B: Thickness of composite material

Subgroup C: Distance from curing unit to resin

Group 4: Paradigm LED 3M ESPE curing light and 3M Paradigm Nano Hybrid Universal Restorative

Subgroup A: Air (control)

Subgroup B: Thickness of composite material

Subgroup C: Distance from curing unit to resin

Group 5: FlashMax P3 460 W LED curing light and Kerr Sonicfill2

Subgroup A: Air (control)

Subgroup B: Thickness of composite material

Subgroup C: Distance from curing unit to resin

Group 6: Valo, Ultradent LED curing light and Kerr Sonicfill2

Subgroup A: Air (control)

Subgroup B: Thickness of composite material

Subgroup C: Distance from curing unit to resin

Group 7: S.P.E.C. 3 LED curing light and Kerr Sonicfill2

Subgroup A: Air (control)

Subgroup B: Thickness of composite material

Subgroup C: Distance from curing unit to resin

Group 8: Paradigm LED 3M ESPE curing light and Kerr Sonicfill2

Subgroup A: Air (control)

Subgroup B: Thickness of composite material

Subgroup C: Distance from curing unit to resin

A total of 168 resin composite samples were fabricated in all the different groups and subgroups.

A jig was fabricated using a glass slab, which was elevated to have the curing light flush with slab. The K-type thermal sensor was then tapped to the glass slab with gorilla tap to stabilize the sensor. The jig was modified with PVS to 1mm thickness and stabilized with a 1mm thick acrylic washer, which was then flattened with a glass slab to ensure a stable surface for testing. (Picture 1, 2)

Initially the LED curing lights were tested without any composite material in different distances (0mm, 1mm, 2mm, 3mm) from the thermosensor. These were tested in all the four different LED curing lights highest irradiance. This gave a control of just air to correlate to the different thicknesses and distance subgroups. Three cycles of each one of those curing distances was taken and logged using the automatic data logger at 1 sec intervals. This was done twice, once on the first day of testing the Paradigm composite and again testing the Sonicfill2 composite for a total of six cycles for each light. This is seen in the subgroups A

After the different thicknesses without composite were tested, composite was used to test thermal changes. This is seen in all the subgroups B. Foil was placed down initially followed by different thicknesses of acrylic washers (Picture 5), which were coated with Vaseline around the inner orifice. Composite was then placed with composite gun into the inner orifice of the acrylic washer to be flush with thickness of washer. A glass microscope cover disc (Picture 3,4) was then placed over the washer/composite complex and was compressed with thicker glass slab to flatten the unpolymerized resin. The washer/composite complex was placed on the prepared jig and placed the tip of curing light flush (0mm) from the washer/composite complex. (Picture 8,9) The four different LED curing lights were then used at their highest irradiance to test the amount of heat that is generated with three different resin thicknesses (1mm, 2mm, 3mm). The datalogger automatically logged every 1-second. Logging was initiated prior to starting the curing lights. The data logger stayed logging until temperature returned to normal temperature. This was repeated three times for 1mm, 2mm, 3mm thicknesses for a total of 9 samples. This was done for each LED curing light and also for both sets of resin composite. The total for amount of samples for subgroup B was 72.

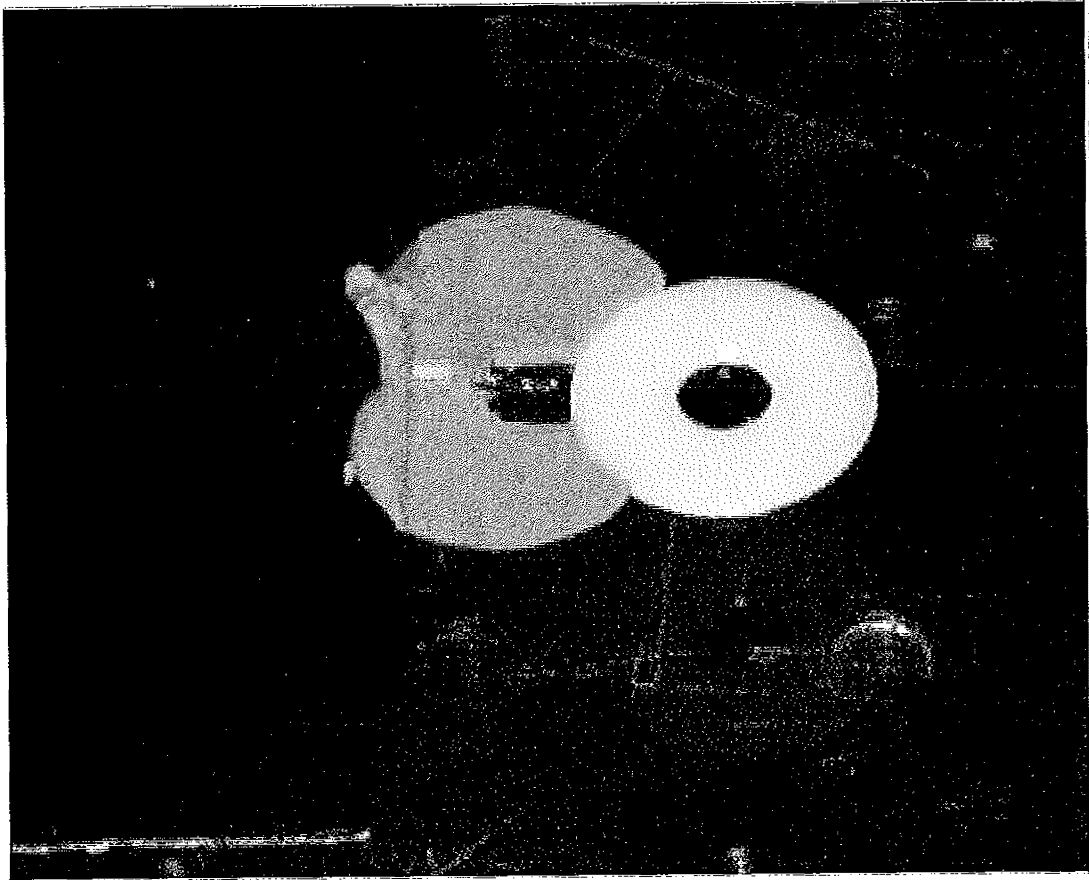
The second set of samples tested distance from curing light. This is seen in subgroup C. A standard 2mm thick acrylic washer was used for all of these distances. The same protocol was used to prepare each 2mm disc with composite to form the washer/composite complex. Different washers were then added to the 2mm washer to increase distance away from the composite and curing light to simulate 0mm, 1mm, 2mm, 3mm distance away from the composite and curing light. Each of these distances was then repeated three times as well and for a total of 12 samples. This was done for each LED curing light and also for both sets of resin composite. The total amount of samples for subgroup C was 96.

The different samples were made over multiple days using the same protocols and same materials in a light controlled room to inhibit early polymerization of the resin material and to adequately form proper samples for each group and subgroup.

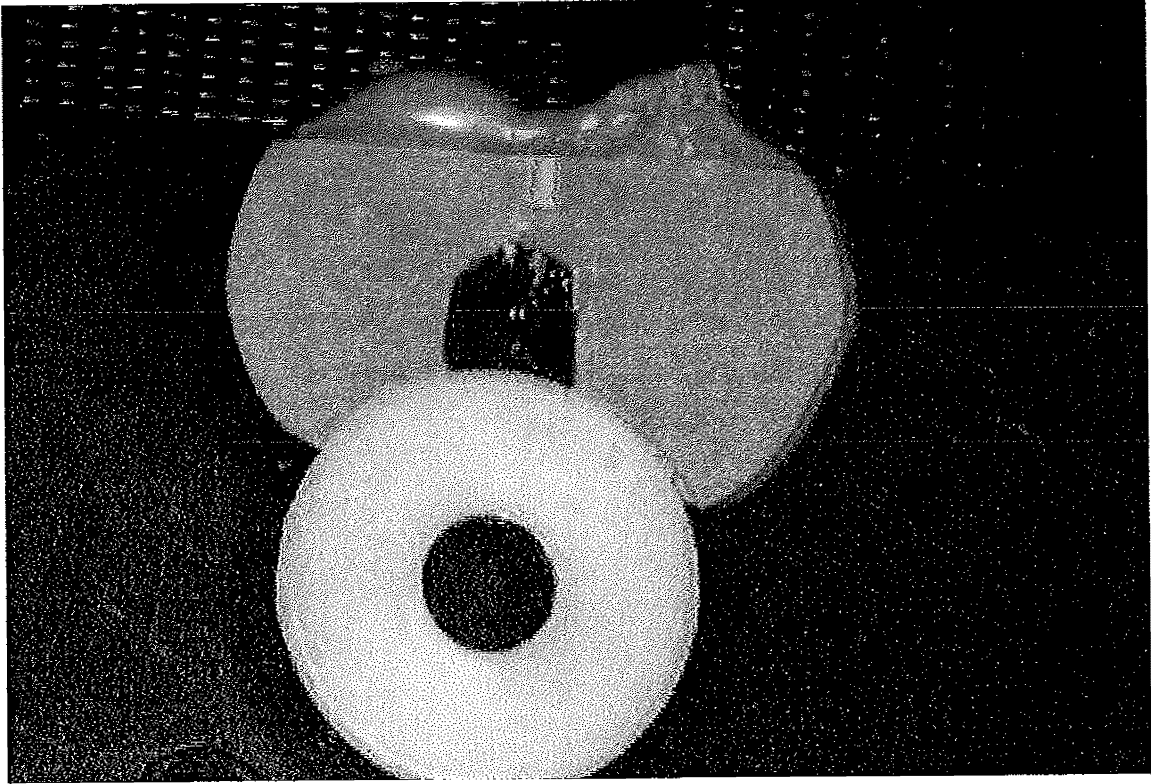
If it was possible the LED curing light was attached to the charging unit while in use to achieve the highest possible irradiance with each sample. If that were not possible, the LED curing light was charged in between usage to still maintain a high level of irradiance that was be standard throughout each sample.

The temperatures recorded by the Extech SDL200 4-Channel Datalogging Thermometer with SD Card Memory with a K-type thermocouple were transferred from the datalogger to an Excel® spreadsheet and recorded.

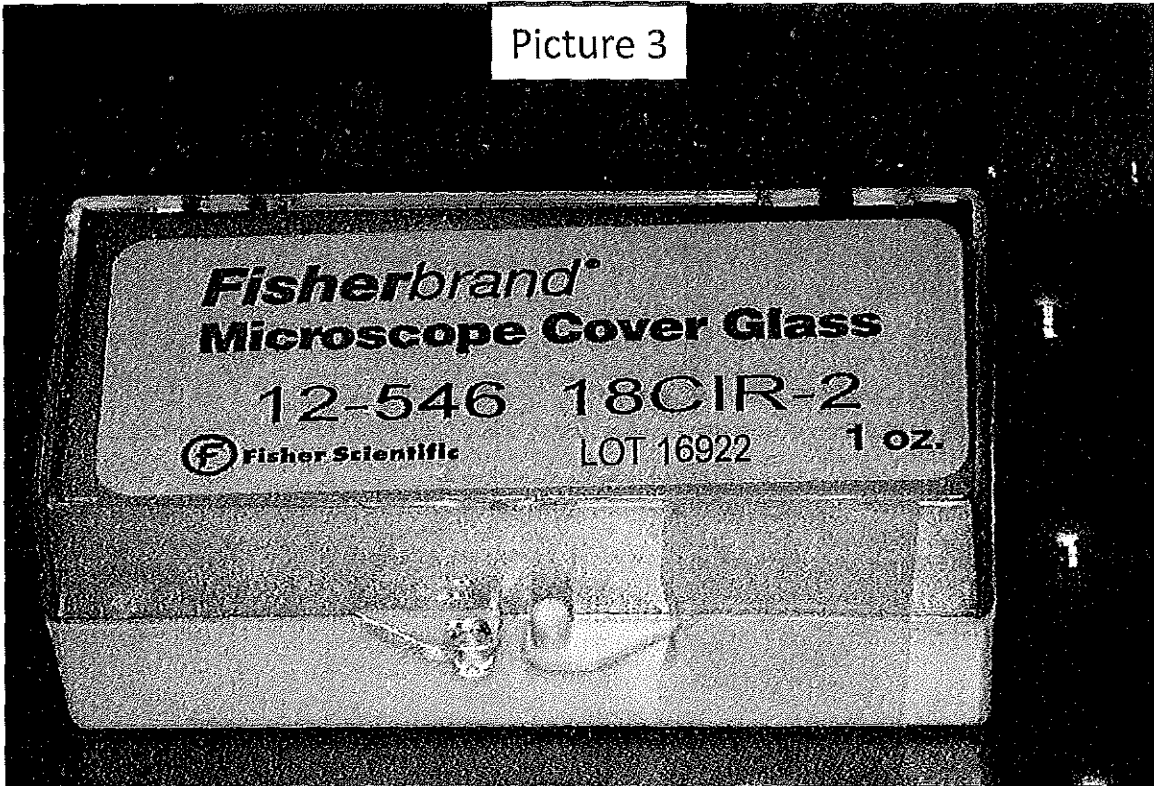
Picture 1



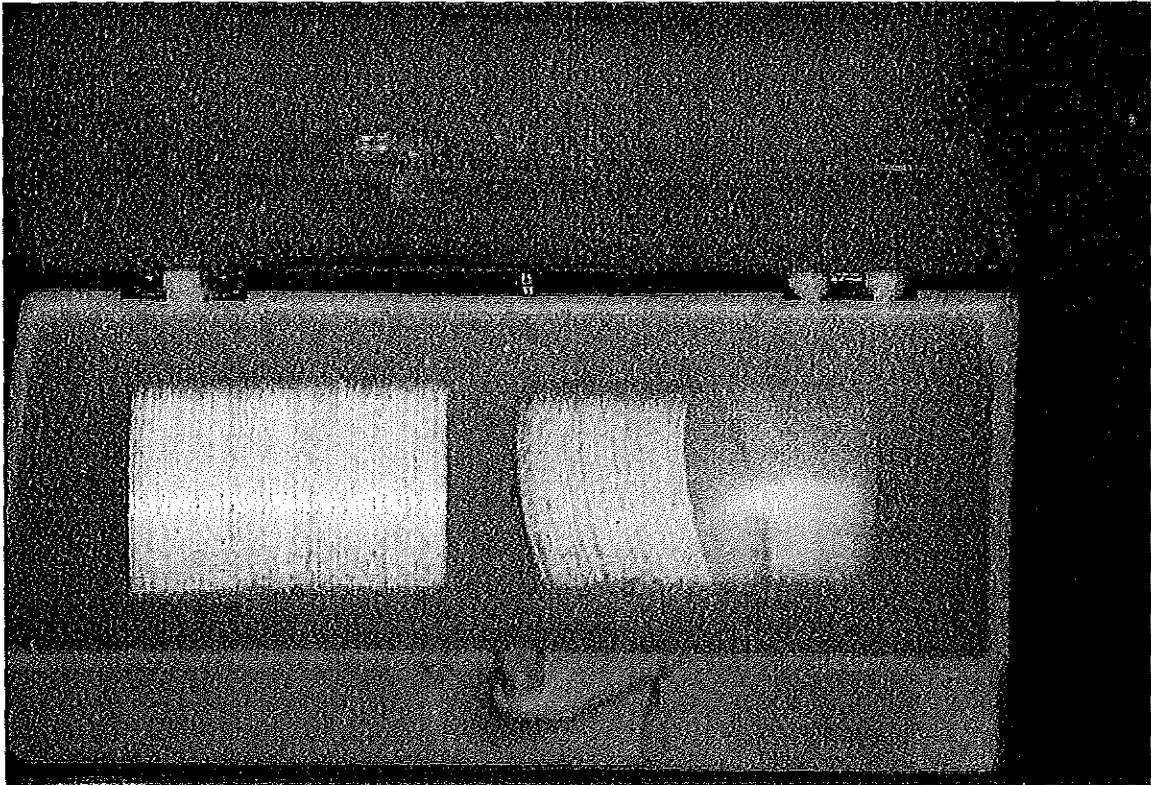
Picture 2



Picture 3



Picture 4



Picture 5

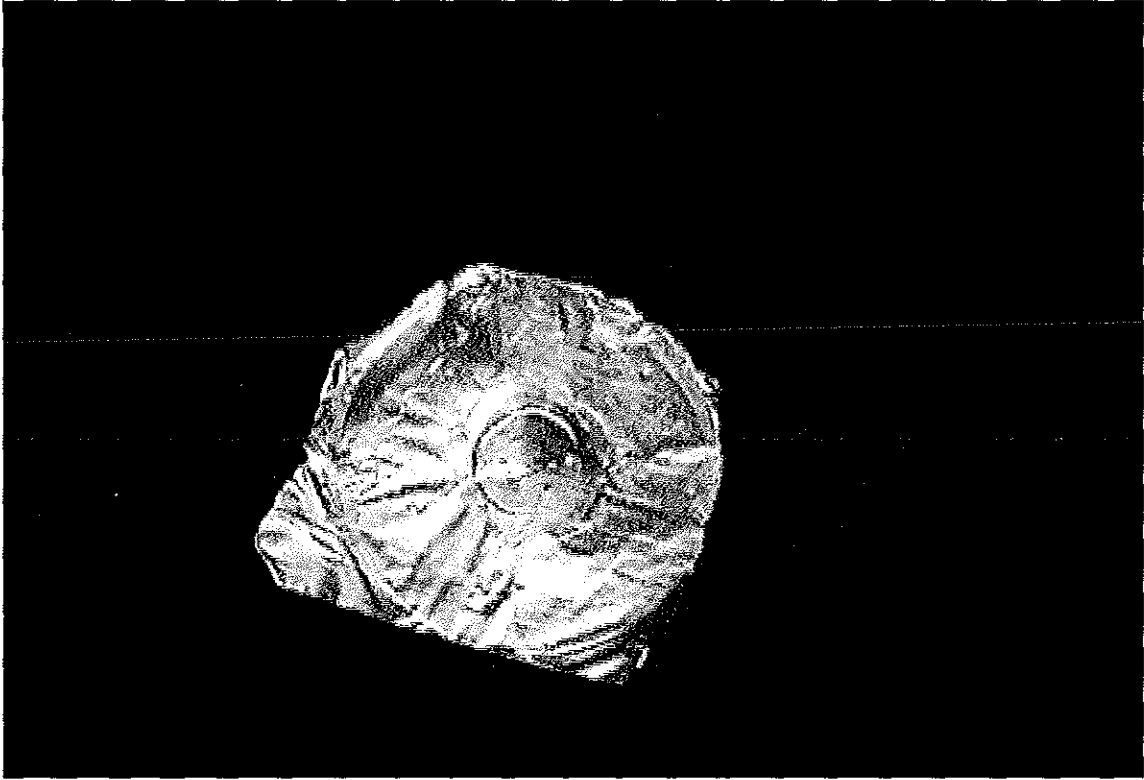
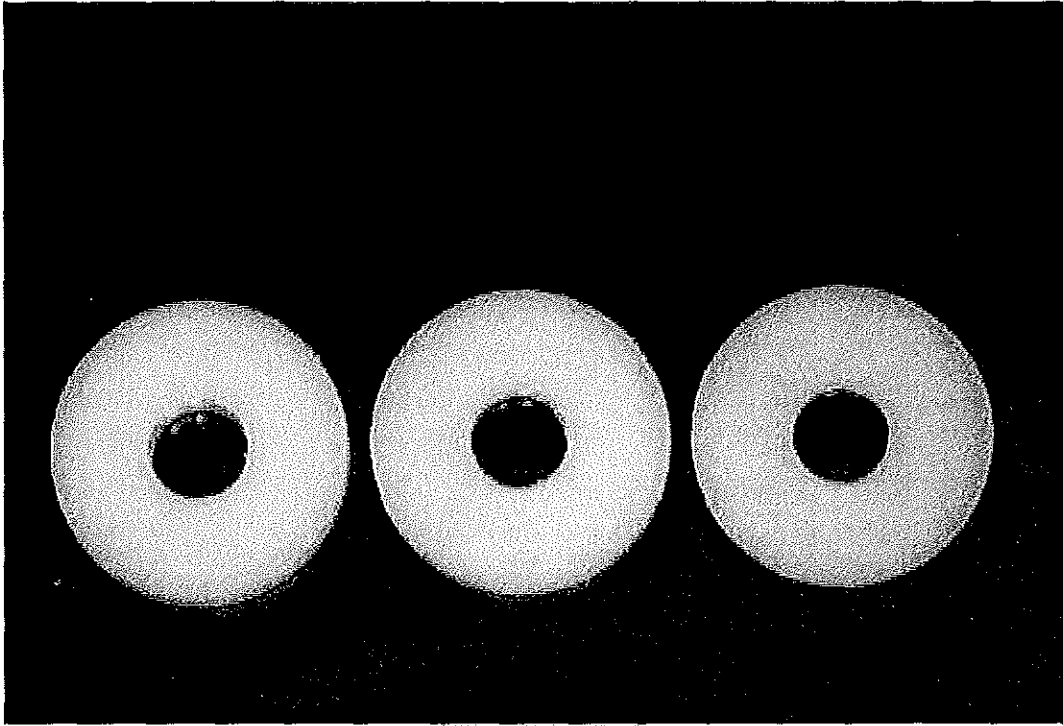
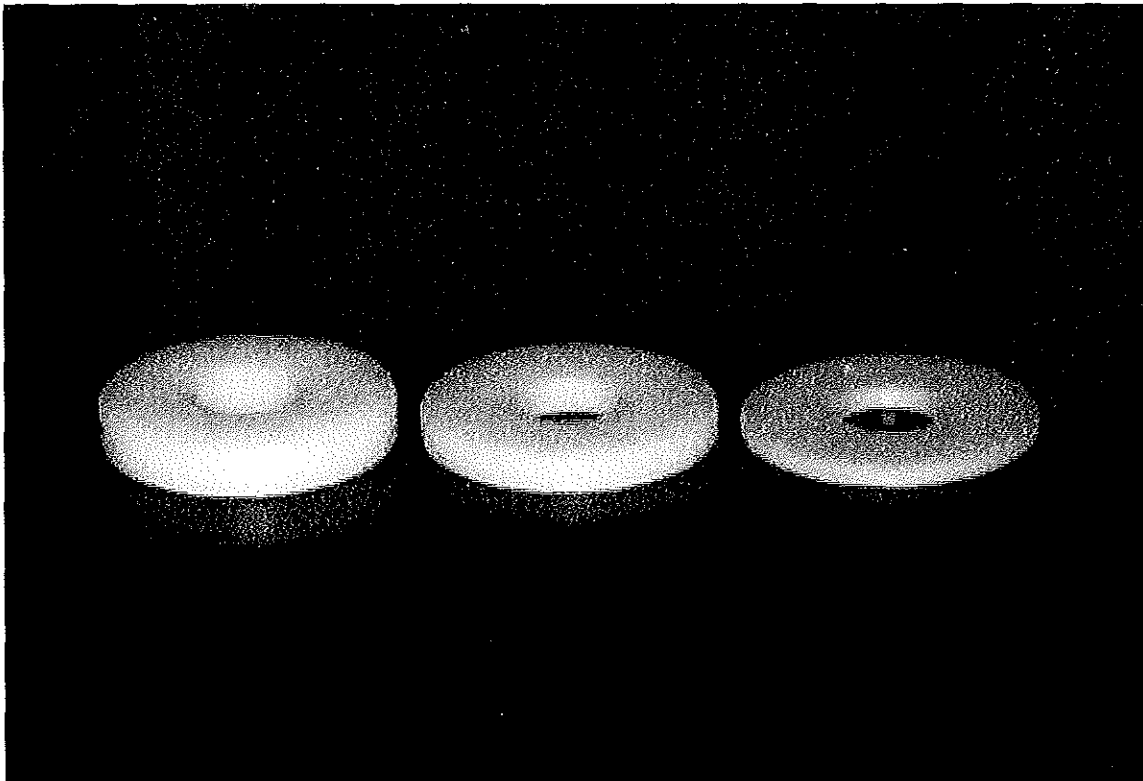


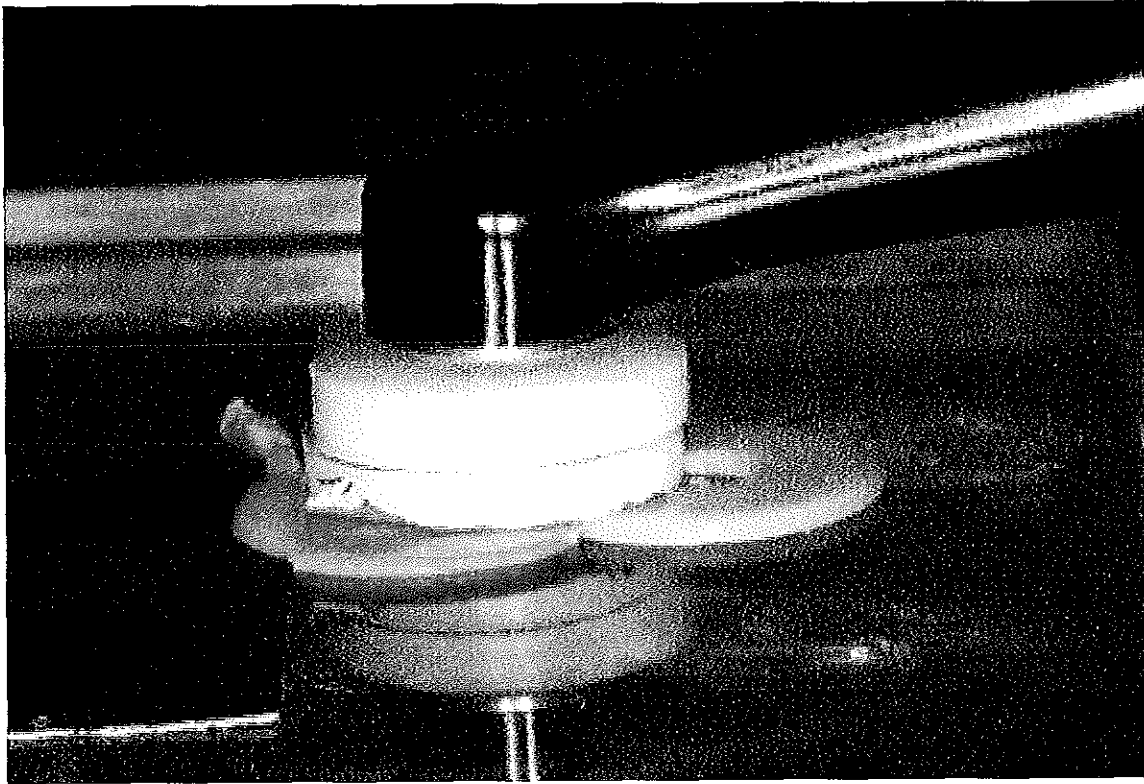
Figure 6



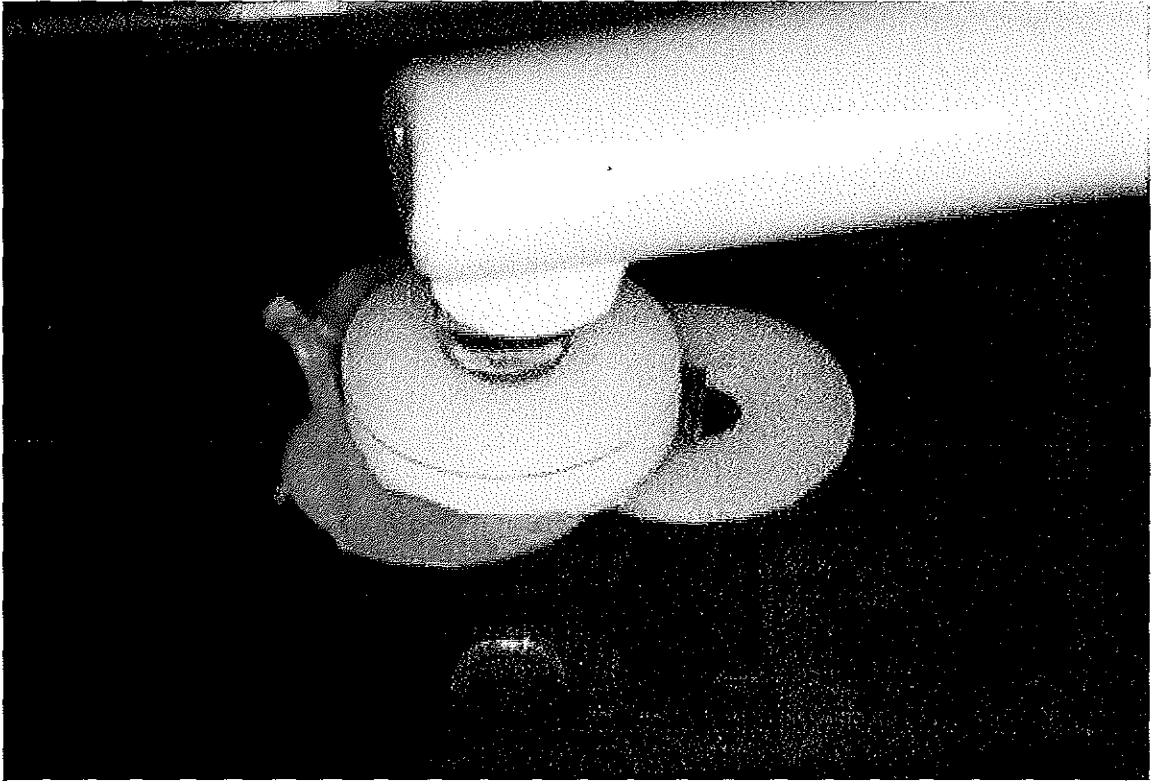
Picture 7



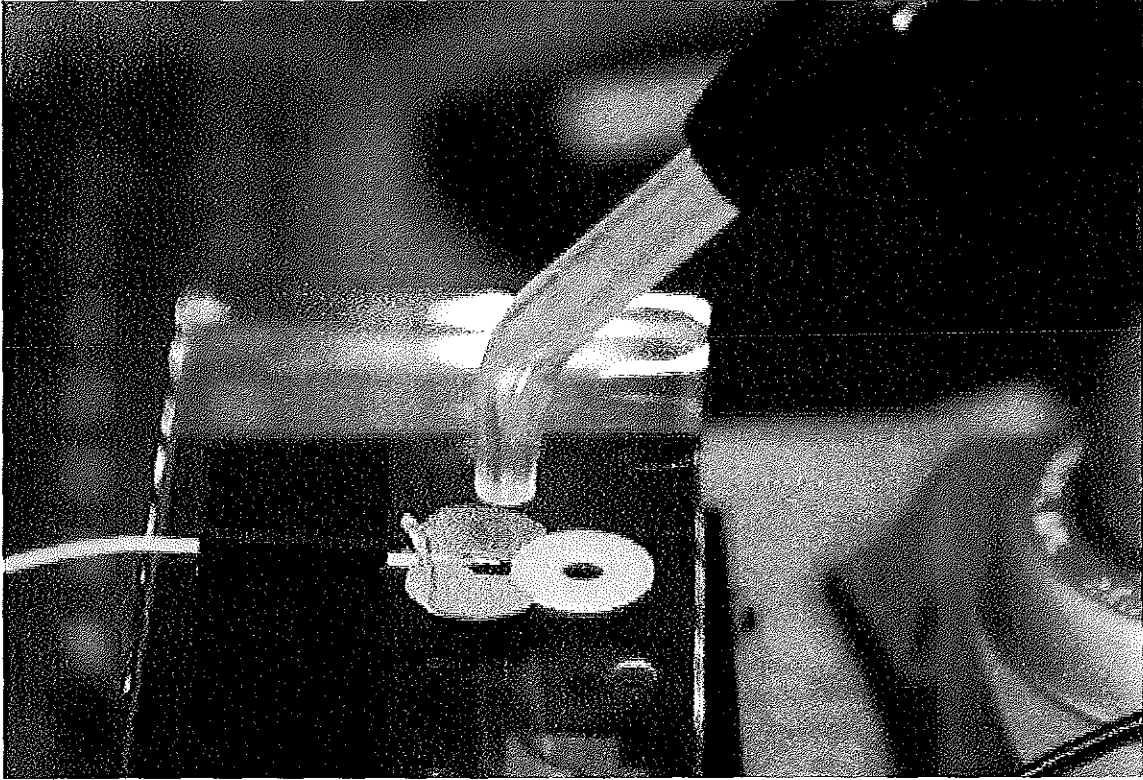
Picture 8



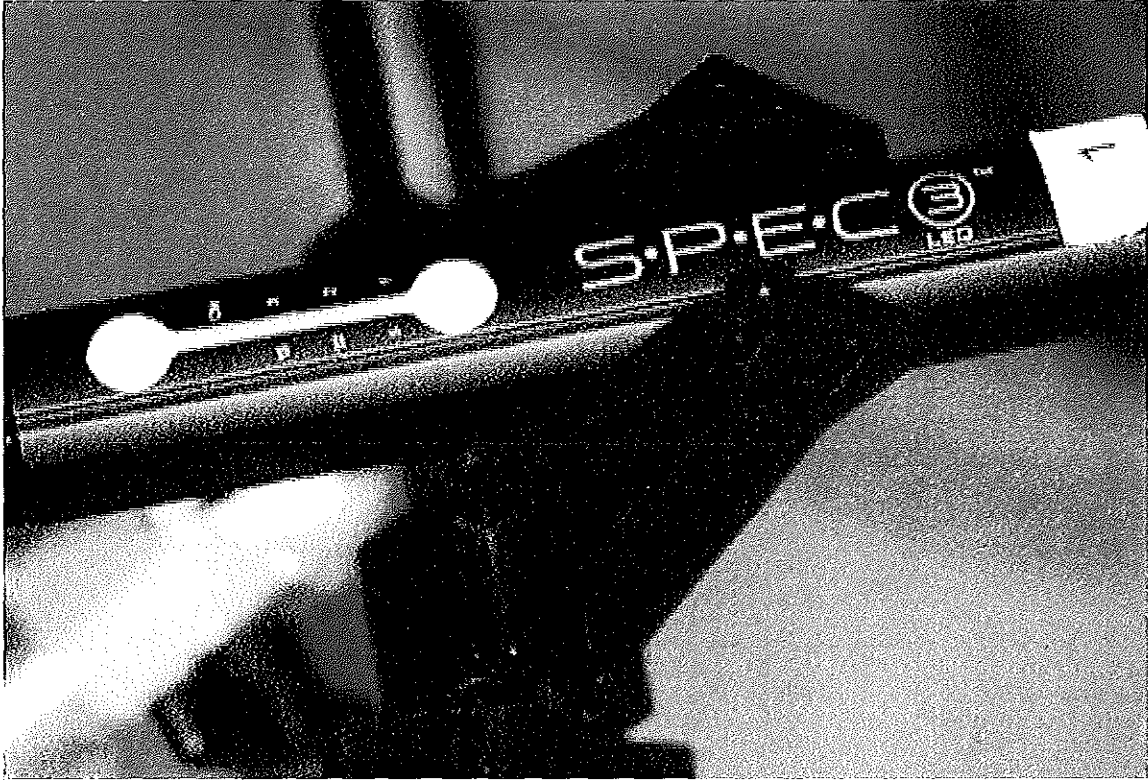
Picture 9



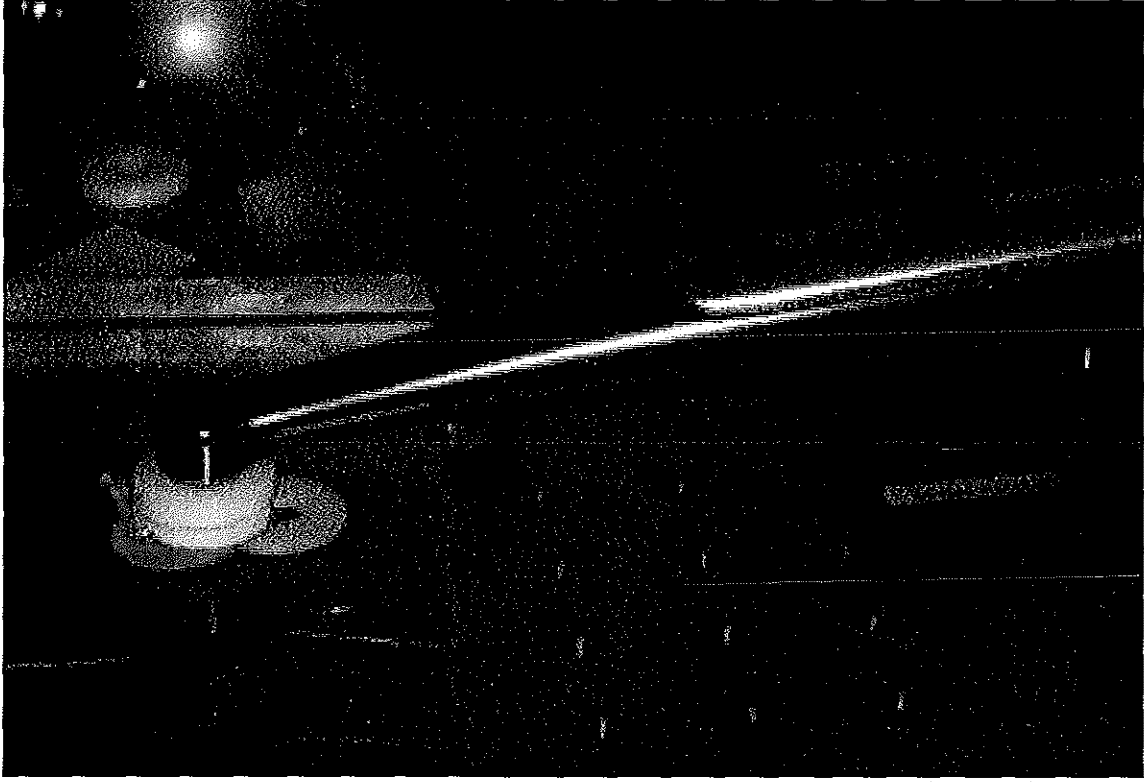
Picture 10



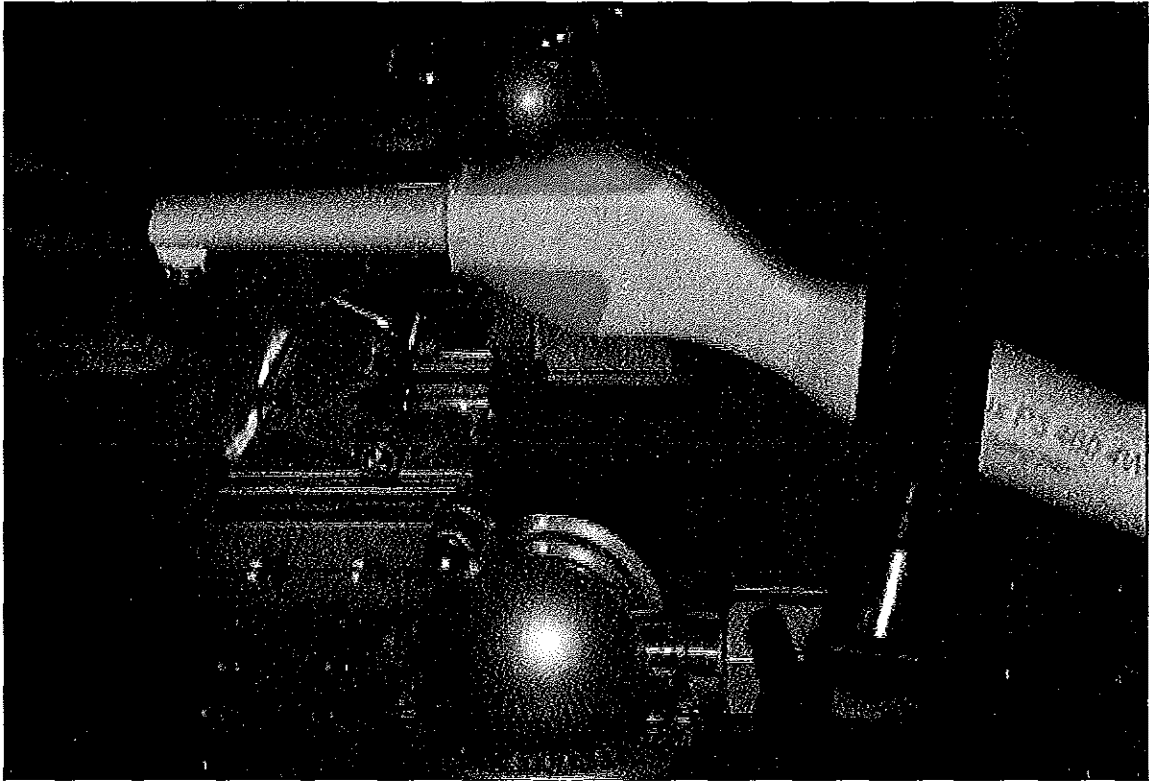
Picture 11



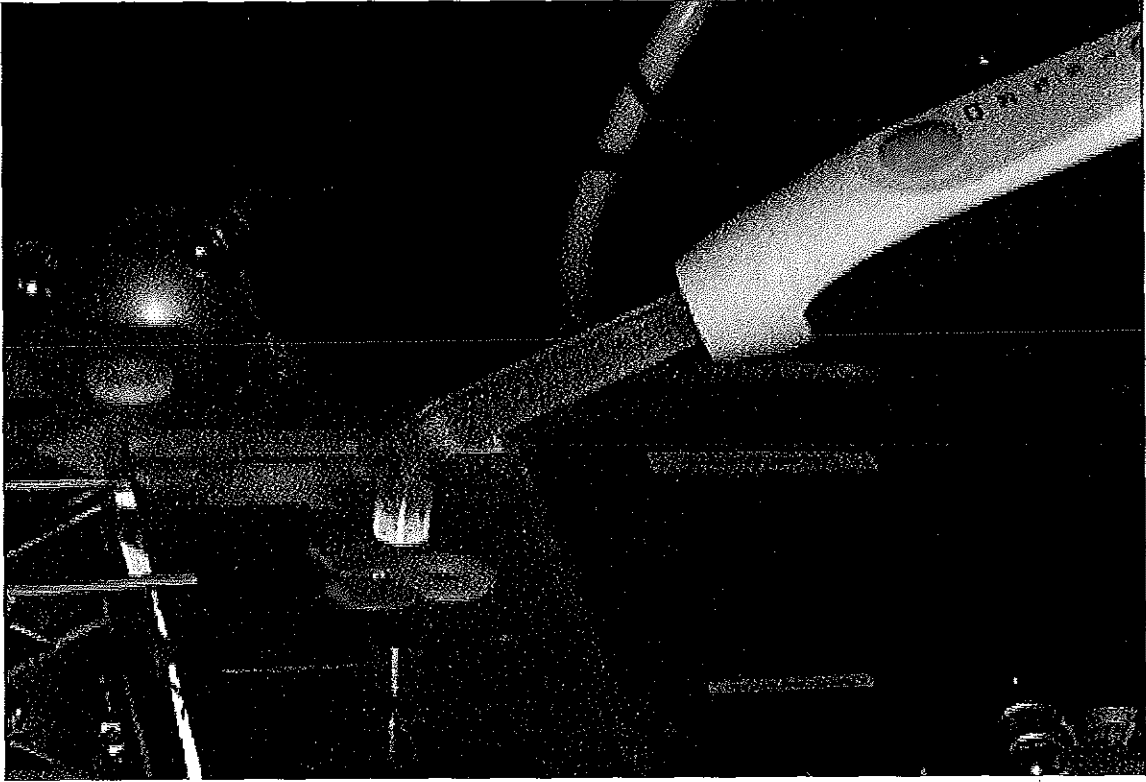
Picture 12



Picture 13



Picture 14



RESULTS

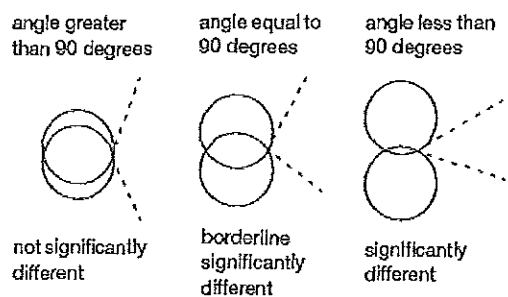
All of the eight sample groups and subgroups were performed according to what was described in the materials and methods section. The data logger recorded for 15 seconds for each of the three high intensity LED curing lights before starting the next sample in each subgroup to see the rise and fall of the temperature from the curing light and also the polymerization of the resin itself after the LED curing light was turned off if there was composite in the subgroup. After each cycle was run the mean, standard deviation and max was taken. For the Paradigm LED 3M ESPE LED curing light the data logger ran for a total of 25 seconds to see the rise and fall of the temperature from the curing light and also the polymerization of the resin itself after the LED curing light was turned off if there was composite in the subgroup. Again after each cycle was run the mean, standard deviation and max was taken. After all the samples were run for all eight groups and subgroups the average mean and mean max along with their corresponding standard deviations were taken. A one-way ANOVA followed by post hoc All-pairs Tukey-Kramer were used to compare the data (JMP® statistical discovery software from SAS). Each of the ten graphs have identical corresponding statistical data. The first table after each graph is a one-way analysis by column report that also shows aspects of the Tukey test.

The one-way platform tests the continuous variable against the nominal variable in relation to the mean differences. The mean diamonds shows the range of 95% confidence interval with the centerline being the mean for the group.

The circles on the Tukey test are a visual representation of all of the group means in the data set. They can be interpreted as being significant or non-significant. This is accomplished by observing whether or not the circles intersect. If they do not intersect, or intersect at an angle

that is less than 90 degrees, then they are statistically significant. If they intersect at an angle equal to or greater than 90 degrees, then they are not significant. (Figure 5)

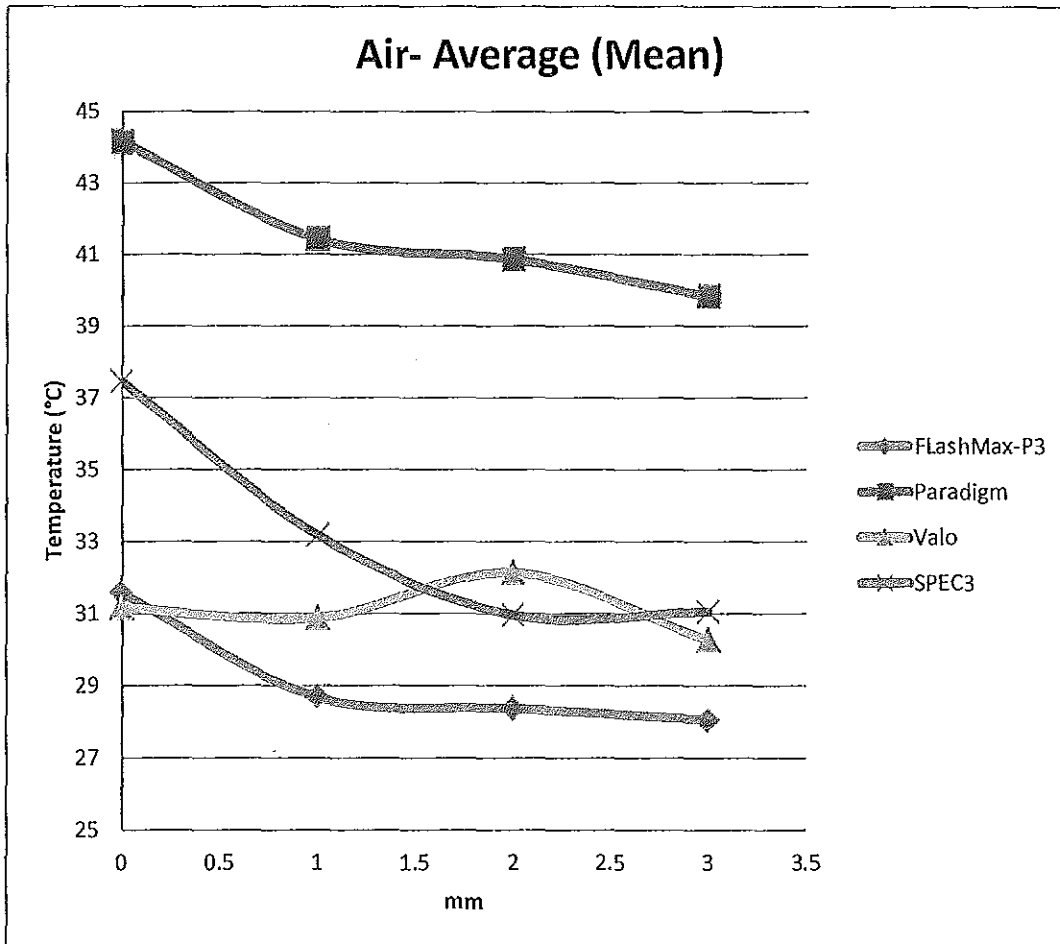
Figure 5



When comparing the means via one-way ANOVA, it depicts whether there is significant differences between the different means within the set. Within the analysis of variance, the probability of F being 0.05 or less indicates statistically significant differences between the means. The means of a one-way ANOVA report shows the number of times the samples were run and shows the confidence intervals.

If there is statistical significance seen in the one-way ANOVA, then it is necessary to compare the means. The test chosen to compare the means was the Tukey-Kramer test. Within the analysis of the Tukey-Kramer test, the connecting letters report shows statistically significant differences by way of letters. If the levels are connected by the same letter, then they are not significantly different. If levels are not connected by the same letter, then they are significantly different. (See figures 6-65)

Figure 6



At 0 mm the Paradigm light has the highest temperature compared to the other three lights. As the distance increases away from the light source, the temperature decreases

Figure 7

Oneway Analysis of Column 1 By Column 2

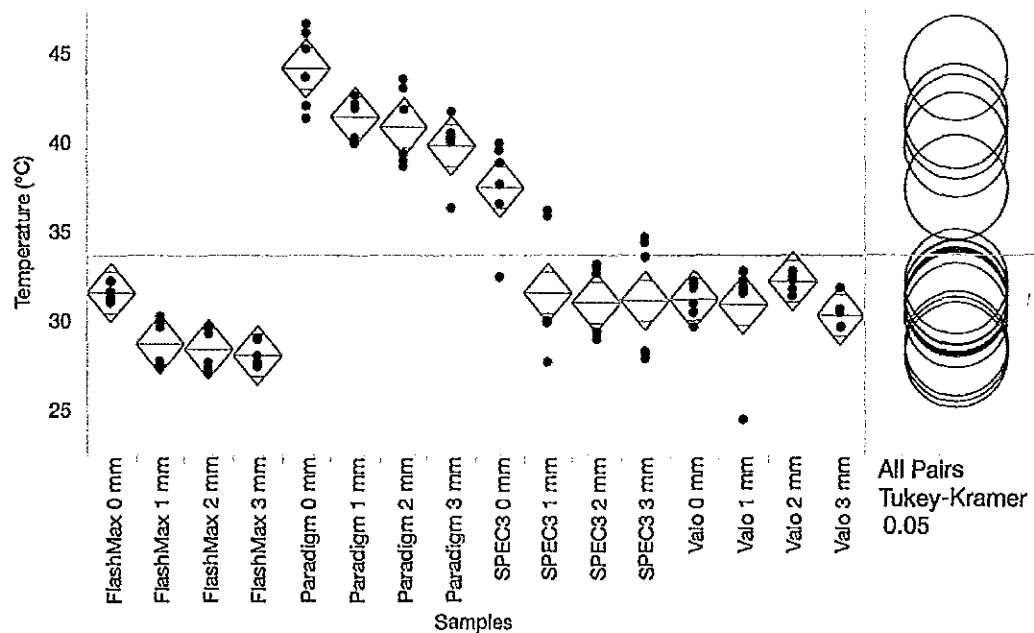


Figure 8

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Column 2	15	2454.0496	163.603	39.4142	<.0001*
Error	80	332.0700	4.151		
C. Total	95	2786.1196			

Figure 9

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FlashMax 0 mm	6	31.5833	0.83175	29.928	33.239
FlashMax 1 mm	6	28.6833	0.83175	27.028	30.339
FlashMax 2 mm	6	28.3667	0.83175	26.711	30.022
FlashMax 3 mm	6	28.0500	0.83175	26.395	29.705
Paradigm 0 mm	6	44.1333	0.83175	42.478	45.789
Paradigm 1 mm	6	41.4333	0.83175	39.778	43.089
Paradigm 2 mm	6	40.8500	0.83175	39.195	42.505
Paradigm 3 mm	6	39.8333	0.83175	38.178	41.489
SPEC3 0 mm	6	37.4500	0.83175	35.795	39.105
SPEC3 1 mm	6	31.5167	0.83175	29.861	33.172
SPEC3 2 mm	6	30.9833	0.83175	29.328	32.639
SPEC3 3 mm	6	31.0833	0.83175	29.428	32.739
Valo 0 mm	6	31.1500	0.83175	29.495	32.805
Valo 1 mm	6	30.8833	0.83175	29.228	32.539
Valo 2 mm	6	32.1667	0.83175	30.511	33.822
Valo 3 mm	6	30.2667	0.83175	28.611	31.922

Std Error uses a pooled estimate of error variance

Figure 10

Connecting Letters Report

Level		Mean
Paradigm 0 mm	A	44.133333
Paradigm 1 mm	A B	41.433333
Paradigm 2 mm	A B	40.850000
Paradigm 3 mm	B	39.833333
SPEC3 0 mm	B	37.450000
Valo 2 mm	C	32.166667
FlashMax 0 mm	C	31.583333
SPEC3 1 mm	C	31.516667
Valo 0 mm	C	31.150000
SPEC3 3 mm	C	31.083333
SPEC3 2 mm	C	30.983333
Valo 1 mm	C	30.883333
Valo 3 mm	C	30.266667
FlashMax 1 mm	C	28.683333
FlashMax 2 mm	C	28.366667
FlashMax 3 mm	C	28.050000

Levels not connected by same letter are significantly different.

Figure 11

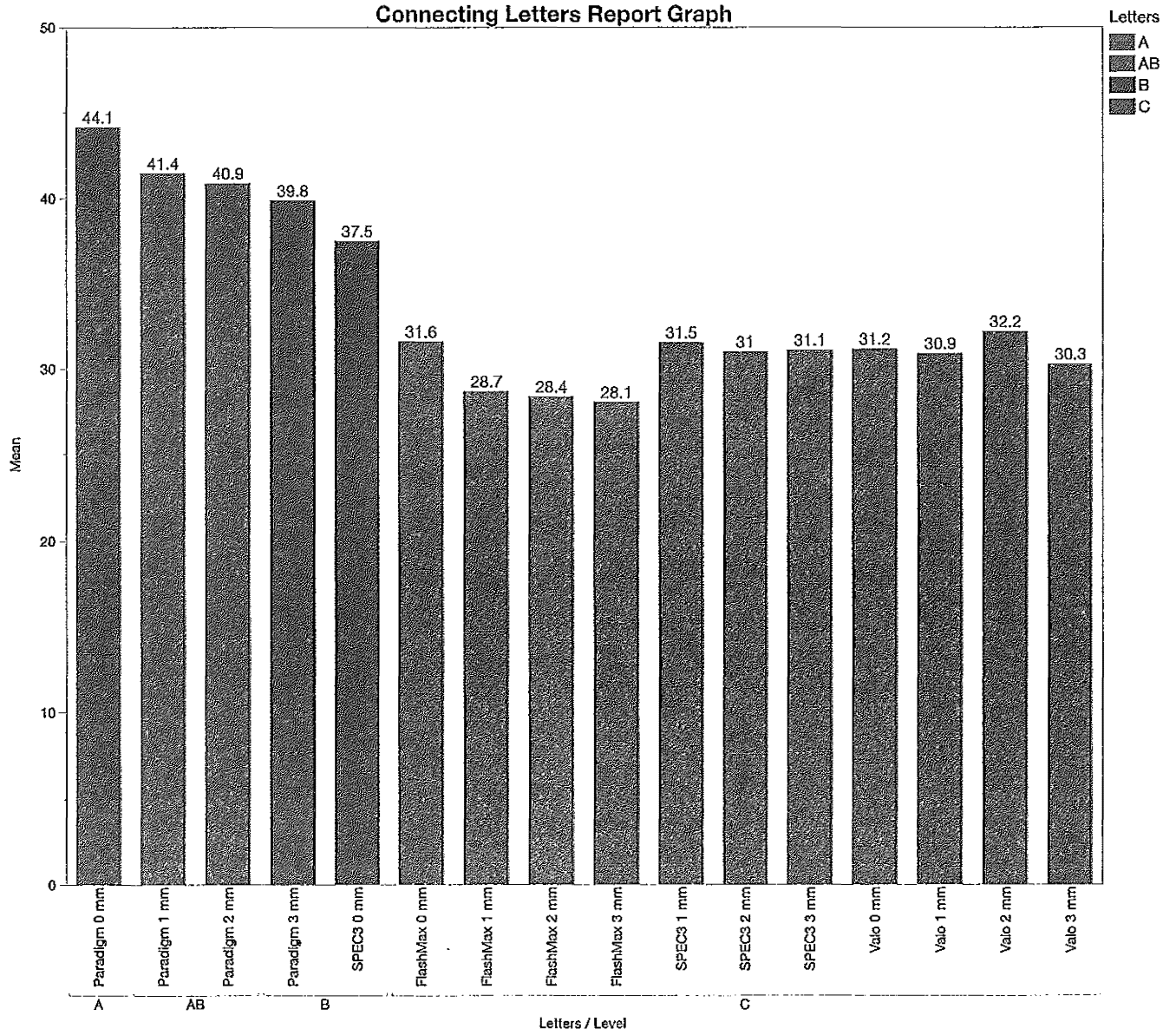
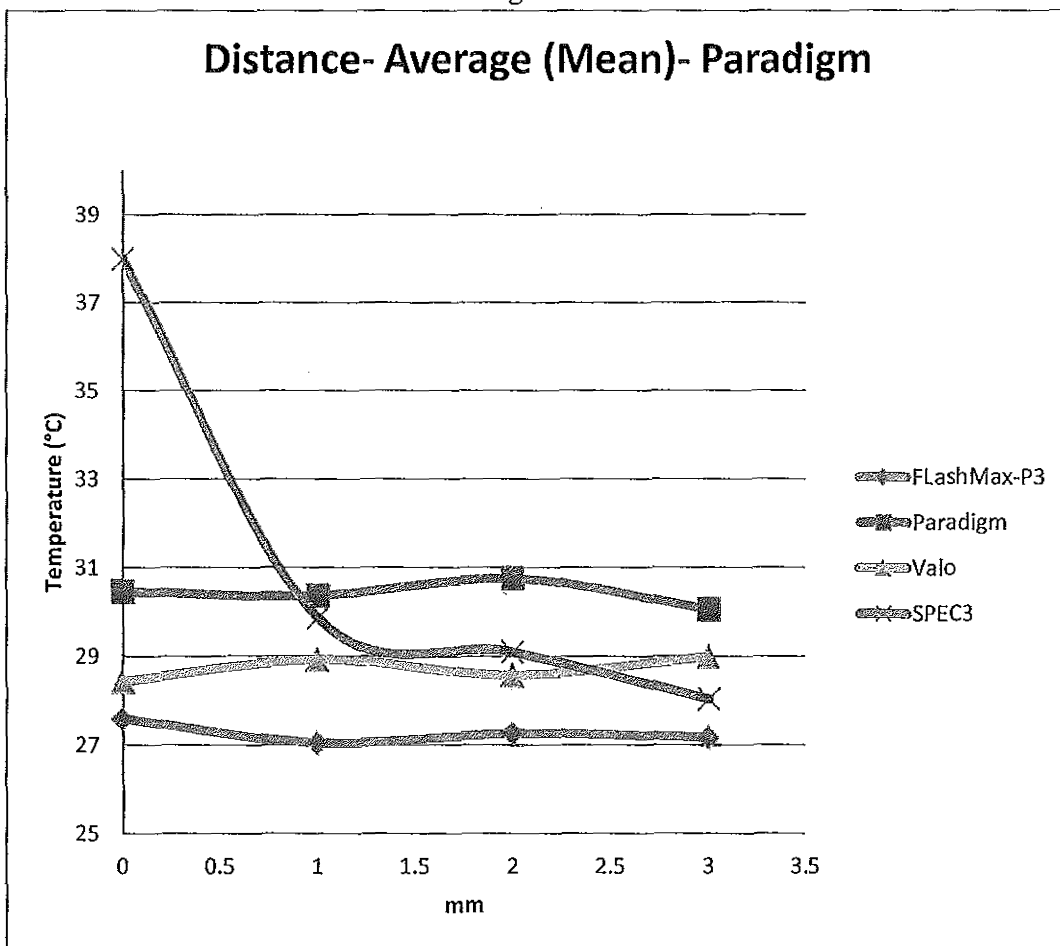


Figure 12



Initially the SPEC3 curing light has the highest temperature at 0 mm curing through the same amount of composite as the other three lights.

Figure 13

Oneway Analysis of Column 1 By Column 2

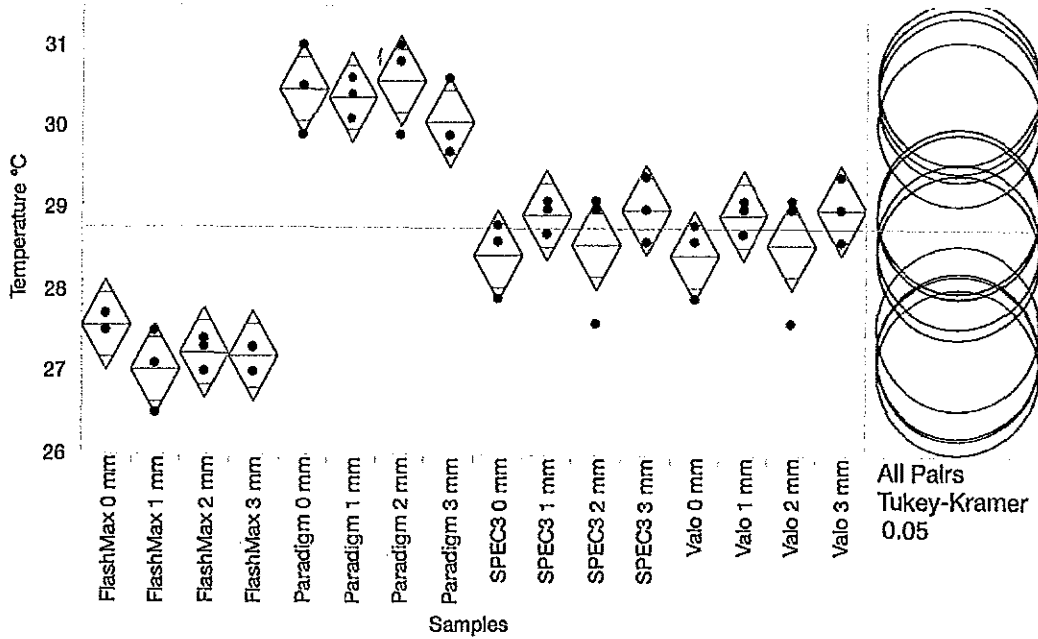


Figure 14

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Column 2	15	60.288125	4.01921	18.2002	<.0001*
Error	32	7.066667	0.22083		
C. Total	47	67.354792			

Figure 15

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FlashMax 0 mm	3	27.5667	0.27131	27.014	28.119
FlashMax 1 mm	3	27.0333	0.27131	26.481	27.586
FlashMax 2 mm	3	27.2333	0.27131	26.681	27.786
FlashMax 3 mm	3	27.2000	0.27131	26.647	27.753
Paradigm 0 mm	3	30.4667	0.27131	29.914	31.019
Paradigm 1 mm	3	30.3667	0.27131	29.814	30.919
Paradigm 2 mm	3	30.5667	0.27131	30.014	31.119
Paradigm 3 mm	3	30.0667	0.27131	29.514	30.619
SPEC3 0 mm	3	28.4333	0.27131	27.881	28.986
SPEC3 1 mm	3	28.9333	0.27131	28.381	29.486
SPEC3 2 mm	3	28.5667	0.27131	28.014	29.119
SPEC3 3 mm	3	29.0000	0.27131	28.447	29.553
Valo 0 mm	3	28.4333	0.27131	27.881	28.986
Valo 1 mm	3	28.9333	0.27131	28.381	29.486
Valo 2 mm	3	28.5667	0.27131	28.014	29.119
Valo 3 mm	3	29.0000	0.27131	28.447	29.553

Std Error uses a pooled estimate of error variance

Figure 16

Connecting Letters Report

Level	Mean
Paradigm 2 mm A	30.566667
Paradigm 0 mm A	30.466667
Paradigm 1 mm A B	30.366667
Paradigm 3 mm A B C	30.066667
SPEC3 3 mm B C D	29.000000
Valo 3 mm B C D	29.000000
SPEC3 1 mm C D E	28.933333
Valo 1 mm C D E	28.933333
SPEC3 2 mm D E F	28.566667
Valo 2 mm D E F	28.566667
SPEC3 0 mm D E F G	28.433333
Valo 0 mm D E F G	28.433333
FlashMax 0 mm E F G	27.566667
FlashMax 2 mm F G	27.233333
FlashMax 3 mm F G	27.200000
FlashMax 1 mm G	27.033333

Levels not connected by same letter are significantly different.

Figure 17

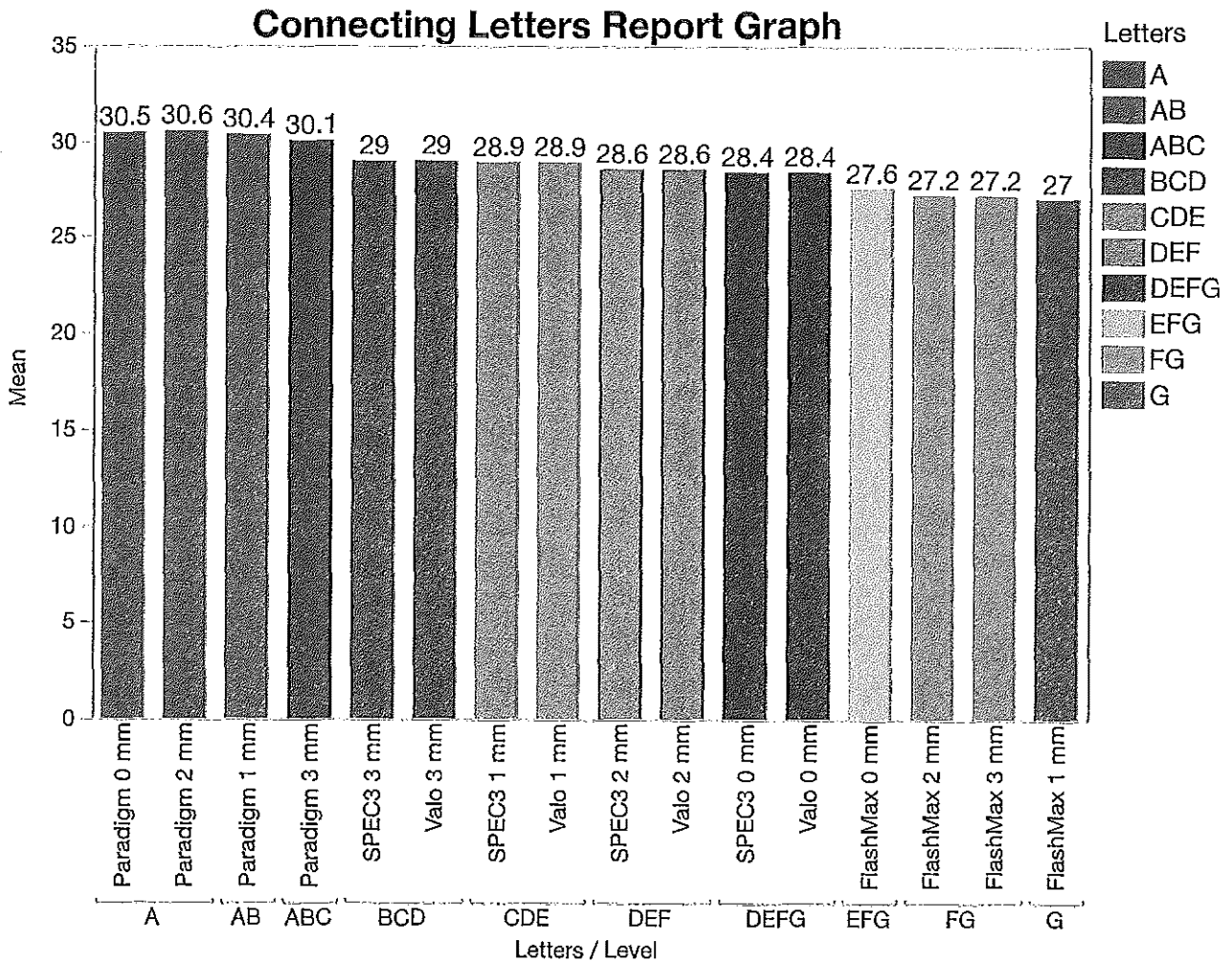
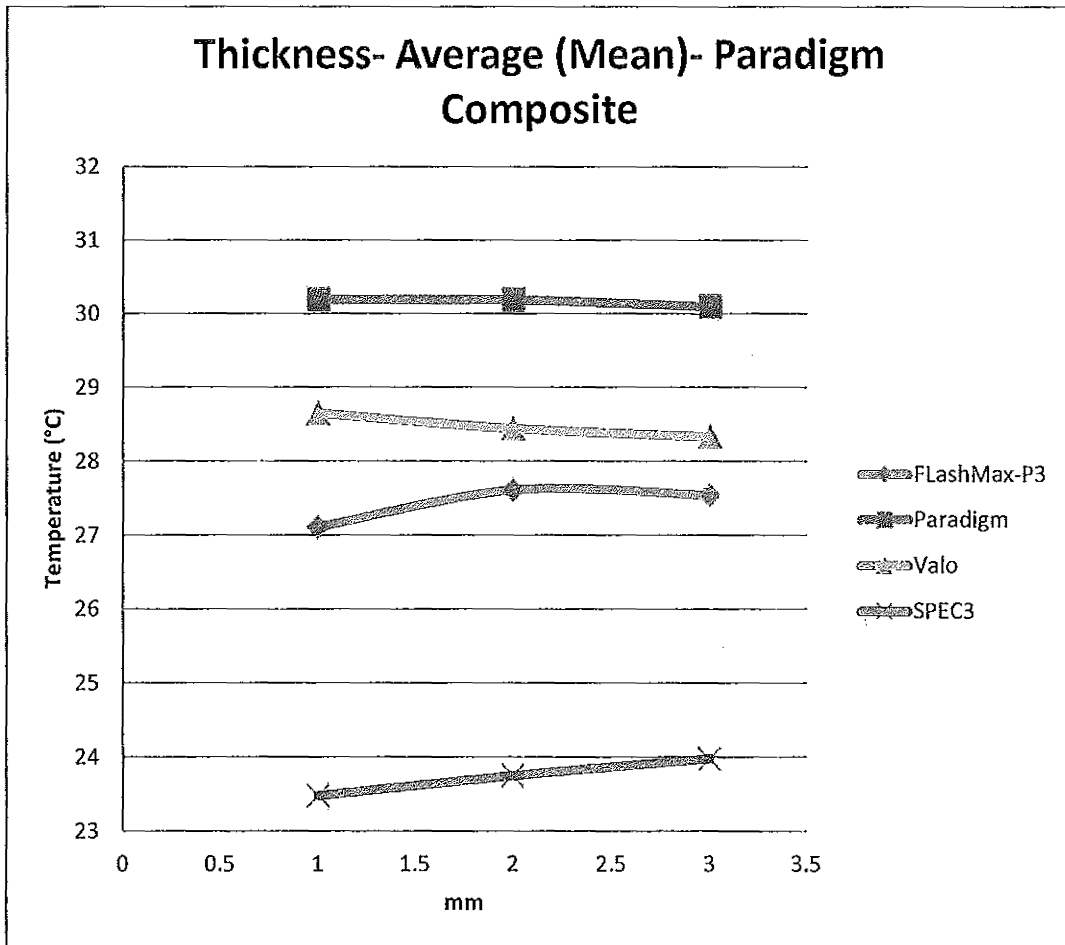


Figure 18



Overall the change in temperature for different thicknesses of composite was about the same for all four curing lights.

Figure 19

Oneway Analysis of Column 1 By Column 2

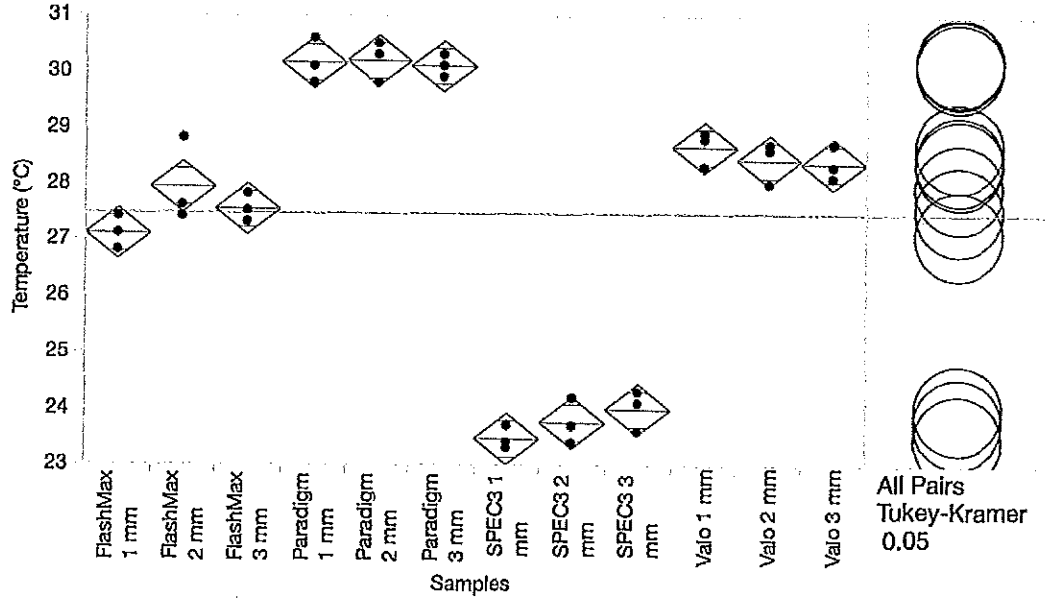


Figure 20

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Column 2	11	200.82889	18.2572	126.1532	<.0001*
Error	24	3.47333	0.1447		
C. Total	35	204.30222			

Figure 21

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FlashMax 1 mm	3	27.1000	0.21964	26.647	27.553
FlashMax 2 mm	3	27.9333	0.21964	27.480	28.387
FlashMax 3 mm	3	27.5333	0.21964	27.080	27.987
Paradigm 1 mm	3	30.1667	0.21964	29.713	30.620
Paradigm 2 mm	3	30.2000	0.21964	29.747	30.653
Paradigm 3 mm	3	30.1000	0.21964	29.647	30.553
SPEC3 1 mm	3	23.4667	0.21964	23.013	23.920
SPEC3 2 mm	3	23.7667	0.21964	23.313	24.220
SPEC3 3 mm	3	24.0000	0.21964	23.547	24.453
Valo 1 mm	3	28.6667	0.21964	28.213	29.120
Valo 2 mm	3	28.4333	0.21964	27.980	28.887
Valo 3 mm	3	28.3667	0.21964	27.913	28.820

Std Error uses a pooled estimate of error variance

Figure 22

Connecting Letters Report

Level	Mean Letters
Paradigm 2 mm A	30.200000 A
Paradigm 1 mm A	30.166667 A
Paradigm 3 mm A	30.100000 A
Valo 1 mm B	28.666667 B
Valo 2 mm B C	28.433333 BC
Valo 3 mm B C	28.366667 BC
FlashMax 2 mm B C D	27.933333 BCD
FlashMax 3 mm C D	27.533333 CD
FlashMax 1 mm D	27.100000 D
SPEC3 3 mm E	24.000000 E
SPEC3 2 mm E	23.766667 E
SPEC3 1 mm E	23.466667 E

Levels not connected by same letter are significantly different.

Figure 23

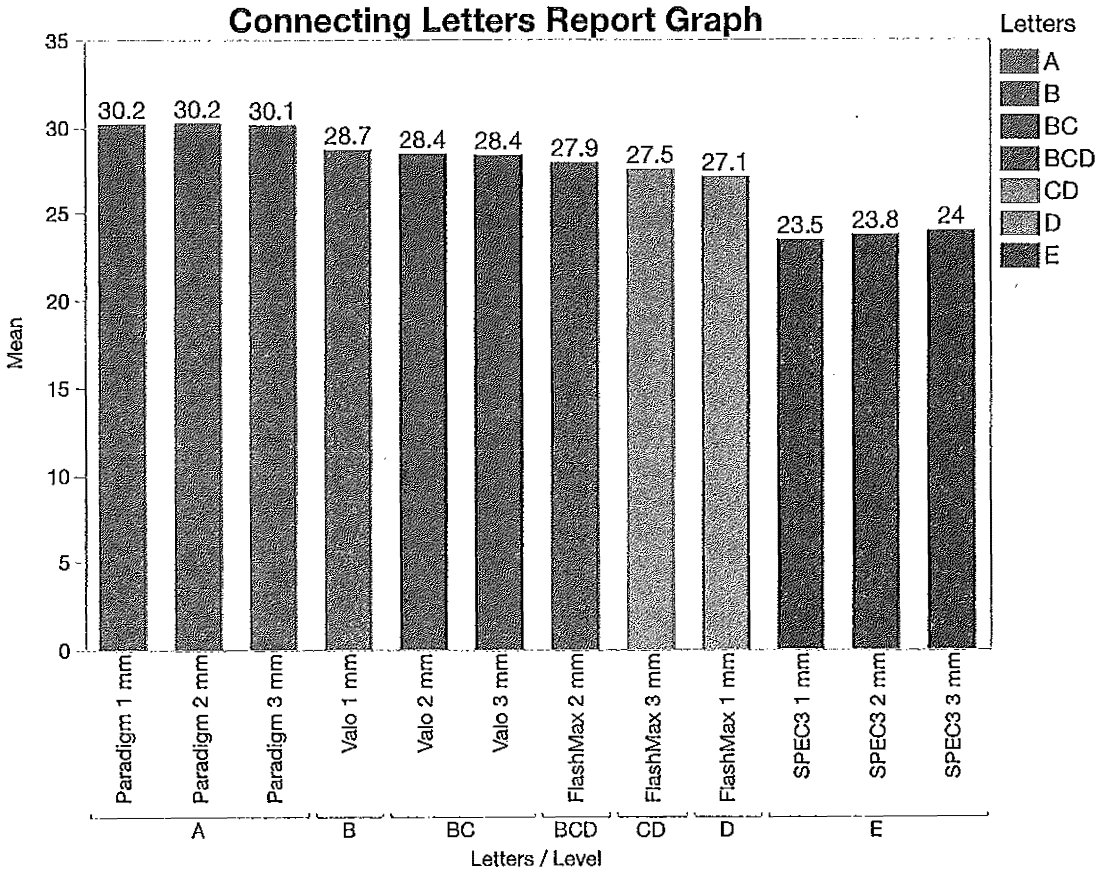
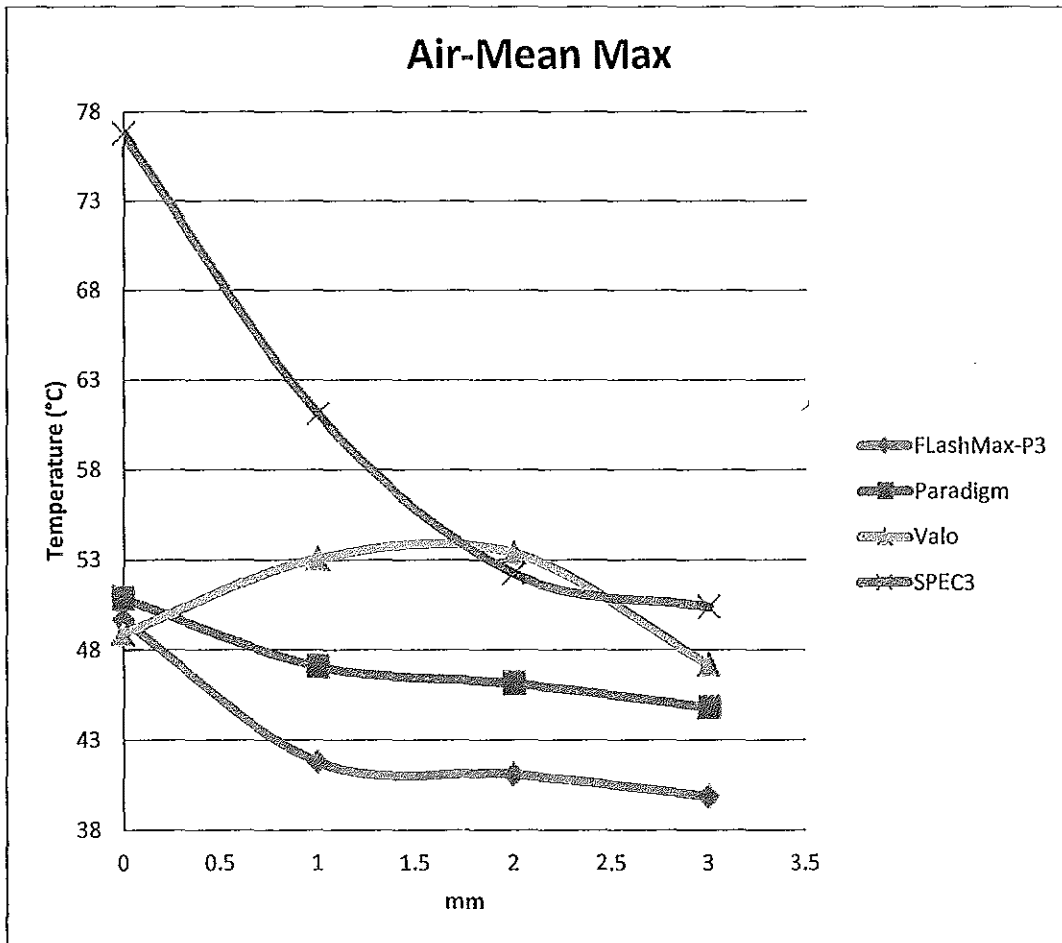


Figure 24



The SPEC3 has the highest temperature at 0 mm. This differs compared to the Average (Mean) where the Paradigm light had the highest temperature. This can show that when curing composite one needs to be careful with the SPEC3 due to the high range in temperature and varies drastically compared to the max to the average.

Figure 25

Oneway Analysis of Column 1 By Column 2

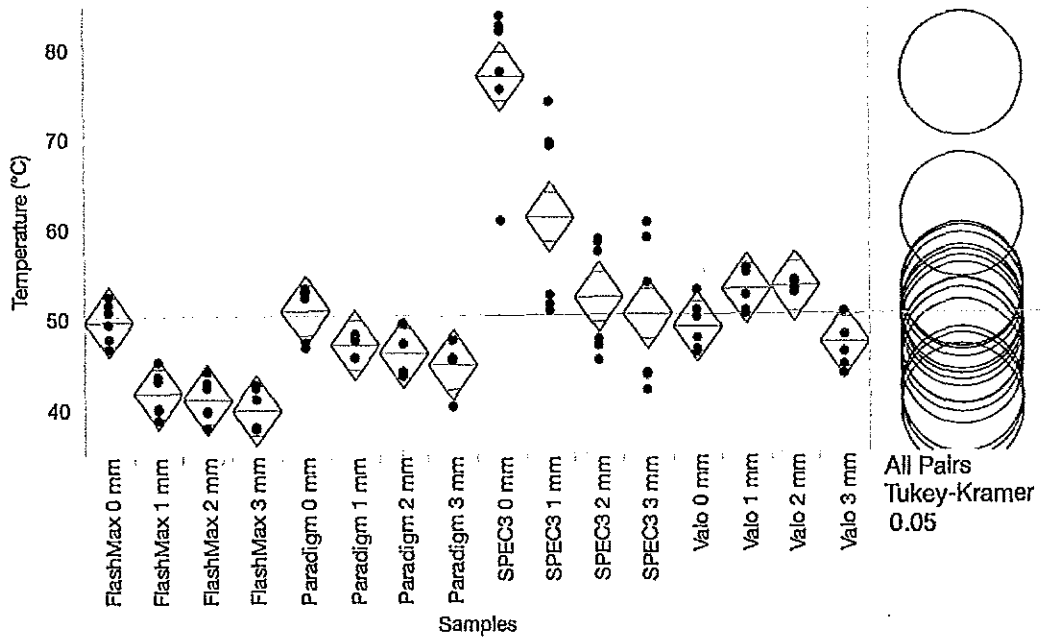


Figure 26

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Column 2	15	7068.4029	471.227	20.6326	<.0001*
Error	80	1827.1167	22.839		
C. Total	95	8895.5196			

Figure 27

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FlashMax 0 mm	6	49.7000	1.9510	45.817	53.583
FlashMax 1 mm	6	41.7833	1.9510	37.901	45.666
FlashMax 2 mm	6	41.1000	1.9510	37.217	44.983
FlashMax 3 mm	6	39.8833	1.9510	36.001	43.766
Paradigm 0 mm	6	50.8667	1.9510	46.984	54.749
Paradigm 1 mm	6	47.0833	1.9510	43.201	50.966
Paradigm 2 mm	6	46.1500	1.9510	42.267	50.033
Paradigm 3 mm	6	44.8167	1.9510	40.934	48.699
SPEC3 0 mm	6	76.8333	1.9510	72.951	80.716
SPEC3 1 mm	6	61.1333	1.9510	57.251	65.016
SPEC3 2 mm	6	52.2500	1.9510	48.367	56.133
SPEC3 3 mm	6	50.4000	1.9510	46.517	54.283
Valo 0 mm	6	48.9167	1.9510	45.034	52.799
Valo 1 mm	6	53.0833	1.9510	49.201	56.966
Valo 2 mm	6	53.3833	1.9510	49.501	57.266
Valo 3 mm	6	47.1833	1.9510	43.301	51.066

Std Error uses a pooled estimate of error variance

Figure 28

Connecting Letters Report

Level		Mean	Letters
SPEC3 0 mm	A	76.833333	A
SPEC3 1 mm	B	61.133333	B
Valo 2 mm	B C	53.383333	BC
Valo 1 mm	B C	53.083333	BC
SPEC3 2 mm	B C	52.250000	BC
Paradigm 0 mm	C D	50.866667	CD
SPEC3 3 mm	C D E	50.400000	CDE
FlashMax 0 mm	C D E	49.700000	CDE
Valo 0 mm	C D E F	48.916667	CDEF
Valo 3 mm	C D E F	47.183333	CDEF
Paradigm 1 mm	C D E F	47.083333	CDEF
Paradigm 2 mm	C D E F	46.150000	CDEF
Paradigm 3 mm	C D E F	44.816667	CDEF
FlashMax 1 mm	D E F	41.783333	DEF
FlashMax 2 mm	E F	41.100000	EF
FlashMax 3 mm	F	39.883333	F

Levels not connected by same letter are significantly different.

Figure 29

Connecting Letters Report Graph

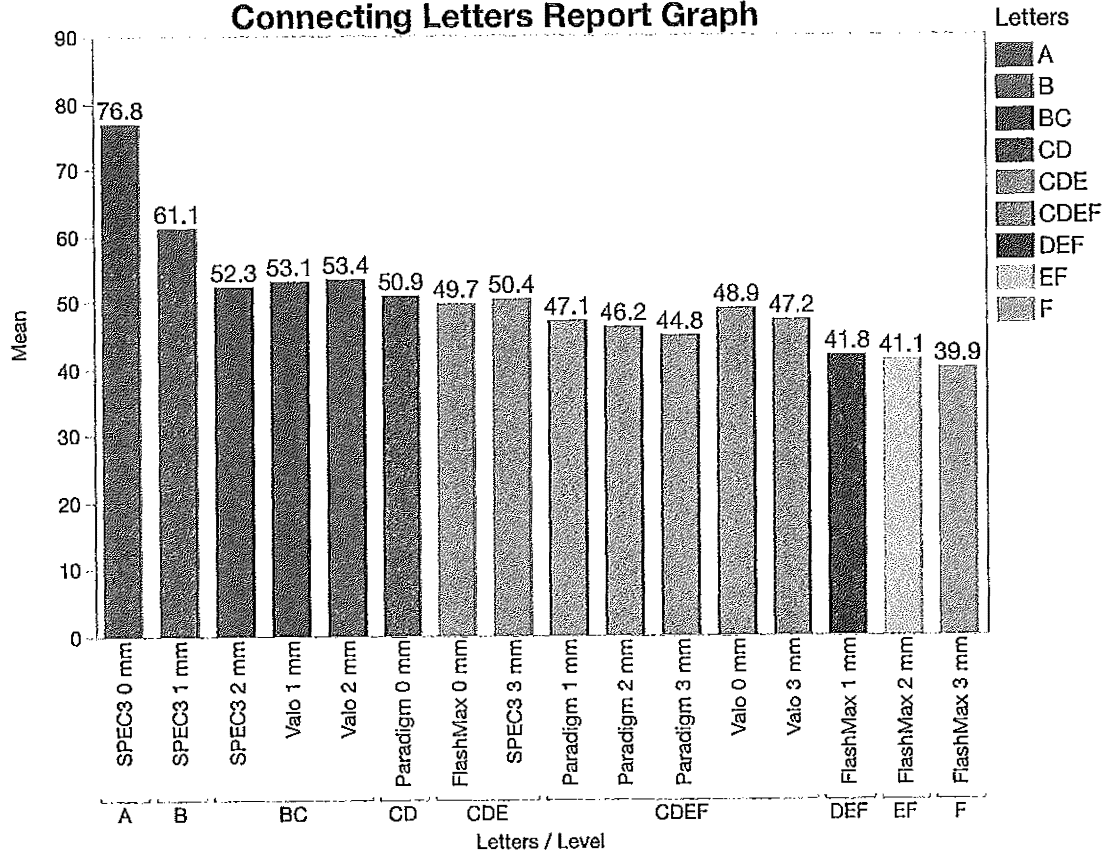


Figure 30

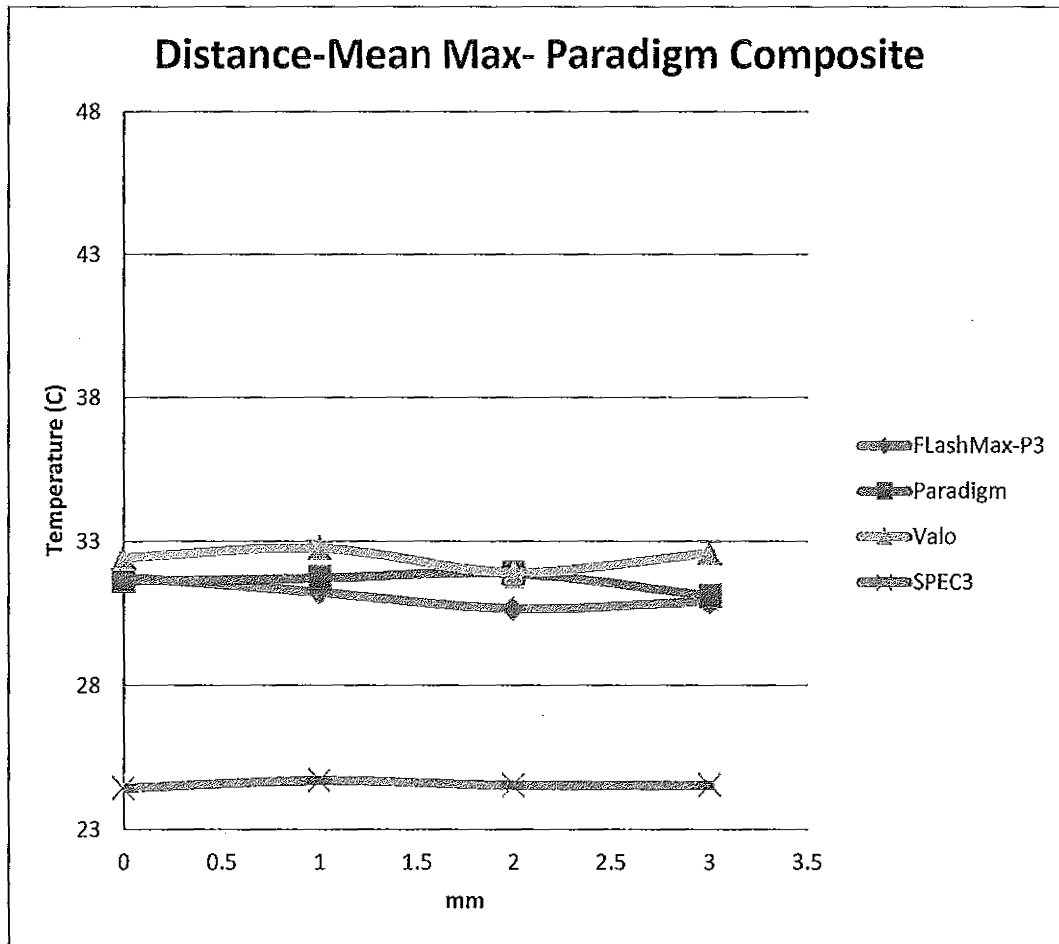


Figure 31

Oneway Analysis of Column 1 By Column 2

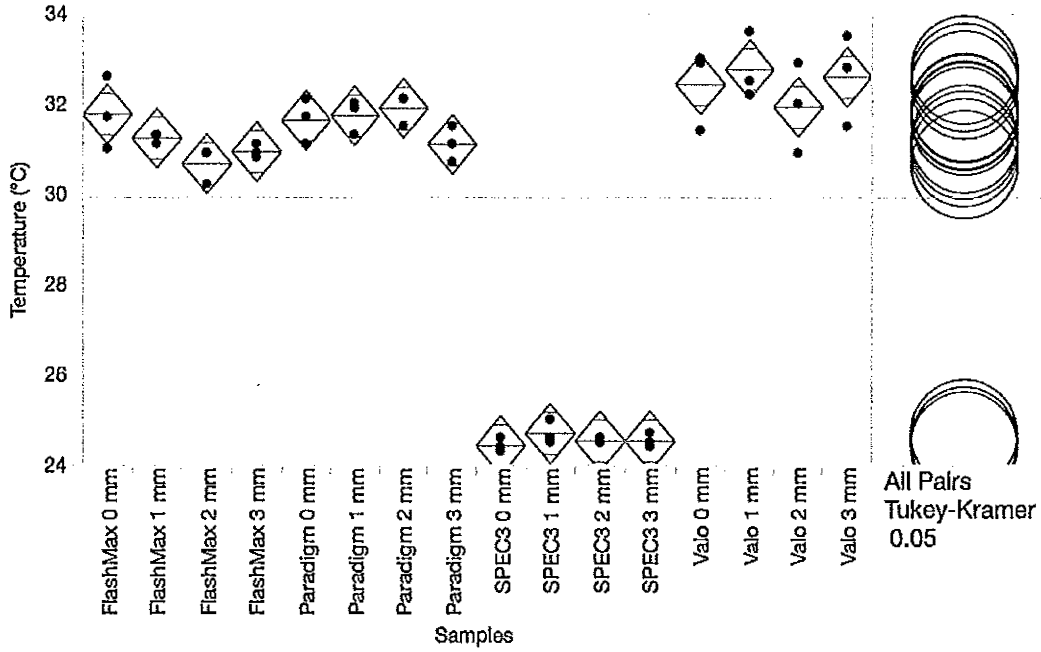


Figure 32

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Column 2	15	477.88313	31.8589	101.5422	<.0001*
Error	32	10.04000	0.3137		
C. Total	47	487.92313			

Figure 33

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FlashMax 0 mm	3	31.7667	0.32339	31.108	32.425
FlashMax 1 mm	3	31.2333	0.32339	30.575	31.892
FlashMax 2 mm	3	30.6667	0.32339	30.008	31.325
FlashMax 3 mm	3	30.9333	0.32339	30.275	31.592
Paradigm 0 mm	3	31.6333	0.32339	30.975	32.292
Paradigm 1 mm	3	31.7333	0.32339	31.075	32.392
Paradigm 2 mm	3	31.9000	0.32339	31.241	32.559
Paradigm 3 mm	3	31.1000	0.32339	30.441	31.759
SPEC3 0 mm	3	24.4333	0.32339	23.775	25.092
SPEC3 1 mm	3	24.7000	0.32339	24.041	25.359
SPEC3 2 mm	3	24.5333	0.32339	23.875	25.192
SPEC3 3 mm	3	24.5333	0.32339	23.875	25.192
Valo 0 mm	3	32.4333	0.32339	31.775	33.092
Valo 1 mm	3	32.7667	0.32339	32.108	33.425
Valo 2 mm	3	31.9333	0.32339	31.275	32.592
Valo 3 mm	3	32.6000	0.32339	31.941	33.259

Std Error uses a pooled estimate of error variance

Figure 34

Connecting Letters Report

Level		Mean	Letters
Valo 1 mm	A	32.766667	A
Valo 3 mm	A B	32.600000	AB
Valo 0 mm	A B	32.433333	AB
Valo 2 mm	A B C	31.933333	ABC
Paradigm 2 mm	A B C	31.900000	ABC
FlashMax 0 mm	A B C	31.766667	ABC
Paradigm 1 mm	A B C	31.733333	ABC
Paradigm 0 mm	A B C	31.633333	ABC
FlashMax 1 mm	A B C	31.233333	ABC
Paradigm 3 mm	A B C	31.100000	ABC
FlashMax 3 mm	B C	30.933333	BC
FlashMax 2 mm	C	30.666667	C
SPEC3 1 mm	D	24.700000	D
SPEC3 2 mm	D	24.533333	D
SPEC3 3 mm	D	24.533333	D
SPEC3 0 mm	D	24.433333	D

Levels not connected by same letter are significantly different.

Figure 35

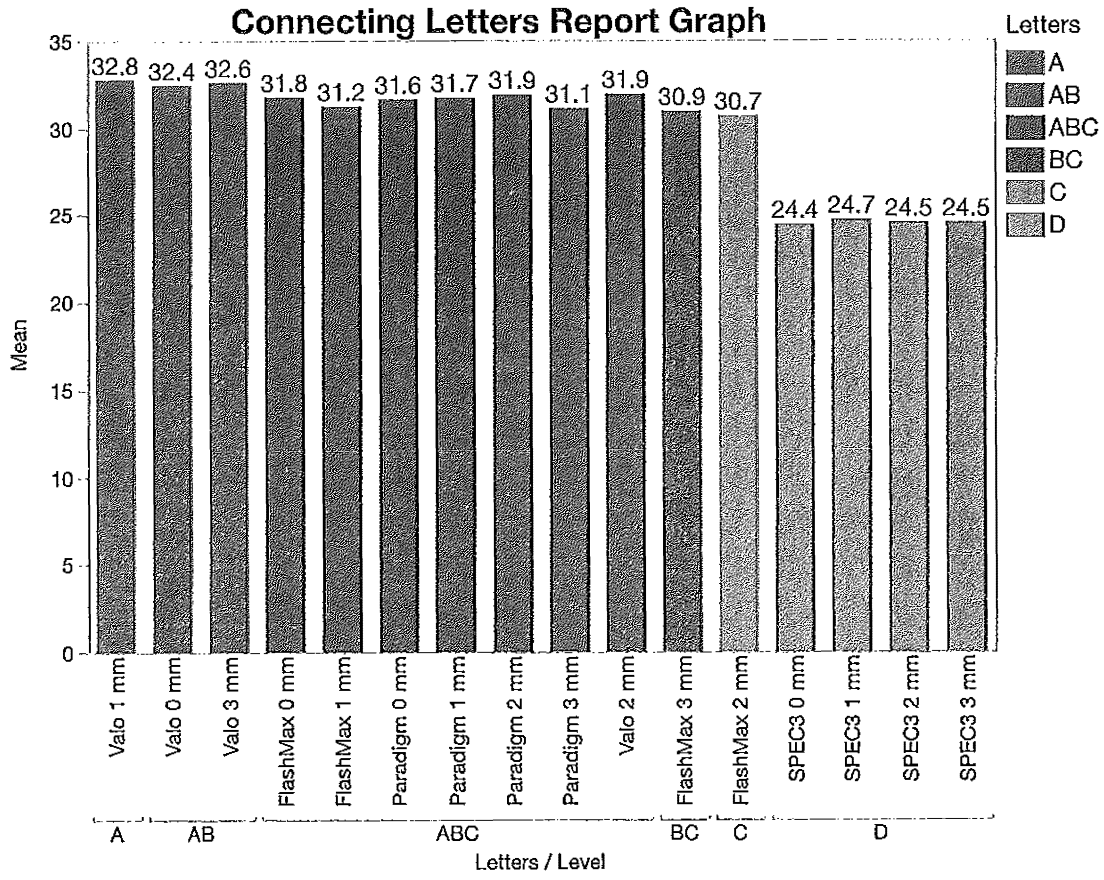
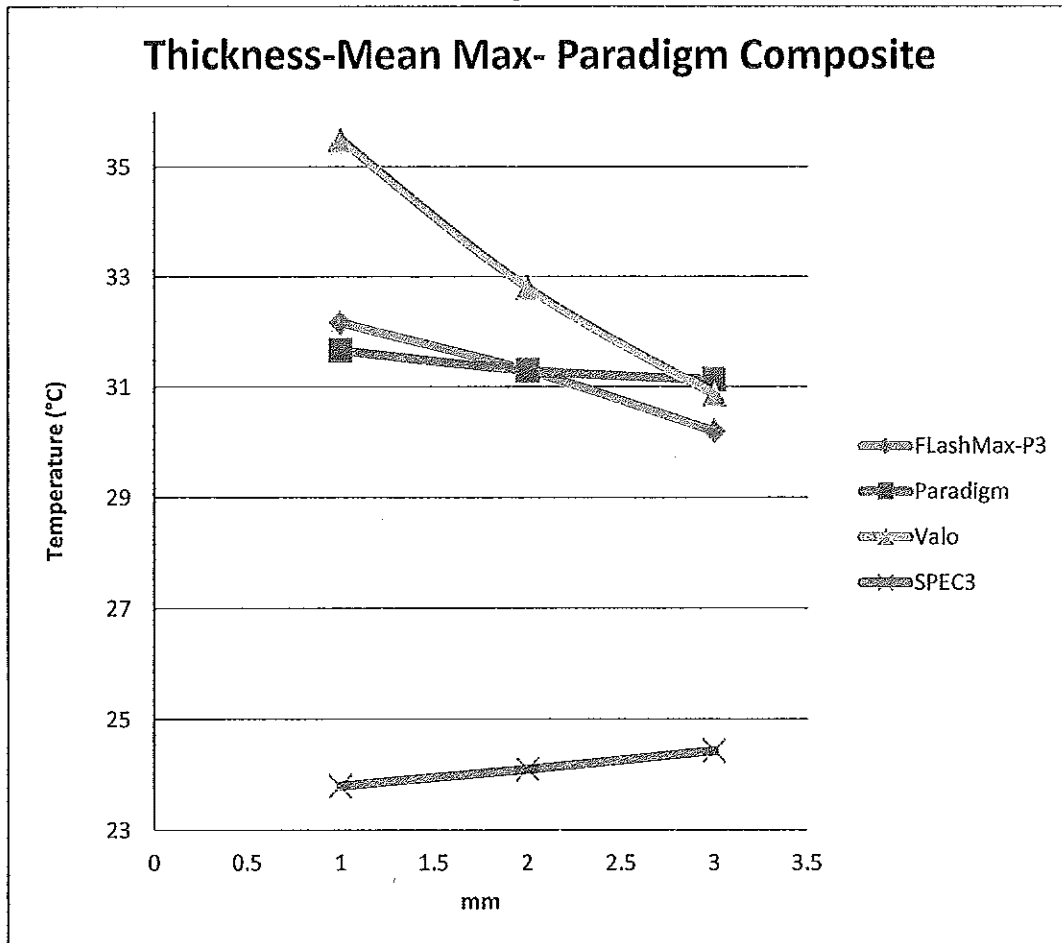


Figure 36



The Valo curing light has the highest temperature at 1 mm thickness of composite. Even though the thickness of composite changed from 1 mm to 3 mm there was not much an overall change in temperature.

Figure 37

Oneway Analysis of Column 1 By Column 2

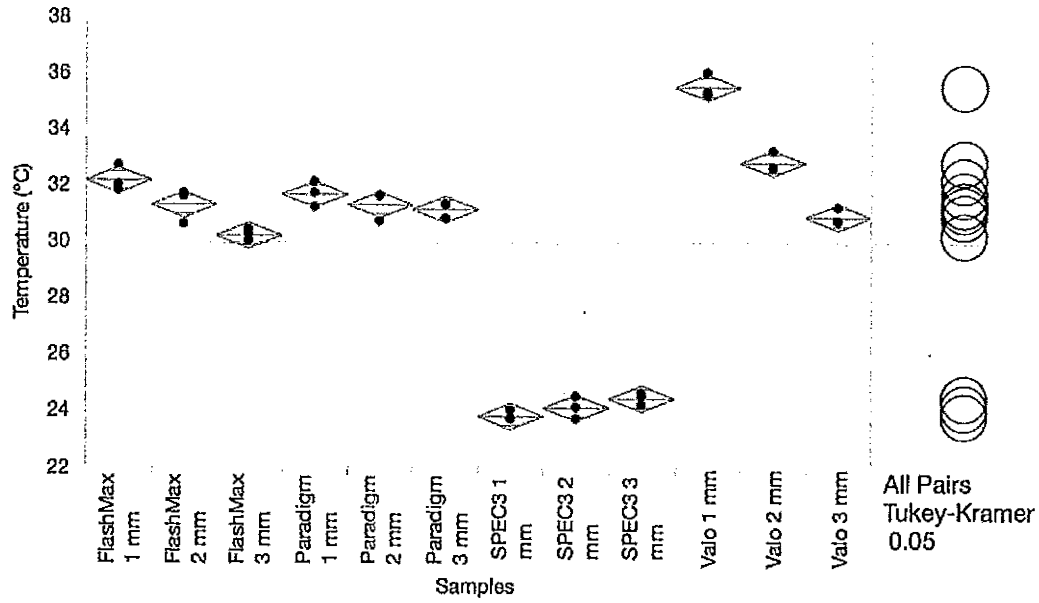


Figure 38

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Column 2	11	465.63222	42.3302	279.6123	<.0001*
Error	24	3.63333	0.1514		
C. Total	35	469.26556			

Figure 39

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FlashMax 1 mm	3	32.1667	0.22464	31.703	32.630
FlashMax 2 mm	3	31.3000	0.22464	30.836	31.764
FlashMax 3 mm	3	30.2000	0.22464	29.736	30.664
Paradigm 1 mm	3	31.6667	0.22464	31.203	32.130
Paradigm 2 mm	3	31.3000	0.22464	30.836	31.764
Paradigm 3 mm	3	31.1333	0.22464	30.670	31.597
SPEC3 1 mm	3	23.8000	0.22464	23.336	24.264
SPEC3 2 mm	3	24.1000	0.22464	23.636	24.564
SPEC3 3 mm	3	24.4333	0.22464	23.970	24.897
Valo 1 mm	3	35.5000	0.22464	35.036	35.964
Valo 2 mm	3	32.8000	0.22464	32.336	33.264
Valo 3 mm	3	30.8667	0.22464	30.403	31.330

Std Error uses a pooled estimate of error variance

Figure 40

Connecting Letters Report

Level	Mean Letters
Valo 1 mm	A
Valo 2 mm	B
FlashMax 1 mm	B C
Paradigm 1 mm	B C D
FlashMax 2 mm	C D E
Paradigm 2 mm	C D E
Paradigm 3 mm	C D E
Valo 3 mm	D E
FlashMax 3 mm	E
SPEC3 3 mm	F
SPEC3 2 mm	F
SPEC3 1 mm	F

Levels not connected by same letter are significantly different.

Figure 41

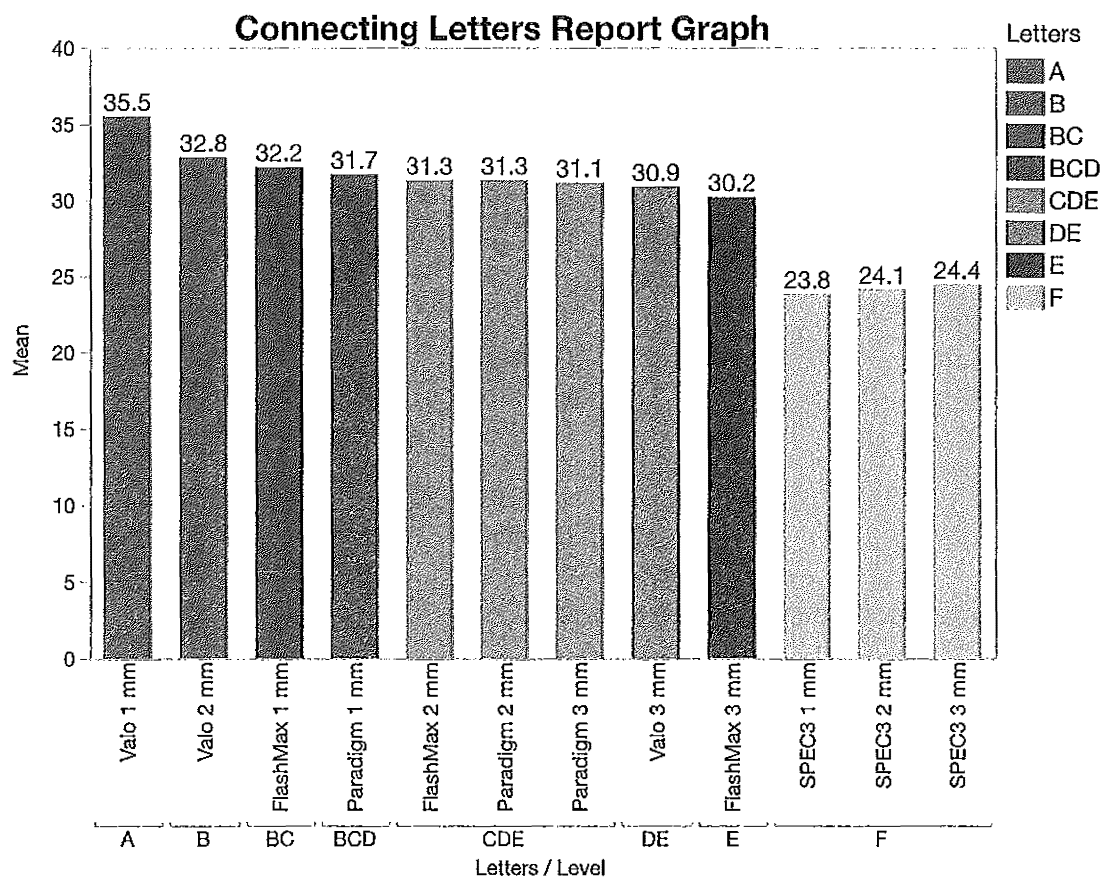
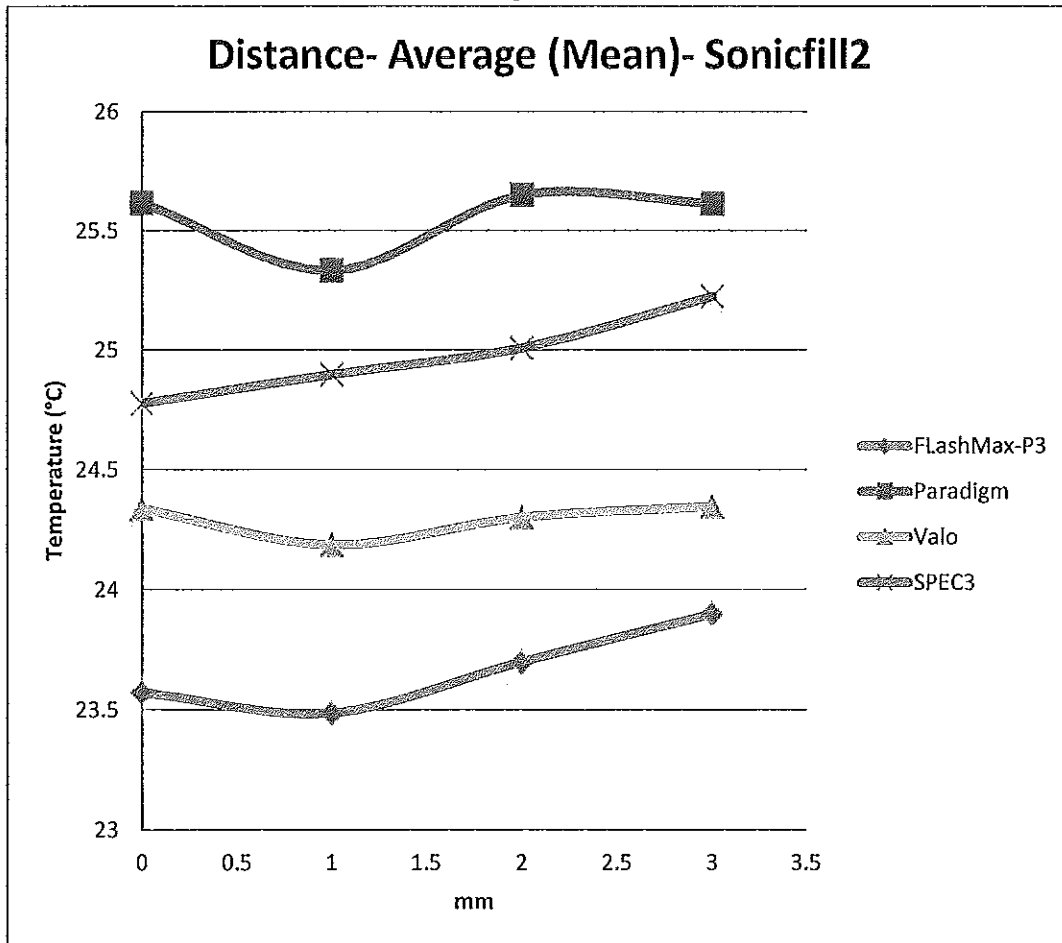


Figure 42



When comparing Sonicfill2 to Paradigm composite in the Average (Mean), the Sonicfill2 has lower overall temperatures for four curing lights. This can ask the question what is the difference in the composition between the two different composites and why does Sonicfill2 have a lower temperature.

Figure 43

Oneway Analysis of Column 1 By Column 2

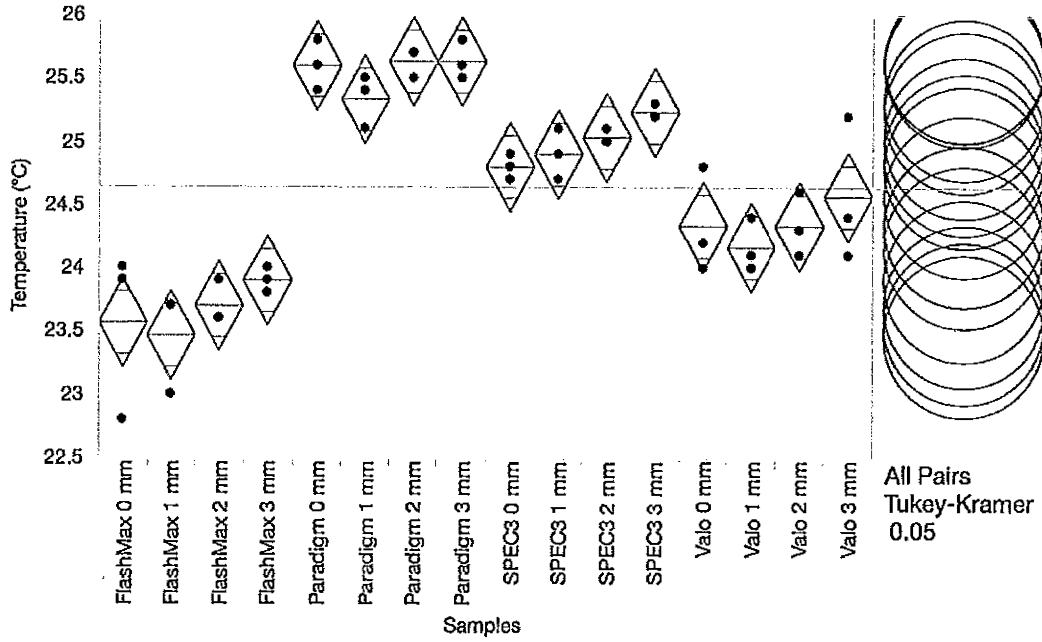


Figure 44

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Column 2	15	25.059167	1.67061	18.7358	<.0001*
Error	32	2.853333	0.08917		
C. Total	47	27.912500			

Figure 45

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FlashMax 0 mm	3	23.5667	0.17240	23.215	23.918
FlashMax 1 mm	3	23.4667	0.17240	23.115	23.818
FlashMax 2 mm	3	23.7000	0.17240	23.349	24.051
FlashMax 3 mm	3	23.9000	0.17240	23.549	24.251
Paradigm 0 mm	3	25.6000	0.17240	25.249	25.951
Paradigm 1 mm	3	25.3333	0.17240	24.982	25.685
Paradigm 2 mm	3	25.6333	0.17240	25.282	25.985
Paradigm 3 mm	3	25.6333	0.17240	25.282	25.985
SPEC3 0 mm	3	24.8000	0.17240	24.449	25.151
SPEC3 1 mm	3	24.9000	0.17240	24.549	25.251
SPEC3 2 mm	3	25.0333	0.17240	24.682	25.385
SPEC3 3 mm	3	25.2333	0.17240	24.882	25.585
Valo 0 mm	3	24.3333	0.17240	23.982	24.685
Valo 1 mm	3	24.1667	0.17240	23.815	24.518
Valo 2 mm	3	24.3333	0.17240	23.982	24.685
Valo 3 mm	3	24.5667	0.17240	24.215	24.918

Std Error uses a pooled estimate of error variance

Figure 46

Connecting Letters Report

Level	Mean Letters
Paradigm 2 mm A	25.633333 A
Paradigm 3 mm A	25.633333 A
Paradigm 0 mm A	25.600000 A
Paradigm 1 mm A B	25.333333 AB
SPEC3 3 mm A B C	25.233333 ABC
SPEC3 2 mm A B C D	25.033333 ABCD
SPEC3 1 mm A B C D	24.900000 ABCD
SPEC3 0 mm A B C D E	24.800000 ABCDE
Valo 3 mm B C D E F	24.566667 BCDEF
Valo 0 mm C D E F G	24.333333 CDEFG
Valo 2 mm C D E F G	24.333333 CDEFG
Valo 1 mm D E F G	24.166667 DEFG
FlashMax 3 mm E F G	23.900000 EFG
FlashMax 2 mm F G	23.700000 FG
FlashMax 0 mm G	23.566667 G
FlashMax 1 mm G	23.466667 G

Levels not connected by same letter are significantly different.

Figure 47

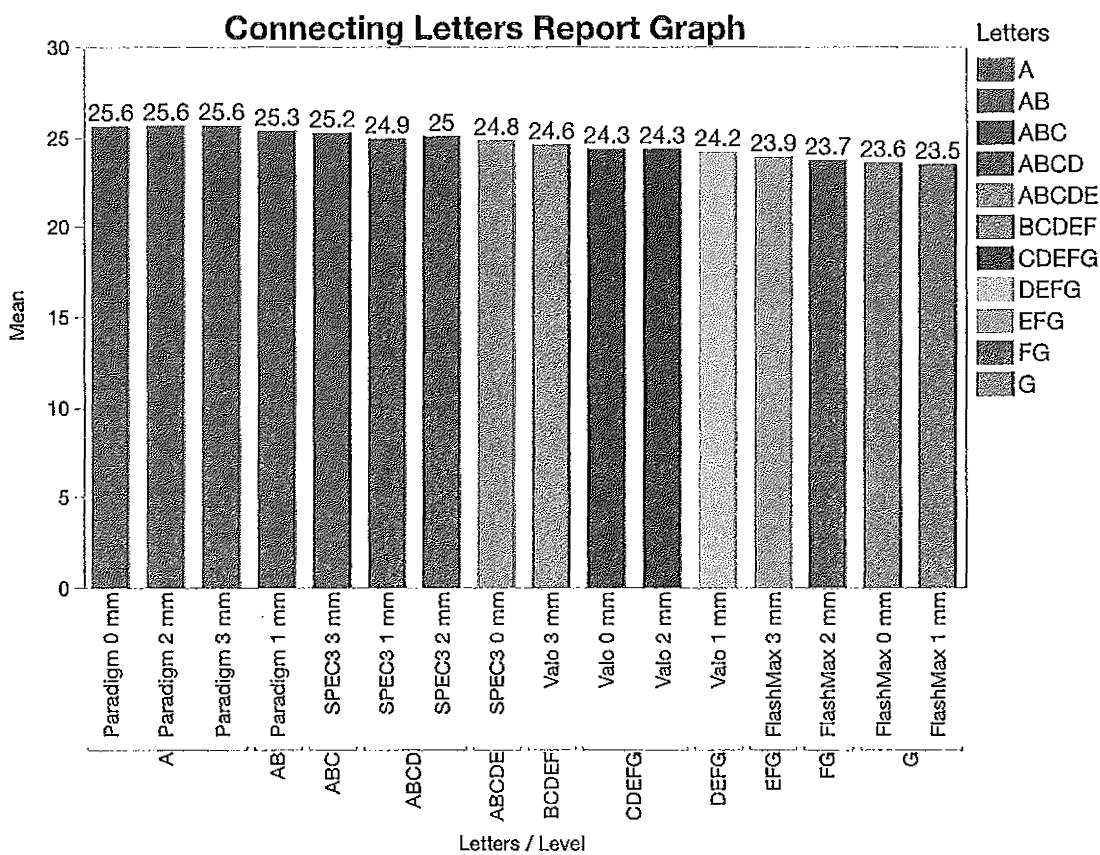
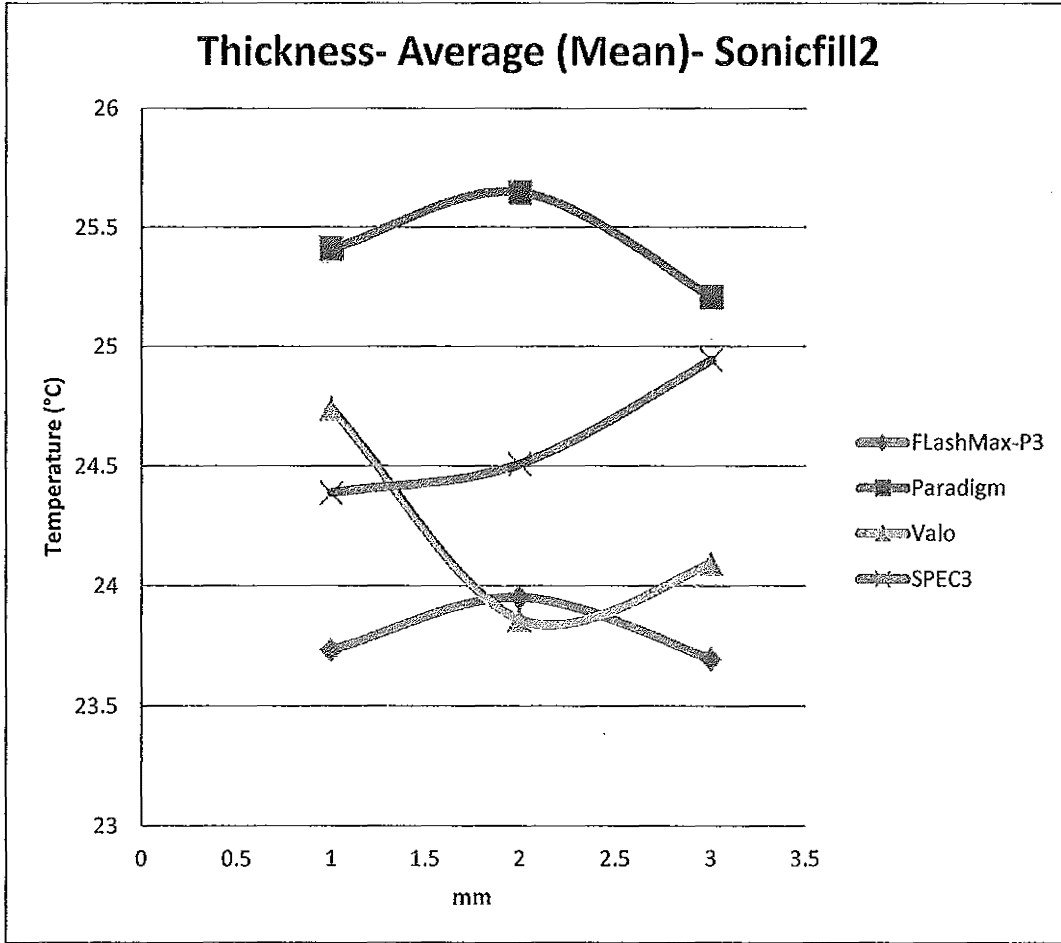


Figure 48



The Paradigm curing light had the highest temperature here, which is the same for the Paradigm composite as well.

Figure 49

Oneway Analysis of Column 1 By Column 2

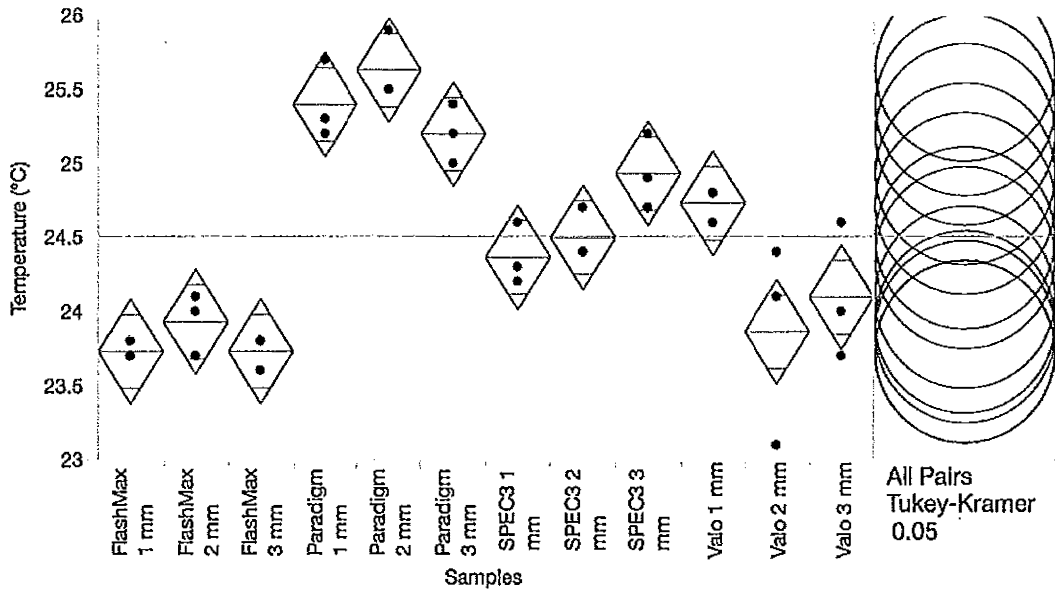


Figure 50

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Column 2	11	14.702222	1.33657	15.3237	<.0001*
Error	24	2.093333	0.08722		
C. Total	35	16.795556			

Figure 51

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FlashMax 1 mm	3	23.7333	0.17051	23.381	24.085
FlashMax 2 mm	3	23.9333	0.17051	23.581	24.285
FlashMax 3 mm	3	23.7333	0.17051	23.381	24.085
Paradigm 1 mm	3	25.4000	0.17051	25.048	25.752
Paradigm 2 mm	3	25.6333	0.17051	25.281	25.985
Paradigm 3 mm	3	25.2000	0.17051	24.848	25.552
SPEC3 1 mm	3	24.3667	0.17051	24.015	24.719
SPEC3 2 mm	3	24.5000	0.17051	24.148	24.852
SPEC3 3 mm	3	24.9333	0.17051	24.581	25.285
Valo 1 mm	3	24.7333	0.17051	24.381	25.085
Valo 2 mm	3	23.8667	0.17051	23.515	24.219
Valo 3 mm	3	24.1000	0.17051	23.748	24.452

Std Error uses a pooled estimate of error variance

Figure 52

Connecting Letters Report

Level	Mean Letters
Paradigm 2 mm	A
Paradigm 1 mm	A B
Paradigm 3 mm	A B C
SPEC3 3 mm	A B C D
Valo 1 mm	B C D E
SPEC3 2 mm	C D E F
SPEC3 1 mm	C D E F
Valo 3 mm	D E F
FlashMax 2 mm	E F
Valo 2 mm	E F
FlashMax 1 mm	F
FlashMax 3 mm	F

Levels not connected by same letter are significantly different.

Figure 53

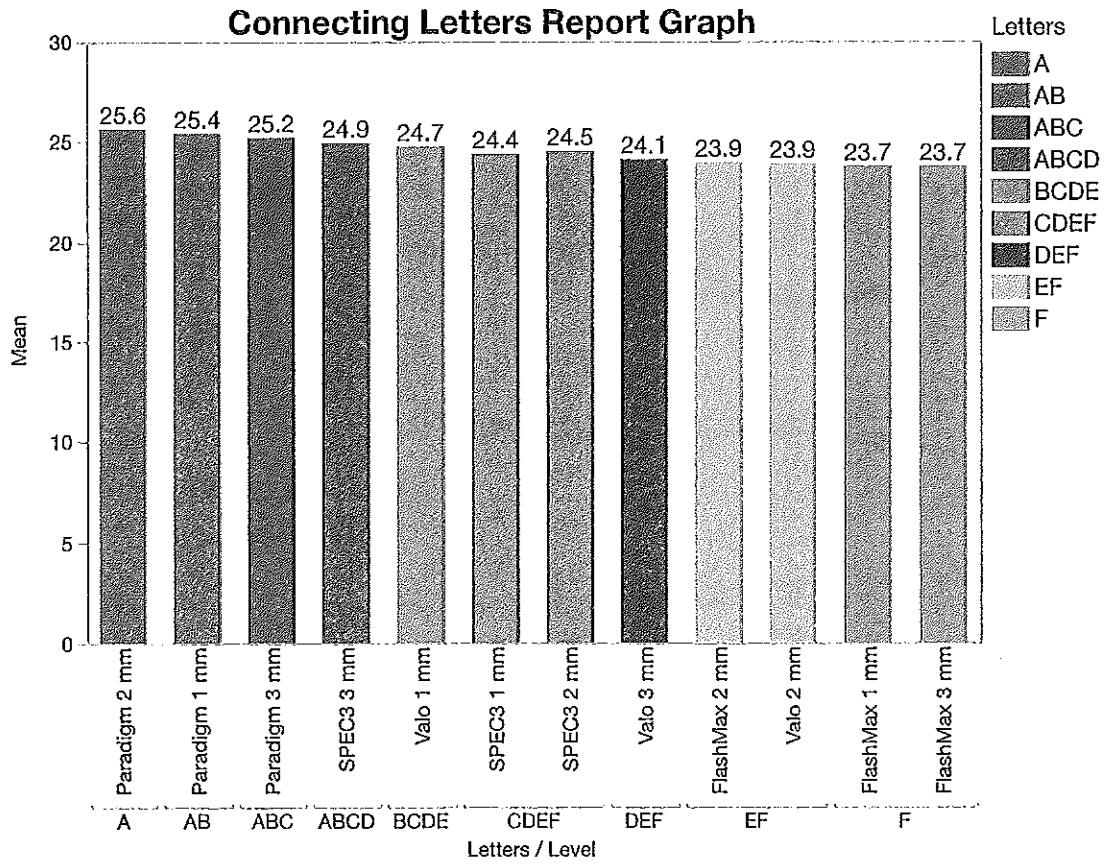
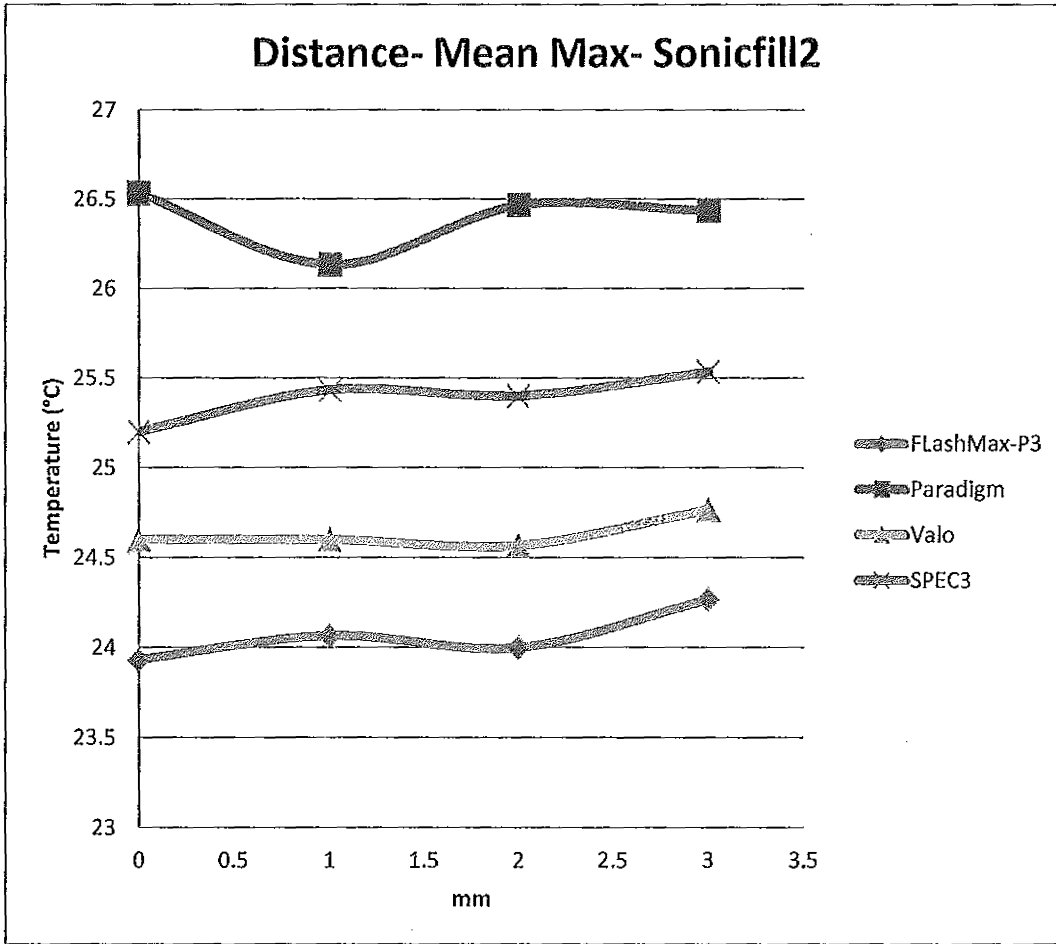


Figure 54



The Paradigm curing light has the highest temperature, which is different comparing the Sonicfill2 to the Paradigm composite. The Paradigm composite had the Flashmax 3 curing light as the highest temperature.

Figure 55

Oneway Analysis of Column 1 By Column 2

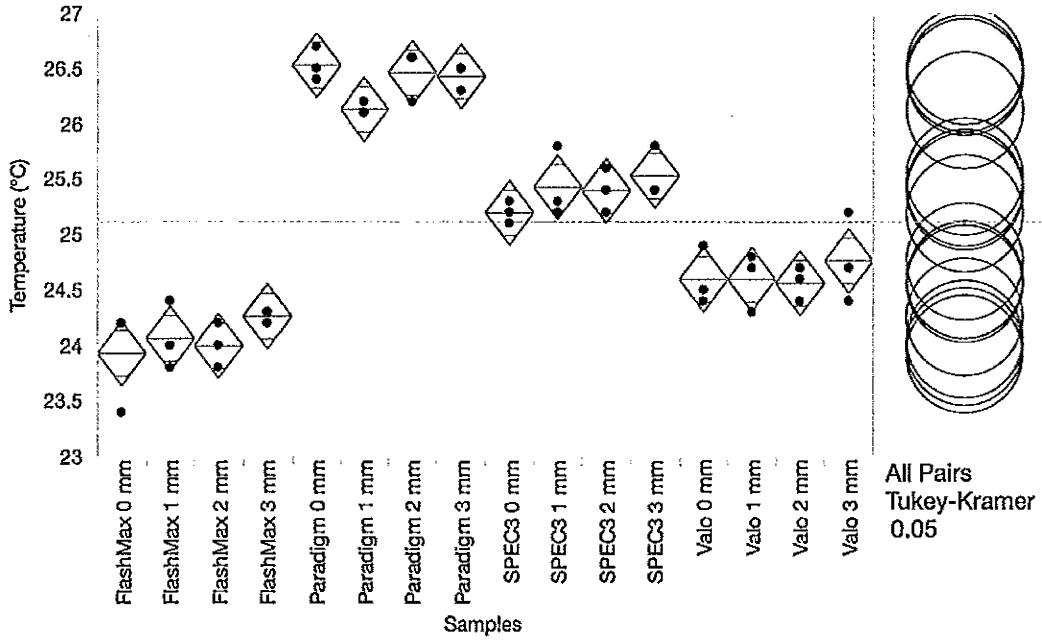


Figure 56

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Column 2	15	37.165833	2.47772	40.5907	<.0001*
Error	32	1.953333	0.06104		
C. Total	47	39.119167			

Figure 57

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FlashMax 0 mm	3	23.9333	0.14264	23.643	24.224
FlashMax 1 mm	3	24.0667	0.14264	23.776	24.357
FlashMax 2 mm	3	24.0000	0.14264	23.709	24.291
FlashMax 3 mm	3	24.2667	0.14264	23.976	24.557
Paradigm 0 mm	3	26.5333	0.14264	26.243	26.824
Paradigm 1 mm	3	26.1333	0.14264	25.843	26.424
Paradigm 2 mm	3	26.4667	0.14264	26.176	26.757
Paradigm 3 mm	3	26.4333	0.14264	26.143	26.724
SPEC3 0 mm	3	25.2000	0.14264	24.909	25.491
SPEC3 1 mm	3	25.4333	0.14264	25.143	25.724
SPEC3 2 mm	3	25.4000	0.14264	25.109	25.691
SPEC3 3 mm	3	25.5333	0.14264	25.243	25.824
Valo 0 mm	3	24.6000	0.14264	24.309	24.891
Valo 1 mm	3	24.6000	0.14264	24.309	24.891
Valo 2 mm	3	24.5667	0.14264	24.276	24.857
Valo 3 mm	3	24.7667	0.14264	24.476	25.057

Std Error uses a pooled estimate of error variance

Figure 58

Connecting Letters Report

Level	Mean Letters
Paradigm 0 mm A	26.533333 A
Paradigm 2 mm A	26.466667 A
Paradigm 3 mm A	26.433333 A
Paradigm 1 mm A B	26.133333 AB
SPEC3 3 mm B C	25.533333 BC
SPEC3 1 mm B C D	25.433333 BCD
SPEC3 2 mm B C D	25.400000 BCD
SPEC3 0 mm C D E	25.200000 CDE
Valo 3 mm D E F	24.766667 DEF
Valo 0 mm E F G	24.600000 EFG
Valo 1 mm E F G	24.600000 EFG
Valo 2 mm E F G	24.566667 EFG
FlashMax 3 mm F G	24.266667 FG
FlashMax 1 mm F G	24.066667 FG
FlashMax 2 mm G	24.000000 G
FlashMax 0 mm G	23.933333 G

Levels not connected by same letter are significantly different.

Figure 59

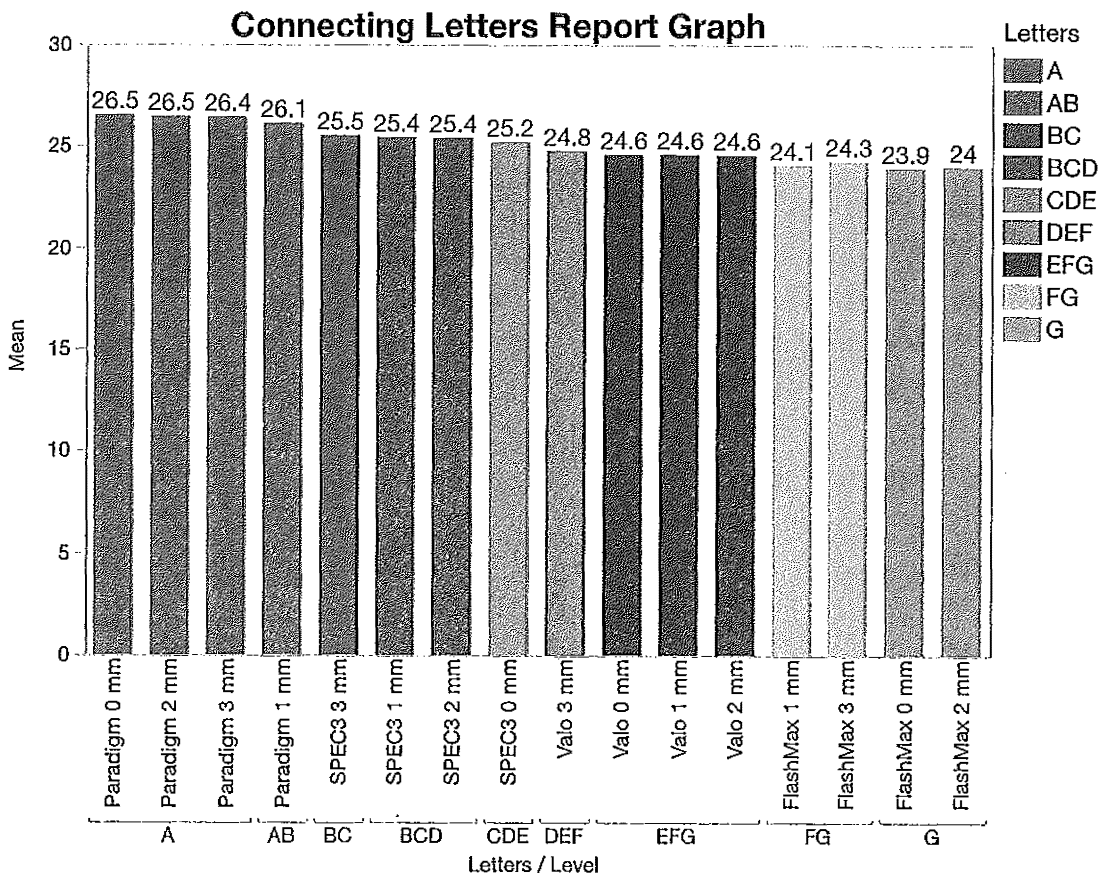
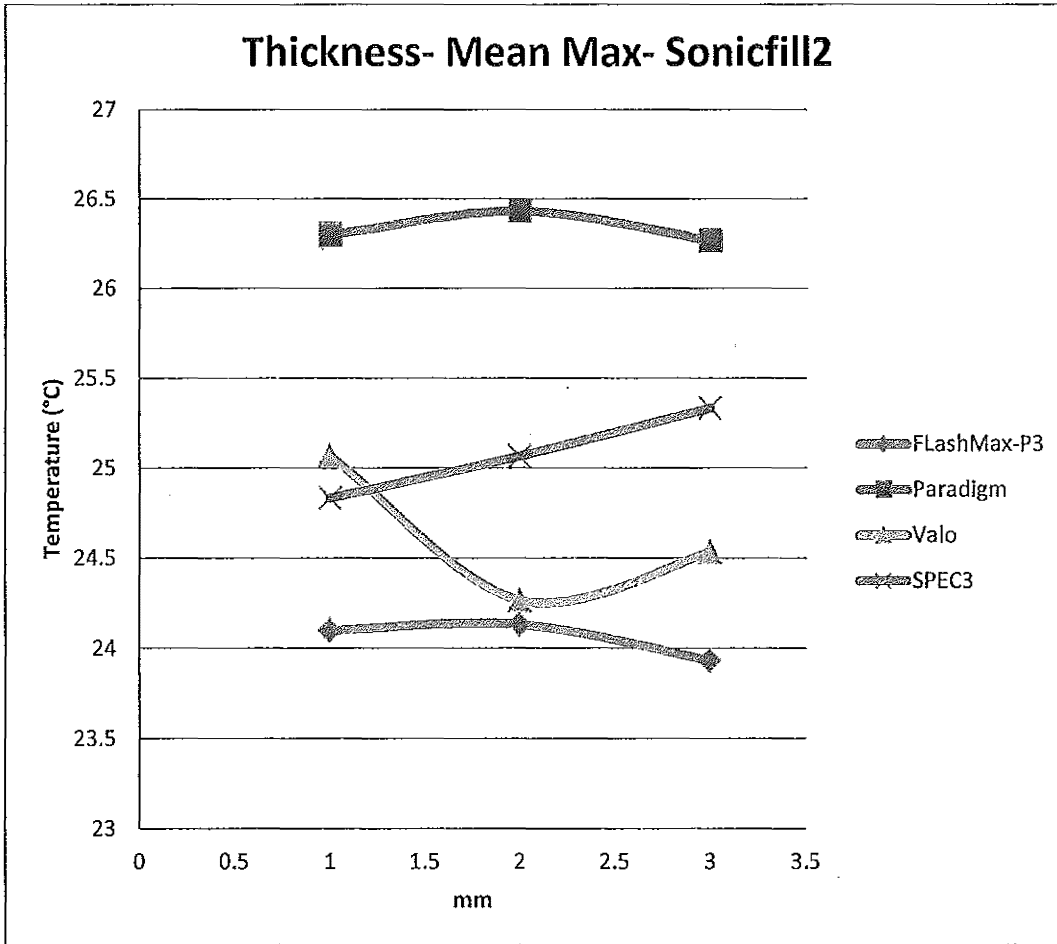


Figure 60



The Sonicfill2 consistently showed lower overall temperatures compared to the Paradigm composite.

Figure 61

Oneway Analysis of Column 1 By Column 2

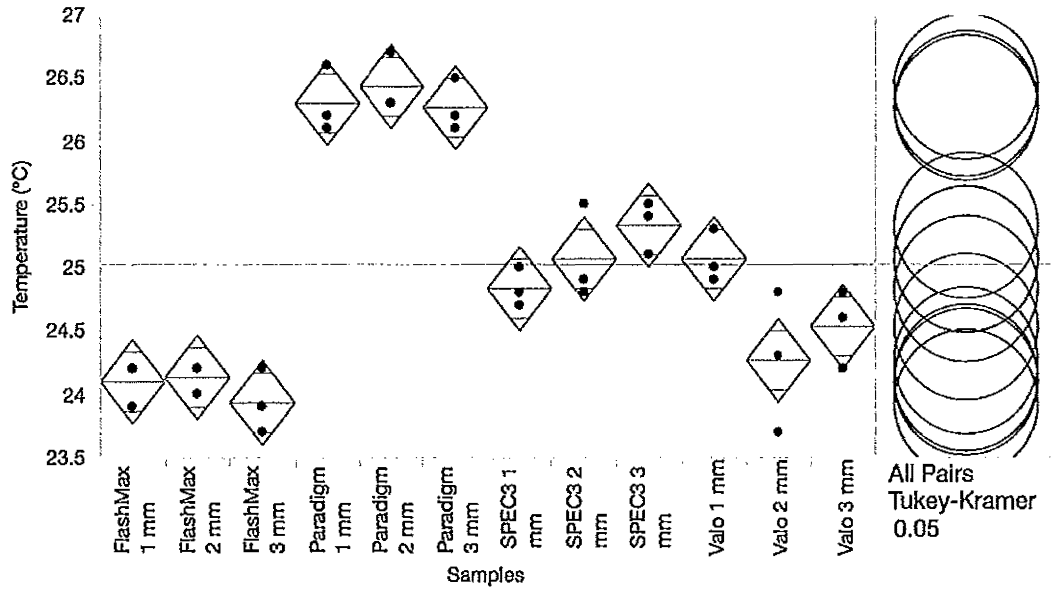


Figure 62

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Column 2	11	26.835556	2.43960	31.7059	<.0001*
Error	24	1.846667	0.07694		
C. Total	35	28.682222			

Figure 63

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
FlashMax 1 mm	3	24.1000	0.16015	23.769	24.431
FlashMax 2 mm	3	24.1333	0.16015	23.803	24.464
FlashMax 3 mm	3	23.9333	0.16015	23.603	24.264
Paradigm 1 mm	3	26.3000	0.16015	25.969	26.631
Paradigm 2 mm	3	26.4333	0.16015	26.103	26.764
Paradigm 3 mm	3	26.2667	0.16015	25.936	26.597
SPEC3 1 mm	3	24.8333	0.16015	24.503	25.164
SPEC3 2 mm	3	25.0667	0.16015	24.736	25.397
SPEC3 3 mm	3	25.3333	0.16015	25.003	25.664
Valo 1 mm	3	25.0667	0.16015	24.736	25.397
Valo 2 mm	3	24.2667	0.16015	23.936	24.597
Valo 3 mm	3	24.5333	0.16015	24.203	24.864

Std Error uses a pooled estimate of error variance

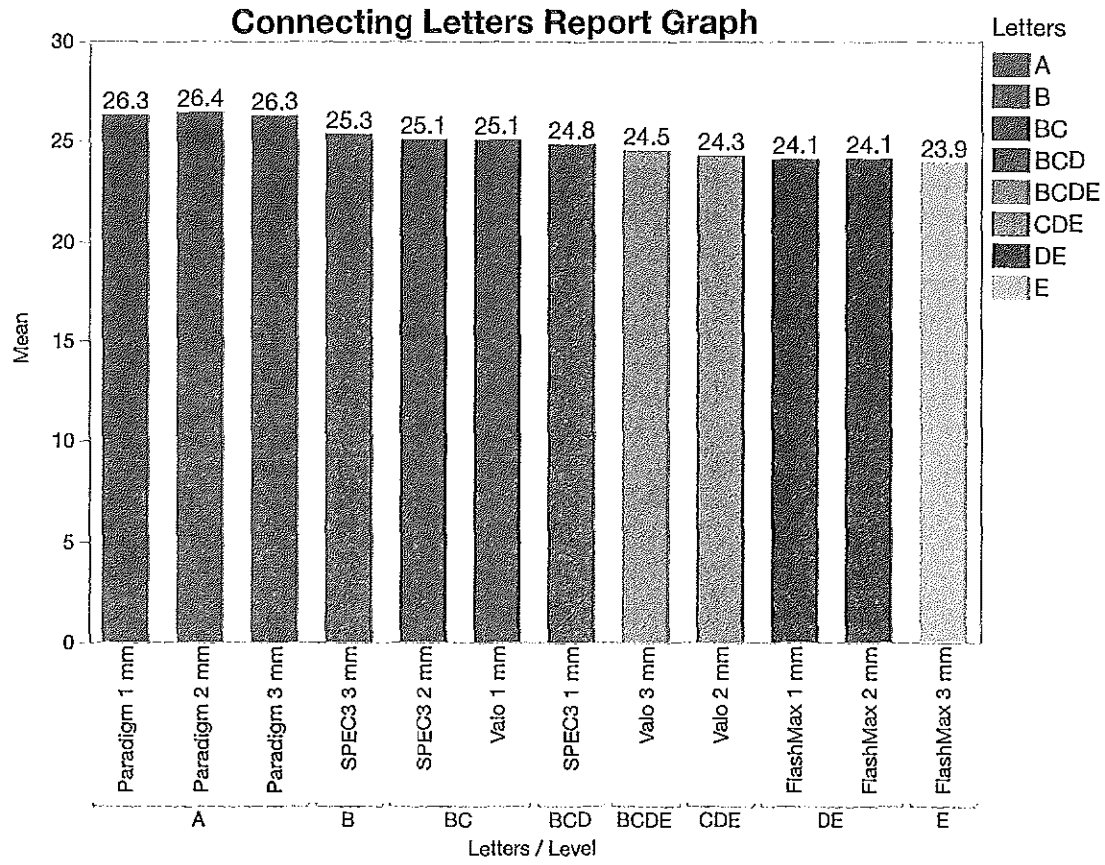
Figure 64

Connecting Letters Report

Level	Mean	Letters
Paradigm 2 mm	26.433333	A
Paradigm 1 mm	26.300000	A
Paradigm 3 mm	26.266667	A
SPEC3 3 mm	25.333333	B
Valo 1 mm	25.066667	BC
SPEC3 2 mm	25.066667	BC
SPEC3 1 mm	24.833333	BCD
Valo 3 mm	24.533333	BCDE
Valo 2 mm	24.266667	CDE
FlashMax 2 mm	24.133333	DE
FlashMax 1 mm	24.100000	DE
FlashMax 3 mm	23.933333	E

Levels not connected by same letter are significantly different.

Figure 65



DISCUSSION

The study examined the heat that was transmitted through two different composites, 3M Paradigm Nano Hybrid Universal Restorative and Kerr Sonicfill 2 bulk fill resin material polymerized with four different curing lights, Valo, Ultradent LED curing light, S.P.E.C. 3 LED curing light, FlashMax P3 460 4W curing light, Paradigm LED 3M ESPE commonly used in dentistry.

Multiple different thicknesses and distances were tested along with just air alone to determine the amount of heat that was transmitted to the thermosensor and make inference to the amount of heat felt by the tooth. From previous studies by Eriksson et al and Pohto and Scheinin, they indicated that a critical temperature of 42 degrees Celsius was the temperature at which irreversible damage occurs^{9,10}. Trowbridge et al also indicated that a normal pulp temperature of is in the range of 34-35 degrees Celsius.

By comparing the results from all the different subgroups within the main eight groups we can see that there were many combinations that could indicate some possible pulpal tissue damage.

In the first set of means in the results the subgroup of air was plotted along with being analyzed for statistically significant differences between the different means. We see that from the analysis of variance that the P value was less than .0001 indicating that there was a significant difference between the continuous variable, temperature, and the nominal variable, the different combinations of lights and distances. When comparing the means the Tukey-Kramer tests shows from the connecting letters report that the Paradigm curing light at 0mm is significantly different compared to all the other light combinations except for the Paradigm 1

mm and 2 mm. We also can see that the average mean temperature of the Paradigm curing light at 0 mm is 44.1 degrees Celsius is the only combination in this set that is above the critical temperature level that would cause irreversible damage to the pulp.

In the second set in the results, the subgroup of distance compared with the average temperature using the Paradigm composite was plotted along with being analyzed for statistically significant differences between the different means. We see that from the analysis of variance that the P value was less than .0001 indicating that there was a significant difference between the continuous variable, temperature, and the nominal variable, the different combinations of lights and distances. When comparing the means the Tukey-Kramer tests shows from the connecting letters report that the Paradigm curing light at 2 mm, 0mm and the FlashMax 1mm are significantly different compared to all the other light combinations. We also can see that the average mean temperature for all the curing lights is below the critical temperature of 42 degrees Celsius. This indicates that the average temperature when curing the Paradigm composite at different distances is safe regardless of the curing light used in this study.

In the third set in the results, the subgroup of thickness compared with the average temperature using the Paradigm composite was plotted along with being analyzed for statistically significant differences between the different means. We see that from the analysis of variance that the P value was less than .0001 indicating that there was a significant difference between the continuous variable, temperature, and the nominal variable, the different combinations of lights and distances. When comparing the means the Tukey-Kramer tests shows from the connecting letters report show that there were differences between the different light combinations. We also can see that the average mean temperature for all the curing lights is below the critical temperature of 42 degrees Celsius. This indicates that the average temperature when curing the

Paradigm composite with different thicknesses of composite is safe regardless of the curing light used in this study.

In the fourth set in the results, the subgroup of air compared with the mean max temperature was plotted along with being analyzed for statistically significant differences between the different means. We see that from the analysis of variance that the P value was less than .0001 indicating that there was a significant difference between the continuous variable, temperature, and the nominal variable, the different combinations of lights and distances. When comparing the means the Tukey-Kramer tests shows from the connecting letters report show that there were differences between the different light combinations. For all the different curing lights for the air mean max, all but three of the curing light combinations, FlashMax 1mm, 2mm, 3mm, indicate a level above the critical temperature level of 42 degrees Celsius. This indicates that the max temperature when just curing through air as the medium can be damaging to the pulp.

In the fifth set in the results, the subgroup of distance compared with the mean max temperature using the Paradigm composite was plotted along with being analyzed for statistically significant differences between the different means. We see that from the analysis of variance that the P value was less than .0001 indicating that there was a significant difference between the continuous variable, temperature, and the nominal variable, the different combinations of lights and distances. When comparing the means the Tukey-Kramer tests shows from the connecting letters report show that there were differences between the different light combinations. We also can see that the mean max temperature for all the curing lights is below the critical temperature of 42 degrees Celsius. This indicates that the max temperature when curing the Paradigm composite at different distances is safe regardless of the curing light used in this study.

In the sixth set in the results, the subgroup of thickness compared with the max temperature using the Paradigm composite was plotted along with being analyzed for statistically significant differences between the different means. We see that from the analysis of variance that the P value was less than .0001 indicating that there was a significant difference between the continuous variable, temperature, and the nominal variable, the different combinations of lights and distances. When comparing the means the Tukey-Kramer tests shows from the connecting letters report show that there were differences between the different light combinations. We also can see that the mean max temperature for all the curing lights is below the critical temperature of 42 degrees Celsius. This indicates that the max temperature when curing the Paradigm composite with different thicknesses of composite is safe regardless of the curing light used in this study.

In the seventh set in the results, the subgroup of distance compared with the average temperature using the Sonicfill2 composite was plotted along with being analyzed for statistically significant differences between the different means. We see that from the analysis of variance that the P value was less than .0001 indicating that there was a significant difference between the continuous variable, temperature, and the nominal variable, the different combinations of lights and distances. When comparing the means the Tukey-Kramer tests shows from the connecting letters report show that there were differences between the different light combinations. We also can see that the average temperature for all the curing lights is below the critical temperature of 42 degrees Celsius. This indicates that the average temperature when curing the Sonicfill2 composite from different distances is safe regardless of the curing light used in this study.

In the eighth set in the results, the subgroup of thickness compared with the average temperature using the Sonicfill2 composite was plotted along with being analyzed for statistically significant differences between the different means. We see that from the analysis of variance that the P value was less than .0001 indicating that there was a significant difference between the continuous variable, temperature, and the nominal variable, the different combinations of lights and distances. When comparing the means the Tukey-Kramer tests shows from the connecting letters report show that there were differences between the different light combinations. We also can see that the average mean temperature for all the curing lights is below the critical temperature of 42 degrees Celsius. This indicates that the average temperature when curing the Sonicfill2 composite with different thicknesses of composite is safe regardless of the curing light used in this study.

In the ninth set in the results, the subgroup of distance compared with the mean max temperature using the Sonicfill2 composite was plotted along with being analyzed for statistically significant differences between the different means. We see that from the analysis of variance that the P value was less than .0001 indicating that there was a significant difference between the continuous variable, temperature, and the nominal variable, the different combinations of lights and distances. When comparing the means the Tukey-Kramer tests shows from the connecting letters report show that there were differences between the different light combinations. We also can see that the mean max temperature for all the curing lights is below the critical temperature of 42 degrees Celsius. This indicates that the max temperature when curing the Sonicfill2 composite at different distances is safe regardless of the curing light used in this study.

In the tenth set in the results, the subgroup of thickness compared with the max temperature using the Sonicfill2 composite was plotted along with being analyzed for statistically significant differences between the different means. We see that from the analysis of variance that the P value was less than .0001 indicating that there was a significant difference between the continuous variable, temperature, and the nominal variable, the different combinations of lights and distances. When comparing the means the Tukey-Kramer tests shows from the connecting letters report show that there were differences between the different light combinations. We also can see that the mean max temperature for all the curing lights is below the critical temperature of 42 degrees Celsius. This indicates that the max temperature when curing the Sonicfill2 composite with different thicknesses of composite is safe regardless of the curing light used in this study.

We see from all the results that the Sonicfill2 composite had a lower overall average and max compared to the Paradigm composite. This can possibly be due to the fact that the components within the two composites are different. The shades for both were A2, so that should not have been a factor.

From the results we see that many factors can affect the amount of increase of temperature. The light irradiance of the curing light and the exothermic reaction of the composite both increase the temperature.² Another factor that has been established to play a role is the distance from the light curing unit and the surfaces being irradiated.^{21,22} As indicated before Lloyd et al. along with Yap et al. specify that the main factor that determines the intrapulpal temperature rise is the energy taken in during curing.^{2,7} whereas Matsutani et al. say that the exothermic reaction of the resin play a greater role in temperature increase.³

There were factors that could not be accounted for in this study that could possibly help with understanding what the actual levels of temperature mean and can be interpreted. One factor is the role of the pulpal microcirculation in response to a thermal stimulus.²³ It is shown that when the pulp temperature exceeds the critical temperature the neurons within the pulp cause the circulation of the blood to increase, which aids in decreasing the temperature in the pulp.^{24,25} Along with the increase in pulpal circulation another factor that can play a role in decreasing the temperature is the periodontal tissues and the fluid within the dentinal tubules.^{26,27}

It is important to understand these findings and to apply them to our dental needs. If manufactures can create curing lights that have increased irradiance along with maintaining low temperature, then dental procedures can be accelerated. This could aid in many fields of dentistry from pedodontics to curing sealants and composite where there is a moisture issue.²⁸ The highest temperature increases were seen in the air control. This can lead providers to change the way they cure their composites. It is important to understand the manufactures instructions in how to cure the composite during the high irradiance settings. If the curing is done incorrectly for longer periods of time, then increases in the pulpal temperature could cause damage to the tooth irreversibly.

CONCLUSION

Deductions that can be made from the results of this in-vitro study include:

1. There is a potential for pulpal damage from LED curing lights when the light is activated along with the heat from the polymerization reaction from the composite.
2. The highest temperature increases were seen in the air control at its max.

From these results we can reject the null hypothesis #1, #2, #3. We can see from the data that the alternative hypothesis is accepted. More information regarding in-vivo studies will aid in determining more about this topic.

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