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The Effect of Pre-heating on Depth of Cure and Surface Hardness of Resins

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by

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A Thesis submitted in partial satisfaction
of the requirements for the degree of
Master of Science in Pediatric Dentistry

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Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree of Master of Science.

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Daniel Tan, Professor of Restorative Dentistry

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ABBREVIATIONS

F	Farenheit
mm	millimeter
ADA	American Dental Association
LED	light emitting diode
Hal	halogen

ABSTRACT OF THE THESIS

The Effect of Pre-heating on Depth of Cure and Surface Hardness of Light-cured Composite Resins

by

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Master of Science, Graduate Program in Pediatric Dentistry
Loma Linda University, June 2005
Dr. John Peterson, Chairperson

Introduction of a device to pre-heat composites prior to curing has prompted this study to evaluate the effect of pre-heating on the surface hardness and depth of cure of composite resins. Factors considered in this study included curing time (10, 20 and 40 seconds), curing temperature (70, 100 and 140 degrees F), curing light type (halogen and LED), and composite type (hybrid and microhybrid).

The surface hardness portion of the study included 180 samples (5 of each of 36 combinations of factors) prepared according to the ADA standard for surface hardness. Four Knoop hardness measurements were obtained from both the top and bottom surfaces, and the data was analyzed by using the two sample t-test. For both the hybrid and microhybrid, there were statistically significant increases in hardness with increases in temperature and curing time ($\alpha = 0.5$, $p<0.0001$). The hybrid group showed no statistically significant difference in hardness by curing type ($\alpha = 0.5$, $p>0.4428$). The LED light was statistically significantly better than the Halogen in the microhybrid group ($\alpha = 0.5$, $p<0.0203$).

The ADA standard for surface hardness states that the bottom surface of a 2 mm sample must have 80% of the hardness of the top surface. In this study, it was noted that

the standard was met in the hybrid group at any times or temperatures when using the LED. The halogen did not meet the standard at the 10 second curing time for any temperature or time, but was met at the 20 and 40 second time for all other temperatures. The microhybrid group had a very different result compared to the hybrid. Using the halogen, the standard was only met at 140 degrees and 40 seconds curing time. For the LED, the standard was met at the 40 second curing time at all temperatures, and at the 20 second time for the 70 degree sample. It should be noted that even though the standard was not met in many circumstances, the hardness values increased significantly as curing time and temperature increased.

The depth of cure portion included the same number of samples as the surface hardness portion, using the same combinations of factors. Six mm deep samples were prepared, and each sample was tested on the top surface, and at locations along the following mm increments after being sectioned: 0.5, 1.5, 2.5, 3.5, 4.5, and 5.5, or until unreliable measurements were obtained. The 0.5 and 3.5 mm increments were chosen for statistical analysis. For both composite types, there was a statistically significant increase in hardness as temperature and curing time increased ($\alpha = 0.5$, $p<0.0001$). The LED light performed statistically significantly better than the halogen ($\alpha = 0.5$, $p<0.0001$).

CHAPTER ONE

INTRODUCTION

Adult dentistry appears to be headed towards a cosmetic future. Most general dentists are placing tooth-colored restorations, and the number of composite restorations placed each year is rivaling the number of amalgam restorations placed. Many of those adult patients will want to have the same types of restorations placed in their children's mouths, either out of esthetic concerns, or because of worries from the amalgam "controversy". Pediatric dentists must be comfortable with placing composite resin restorations if they are to be competitive in the fee-for-service market.

The properties of composite resins dictate the manner in which they are placed. A clean, dry field, proper etching, an appropriately designed preparation, and adequate curing time are critical for success in placing these restorations. Obtaining all of these on a moving, impatient, and oftentimes uncooperative child can create a significant challenge. Reducing the amount of time for curing would be beneficial to the practitioner as well as the patient, making procedures faster and perhaps more comfortable.

Calset, a device manufactured by AdDent, Inc. has been advertised as a way to decrease the amount of time required to cure composite resins. At the time of data collection for this study, the device heated compules of resin to 130 or 140 degrees F. Subsequent design changes in the product have resulted in temperatures of 98, 130 and 155 degrees F. The manufacturer claims that increasing the temperature of the resin prior to curing will result in a significant decrease in curing time—up to 80%--and will increase the degree of cure. Handling characteristics are said to be improved, allowing the resin to perform more like a flowable composite, while maintaining the properties of the original composite.[1,2]

Decreasing the amount of curing time is not a new concept. Attempts to shorten the curing time have traditionally been focused on the type or intensity of curing lights, and also on altering the chemical properties of the resin. A literature search on the effect of pre-curing temperature of resins revealed a lack of published research on the subject. Published data is limited to non-peer reviewed journals, and the articles were submitted by AdDent, Inc.[1, 2] There are several unpublished studies that are presented as abstracts on the International Academy of Dental Research (IADR) website. Abstracts available on the IADR website investigated the microleakage of a preheated resin, the effect of temperature on degree of conversion and polymerization rates, shrinkage, and surface hardness.[3, 4, 5, 6, 7, 8]

The abstract that discussed the surface hardness was from a study that investigated two types of composites, with curing performed at room temperature and 130 degrees F. There were five samples for each group, and Knoop (kg/mm^2) hardness tests were performed. The results of that study showed that overall surface hardness was increased, but not at stastically significant levels.[8] The abstract did not discuss curing time, and depth of cure was not part of the study.

More investigation is necessary to determine if there is a real clinical benefit in heating composites. The purpose of this study was to examine how the depth of cure and surface hardness were affected by the temperature of light-cured composite resins. In addition, the study will help to evaluate if an increase in temperature allows a reduction in clinical curing time.

Hypotheses

The null hypothesis of this study was: Increasing the temperature of resins before curing does not alter the depth of cure and surface hardness.

The alternative hypothesis of this study was: Increasing the temperature of resins before curing will increase the depth of cure and surface hardness.

CHAPTER TWO

MATERIALS AND METHODS

Methods

The design of the study included multiple variables in order to have a better understanding of how temperature may affect the outcome variables--surface hardness and depth of cure. Two different types of composites were used to determine if filler characteristics would affect the outcome variables. The composites chosen for this study were a microhybrid (Esthet-X, Caulk-Dentsply) and a hybrid (TPH, Caulk-Dentsply). A2 was chosen as the shade for both types of composites. These resins were chosen because of their wide spread use and clinical reliability.

Two types of curing lights were used in this study. A halogen (Spectrum 800, Caulk-Dentsply) was used due to its popularity. A new bulb was placed in the halogen before the study. An LED curing light (Smartlite iQ, Dentsply-Caulk) was chosen as the second light, because of increasing popularity of this device. A photospectrometer was used to verify the wavelength of the halogen lamp and the LED light. The output intensity for the lights was checked before and during the study.

Three different curing times were used, to see what effect curing time had on the outcome variables. The curing times chosen were 10, 20 and 40 seconds. These increments were chosen, because they are increments that are commonly used in curing. The timers on the curing lights were verified for accuracy prior to use.

Three different temperatures were used—70, 100, and 140 degrees F. 70 degrees was chosen because it represents the temperature of a hypothetical typical dental office. 100 degrees was chosen because it was between the 70 degree sample and the 140 degrees produced by the Calset device, and because it is close to the temperature of the mouth. The 100 degree samples were heated in a laboratory oven. To determine the amount of time necessary to heat the compules to 100 degrees, several samples were placed in the oven and their internal temperatures were measured at five-minute intervals until the composite at the center of the compule was at 100 degrees. The amount of time to reach 100 degrees was found to be 30 minutes. The Calset device was used to heat the composite to 140 degrees, and was used according to the manufacturer's instructions.

The heated samples were prepared immediately when taken from the oven or Calset device, in an attempt to prevent heat loss. Another means to prevent heat loss from the resin was to use a new, clean glass slab to prepare the resin samples. The slabs were pre-heated to the corresponding temperature being evaluated. A total of four slabs were used, and were heated in the laboratory oven for one hour prior to use. Each slab was used for one sample, and then immediately placed in the oven for re-heating. This was done to insure that the resin was not cooled significantly while the sample was being prepared.

Table 1. Summary of Factors

Factors		**# of levels**
Curing time (seconds)	10, 20, 40	3
Composite types	Hybrid (TPH), Microhybrid (Esthet-X)	2
Temperature (deg F)	70, 100, 140	3
Curing lights	Halogen (Caulk), LED (Caulk)	2
	Total number of combinations	36

Surface Hardness

The American Dental Association has adopted ISO standards of surface hardness for composite resins.[9] The standard requires that at 2 mm depth, the resin must have 80% of the hardness of the surface. This part of the study was designed to compare the surface hardness of the bottom of the sample with the surface hardness of the top.

For this portion of the study, there were 36 combinations, with five samples per group, for a total of 180 samples. Previous studies performed in the biomaterial research department using this sample preparation technique and measurement method have resulted in low variability between samples within the same group. Due to these findings, the decision was made to use five samples per group. In a room with filtered light fixtures (designed to prevent ambient light from curing the resin) the composite samples were condensed into an aluminum mold measuring 4 mm in diameter and 2 mm in depth. Prior to condensing, the mold was placed onto a glass slab (covered with mylar) that was heated to the same temperature of the resin being studied. Following placement into the mold, a mylar coated glass microscope slide was placed over the resin, and the resin was cured for the specified time.

The measurements for this portion of the study were obtained by using the Leco M-400 H1 hardness tester. After the cured resin disk had been removed from the mold, the top and bottom of each sample was divided into four quadrants with a pencil, and one measurement was made arbitrarily from each quadrant on both surfaces. Each sample was stored in darkness at room temperature for 24 hours before measurements were taken. Twenty-four hours was deemed to be reasonable, as the post-curing stability of composite resins has been established by several studies.[10, 11] The data was recorded.

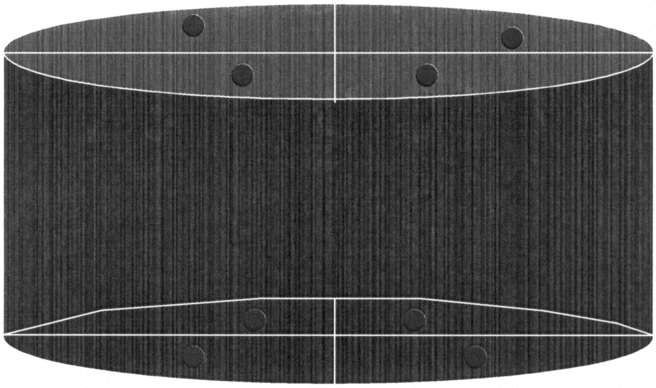

Figure 1. Example of random measurement locations for surface hardness.

Depth of Cure

For the portion of the study that investigated the depth of cure, there were 36 combinations of factors. As previously stated, similar studies have demonstrated low variance within samples, so five samples per group were used. There were a total of 180 samples. In a specially designed room to prevent ambient light from curing the samples, the composite was condensed directly into a standardized aluminum mold that measures 6 mm in depth and 4 mm in diameter. Prior to condensing, the mold was placed onto a mylar coated glass slab that was heated to the same temperature of the resin being studied. Following placement into the mold, a mylar coated glass microscope slide was placed over the resin, and the resin was cured for the specified time. The cured resin was then removed from the mold. Each sample was stored in darkness at room temperature for 24 hours before hardness measurements were taken.

Hardness data was collected from the samples in two ways. The samples were first imbedded in a heated compound material with the bottom surface pressed into the compound so that the samples were as level as possible. Research has shown that when a cured composite resin is subjected to heat for a sustained period of time, there can be an increase in degree of cure.[12] The very limited amount of time these samples were subjected to heat from the compound should minimize any effect on the depth of cure. Surface hardness measurements were obtained from three random locations on the top of each sample. The samples were tested on a Leco M-400 H1 hardness tester, and the Knoop values recorded. The second type of measurements required further preparation of the samples. They were removed from the compound, and re-imbedded horizontally to approximately half their diameter. The samples were then sectioned lengthwise with a water-cooled diamond wheel. The sectioned samples were polished using a HandiMet II roll grinder in the following sequence of grits: 240, 320, 400 and 600. The final polish was obtained using a Ecomet II grinder with .3 micron alumina powder. The polishing sequence was carried out using copious amounts of water to prevent unintended hardening by heating of the samples. Efforts were made to shield the samples from ambient light during this preparation phase. The room lights were dimmed and a barrier shield was placed over the composite samples while being prepared. Knoop hardness measurements were taken using a Leco M-400 H1 hardness tester at 0.5 mm, 1.5 mm, 2.5 mm, 3.5 mm, 4.5 mm, and 5.5 mm, or until unreliable measurements were obtained. At each interval, three measurements were made. The first was in the center of the long axis of the sample, and the other two were one mm on either side of the first, along the horizontal axis of the sample. The data was recorded.

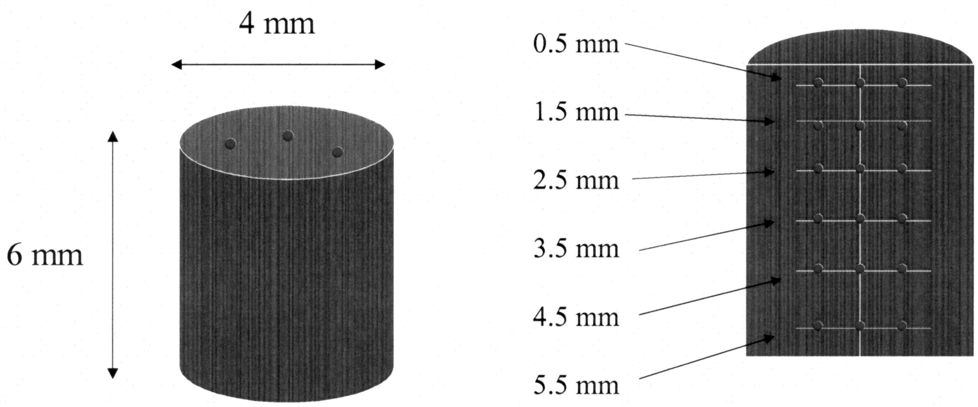

Figure 2. Example of measurement locations for depth of cure

Materials and Equipment

- 3 Calset devices (AdDent, Inc.)
- 3 composite guns (3M)
- Laboratory oven
- Hybrid composite (TPH, Dentsply-Caulk), 350 compules, Shade A2
- Microhybrid composite (Esthet-X, Dentsply Caulk), 350 compules, Shade A2
- Halogen curing light (Spectrum 800, Dentsply-Caulk)
- LED curing light (Smartlite iQ, Dentsply-Caulk)
- Four glass slabs
- Mylar sheets
- 4 mm X 2 mm aluminum mold
- 4 mm X 6 mm aluminum mold
- Hand instruments for composite placement in aluminum mold
- Digital temperature probe
- Leco M-400 H1
- HandiMet II roll grinder
- Ecomet II grinder
- .3 micron alumina powder

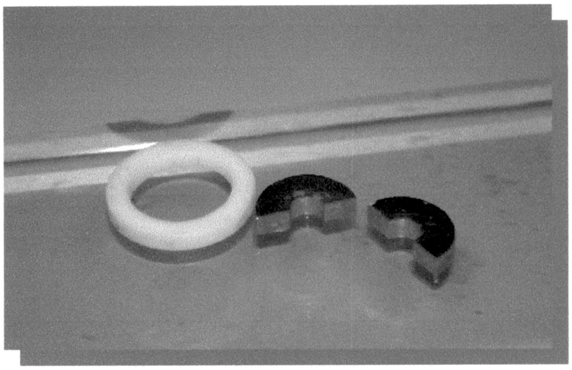

Photo 1--Aluminum mold used to prepare samples

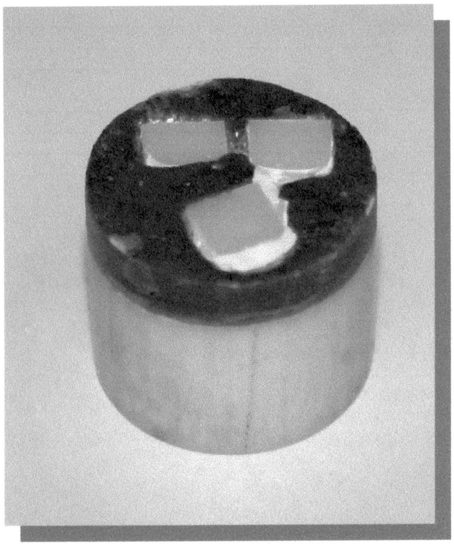

Photo 2--Depth of cure samples mounted in compound

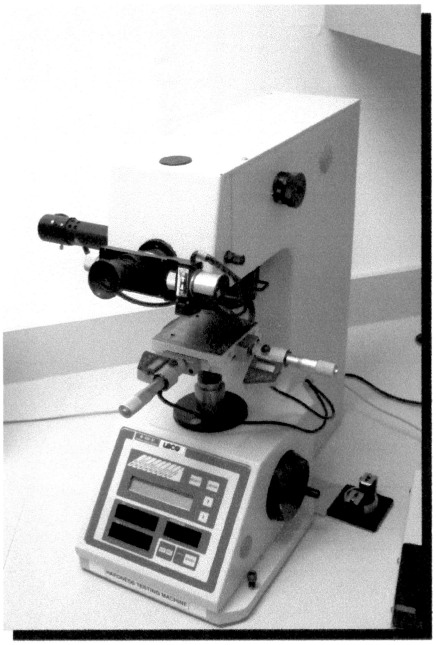

Photo 3--Leco M-400 H1 hardness tester

Photo 4--Equipment used to polish sectioned samples

Statistical Analysis

The data obtained from the samples was analyzed under the guidance of Dr. Jay Kim from the Center for Dental Research, Loma Linda University School of Dentistry.

Knoop Surface Hardness

Data obtained from the surface hardness samples were analyzed using the two-sample t-test at $\alpha = 0.5$. The t-test was used to determine if there were significant differences in the knoop hardness values when comparing the variables of curing time, temperature, and curing light.

In order to determine if samples from the surface hardness portion of the study met the ADA standard for surface hardness, the binomial test at $\alpha = 0.5$ was used.

The hybrid and microhybrid composite types were analyzed separately due to their inherent differences.

Knoop Depth of Cure

Analysis of all of the data from the depth of cure portion of the study proved to be too complicated—therefore, two depth measurements were chosen for analysis. The 0.5 mm and 3.5 mm increments were chosen because reliable measurements were obtained at each of those depths for all samples that were prepared. The two-sample t-test at $\alpha = 0.5$ was used.

To determine what factors resulted in the hardest knoop measurements at each depth, the bionomial test at $\alpha = 0.5$ was used. The hybrid and microhybrid composite types were analyzed separately due to their inherent differences.

CHAPTER THREE

RESULTS

Surface Hardness—Hybrid Composite

The mean values for the surface hardness of hybrid composites are represented in the following graphs:

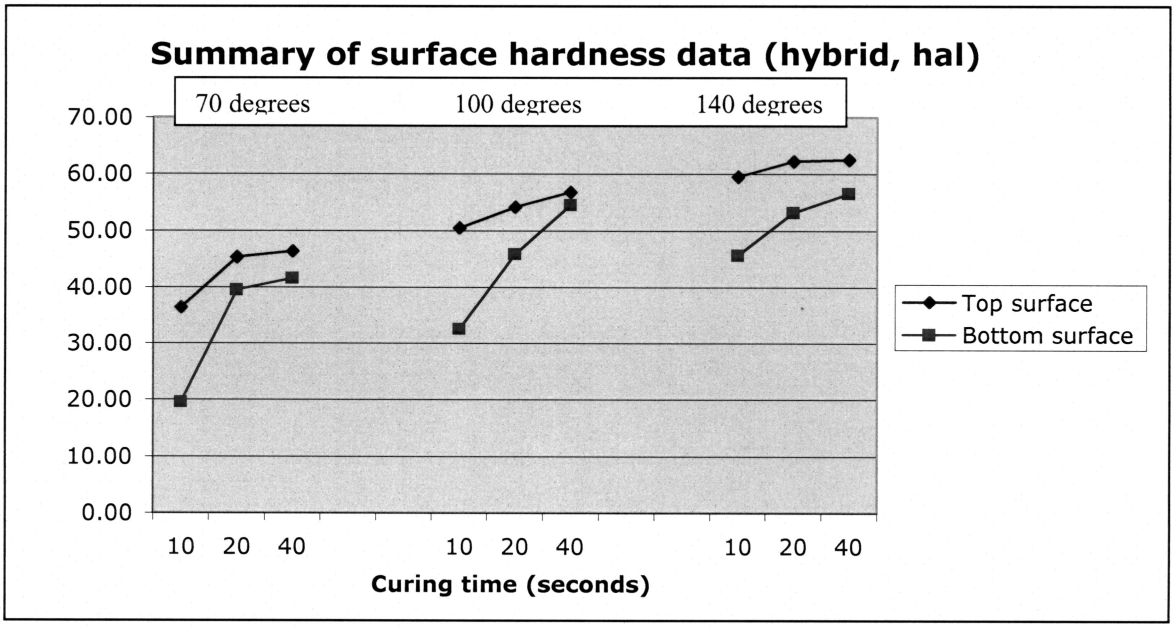

Figure 3. Graph of mean surface hardness data (hybrid, halogen).

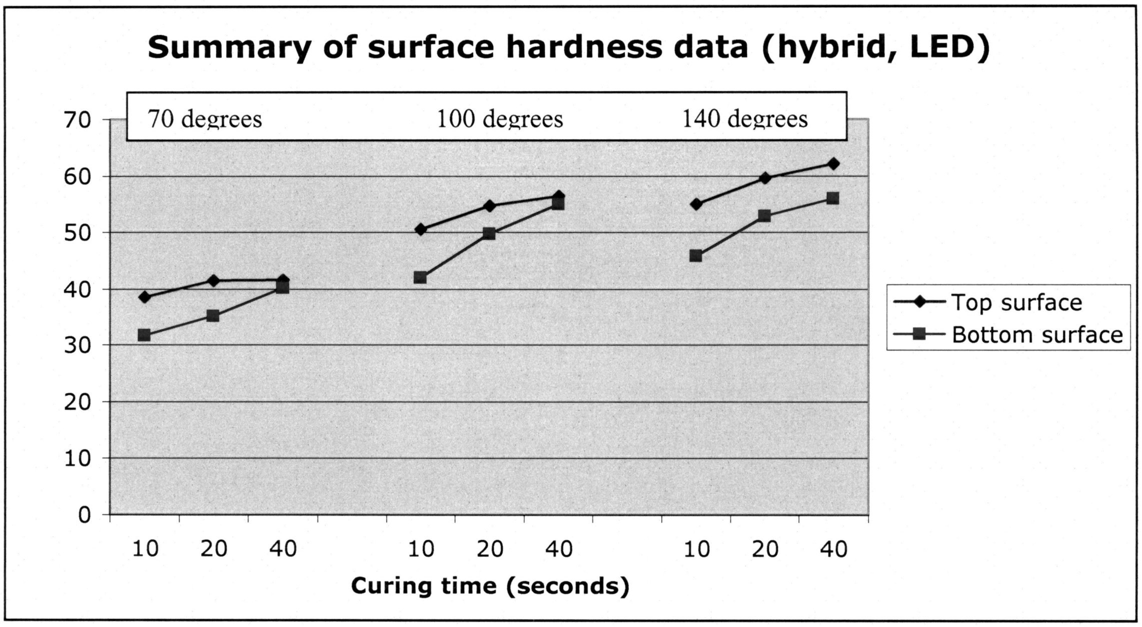

Figure 4. Graph of mean surface hardness data (hybrid, LED).

Surface Hardness—Microhybrid Group

The mean values for the surface hardness of microhybrid composites are represented in the following graphs:

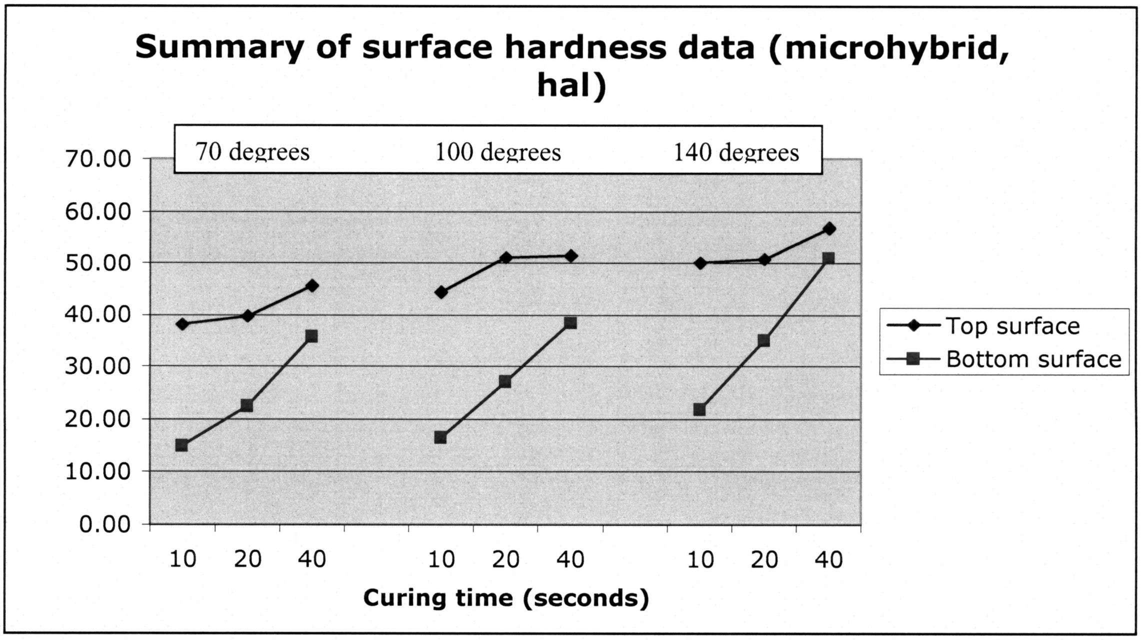

Figure 5. Graph of mean surface hardness data (microhybrid, halogen).

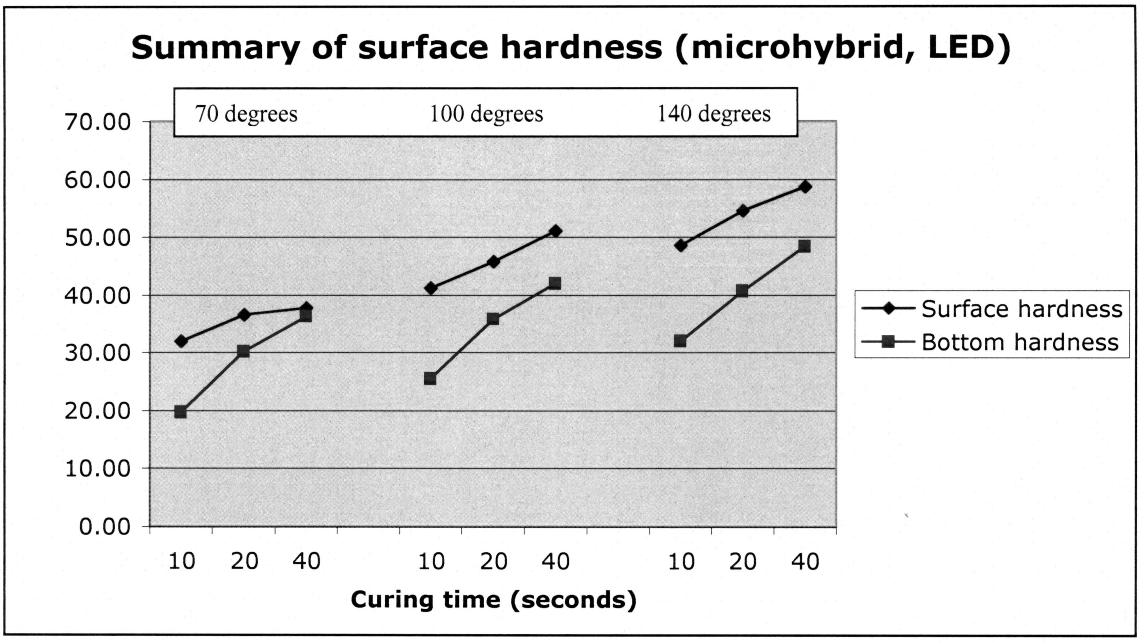

Figure 6. Graph of mean surface hardness data (microhybrid, LED).

Depth of Cure—Hybrid Composite

The mean depth of cure values for the hybrid group are represented in the following graphs:

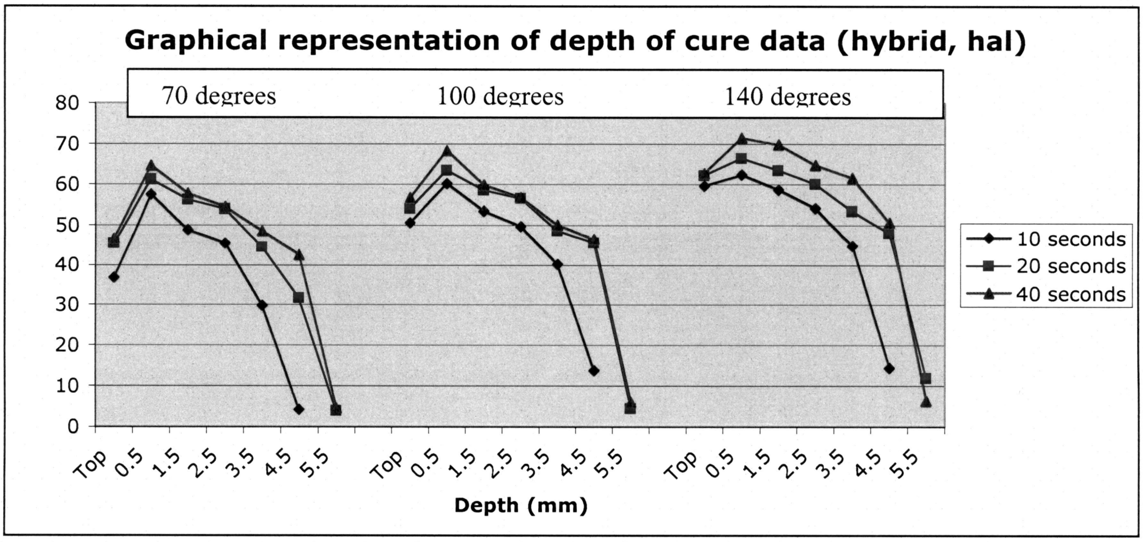

Figure 7. Graph of mean depth of cure measurements (Hybrid, Halogen).

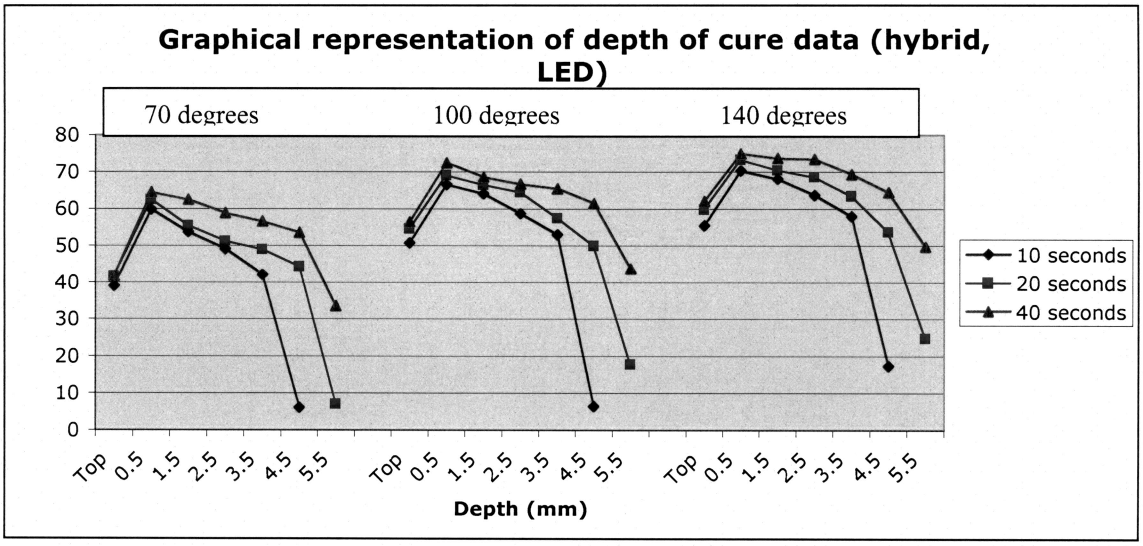

Figure 8. Graph of mean depth of cure data (hybrid, LED).

Depth of Cure—Microhybrid Composite Group

The mean depth of cure measurements for the microhybrid group are represented in the following graphs:

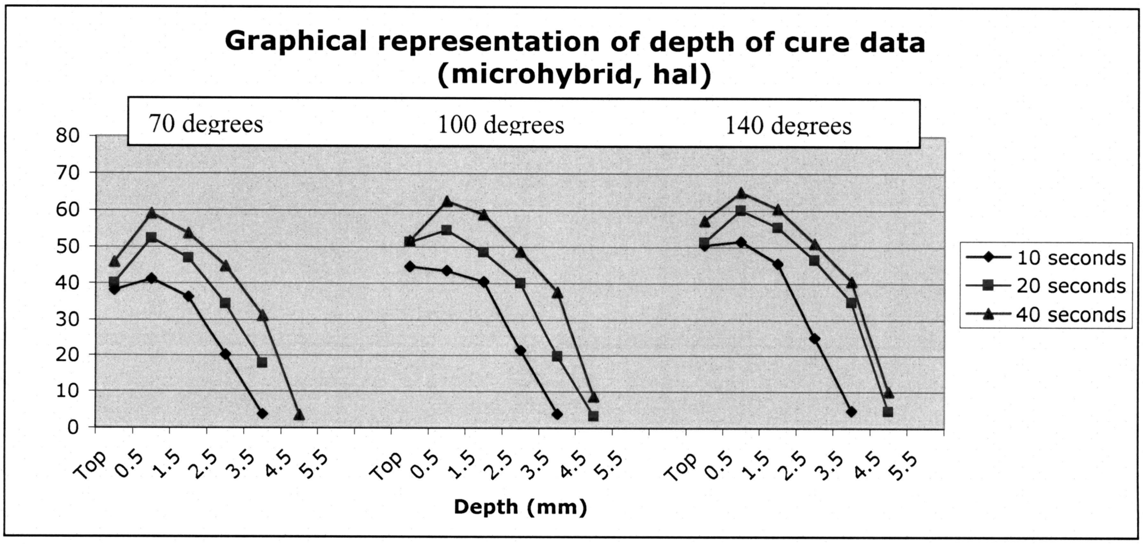

Figure 9. Graph of mean depth of cure data (microhybrid, halogen).

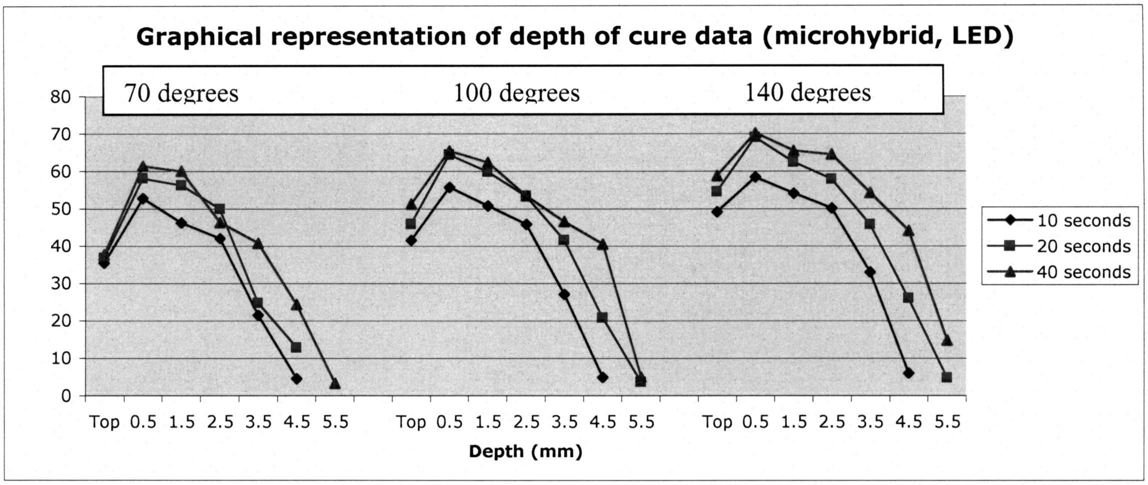

Figure 10. Graph of mean depth of cure data (microhybrid, LED).

CHAPTER FOUR

DISCUSSION

Surface Hardness—Hybrid

The ADA standard for surface hardness requires that the bottom of the 2 mm thick sample have 80% of the hardness of the top. The following table shows the percentage difference between the top and bottom for the hybrid group, based on the averaged data from the top and bottom measurements.

Table 2. Percentage of Bottom Hardness Compared to Top for Hybrid Group

Light	Temp	Time	Top	Bottom	% of Top	Light	Temp	LED	Top	Bottom	% of Top
Hal	70	10	36.45	19.56	54	LED	70	10	38.49	31.66	82
Hal	70	20	45.28	39.48	87	LED	70	20	41.35	35.15	85
Hal	70	40	46.29	41.62	89	LED	70	40	41.46	40.28	97
Hal	100	10	50.47	32.51	64	LED	70	10	50.45	41.95	83
Hal	100	20	54.06	45.84	85	LED	70	20	54.64	49.72	91
Hal	100	40	56.73	54.50	96	LED	70	40	56.31	54.94	97
Hal	140	10	59.45	45.64	77	LED	70	10	54.91	45.76	83
Hal	140	20	62.15	53.21	86	LED	70	20	59.47	52.85	89
Hal	140	40	62.48	56.52	90	LED	70	40	62.00	55.97	90

The LED light met the ADA standard at all temperatures and curing times. The halogen light met the standard at the 20 and 40 second curing time for all temperatures but the 10-second time did not meet the requirement. It can be interpreted that the LED light cures the hybrid resin better than the halogen light during the 10 second interval, but not significantly different at the other times.

Surface Hardness--Microhybrid

The ADA standard for surface hardness requires that the bottom of the sample have 80% of the hardness of the top. The following table provides the percentages based on the averaged data from the top and bottom measurements.

Table 3. Percentage of Bottom Hardness compared to Top for Microhybrid Group

Light	Temp	Time	Top	Bottom	% of Top	Light	Temp	LED	Top	Bottom	% of Top
Hal	70	10	38.04	14.86	39	LED	70	10	31.95	19.70	62
Hal	70	20	39.74	22.45	56	LED	70	20	36.62	30.18	82
Hal	70	40	45.63	35.71	78	LED	70	40	37.69	36.28	96
Hal	100	10	44.32	16.45	37	LED	100	10	41.23	25.55	62
Hal	100	20	51.13	27.16	53	LED	100	20	45.87	35.84	78
Hal	100	40	51.50	38.42	74	LED	100	40	51.05	42.03	82
Hal	140	10	50.02	21.89	44	LED	140	10	48.61	31.98	65
Hal	140	20	50.79	35.01	69	LED	140	20	54.56	40.71	75
Hal	140	40	56.85	51.03	90	LED	140	40	58.60	48.43	83

For the halogen group, the ADA standard was met only when the curing time was 40 seconds and temperature was 140. For the LED group, the standard was met at 70 degrees with 10 and 20 second curing times. However, at 100 and 140 degrees, the 80% standard was met only at the 40 second curing time.

It should be noted that although the ADA standard was not met in many cases, there was a significant increase in hardness on both the top and bottom as temperature and curing time increased.

Effect of temperature on surface hardness

The following tables provide a view of how the hardness of the top and bottom surfaces of the hybrid and microhybrid groups were affected as temperature increased.

Table 4. Percent Increase in Top and Bottom Hardness with Change in Temperature (Hybrid and Microhybrid)

Hybrid Halogen	TOP		BOTTOM	
	% change from 70 degrees	% change from 100 degrees	% change from 70 degrees	% change from 100 degrees
70 degrees				
10 seconds	NA	NA	NA	NA
20 seconds	NA	NA	NA	NA
40 seconds	NA	NA	NA	NA
100 degrees				
10 seconds	**28**	NA	**40**	NA
20 seconds	**16**	NA	**14**	NA
40 seconds	**18**	NA	**24**	NA
140 degrees				
10 seconds	**39**	**15**	**57**	**29**
20 seconds	**27**	**13**	**26**	**14**
40 seconds	**25**	**9**	**26**	**4**

Hybrid LED	TOP		BOTTOM	
	% change from 70 degrees	% change from 100 degrees	% change from 70 degrees	% change from 100 degrees
70 degrees				
10 seconds	NA	NA	NA	NA
20 seconds	NA	NA	NA	NA
40 seconds	NA	NA	NA	NA
100 degrees				
10 seconds	**24**	NA	**25**	NA
20 seconds	**24**	NA	**29**	NA
40 seconds	**26**	NA	**27**	NA
140 degrees				
10 seconds	**30**	**8**	**31**	**8**
20 seconds	**30**	**8**	**34**	**6**
40 seconds	**33**	**9**	**28**	**2**

Microhybrid Halogen	TOP		BOTTOM	
	% change from 70 degrees	% change from 100 degrees	% change from 70 degrees	% change from 100 degrees
70 degrees				
10 seconds	NA	NA	NA	NA
20 seconds	NA	NA	NA	NA
40 seconds	NA	NA	NA	NA
100 degrees				
10 seconds	**14**	NA	**10**	NA
20 seconds	**22**	NA	**17**	NA
40 seconds	**11**	NA	**7**	NA
140 degrees				
10 seconds	**24**	**11**	**32**	**25**
20 seconds	**22**	**0**	**36**	**22**
40 seconds	**20**	**9**	**30**	**25**

Microhybrid LED	TOP		BOTTOM	
	% change from 70 degrees	% change from 100 degrees	% change from 70 degrees	% change from 100 degrees
70 degrees				
10 seconds	NA	NA	NA	NA
20 seconds	NA	NA	NA	NA
40 seconds	NA	NA	NA	NA
100 degrees				
10 seconds	**23**	NA	**23**	NA
20 seconds	**20**	NA	**16**	NA
40 seconds	**26**	NA	**14**	NA
140 degrees				
10 seconds	**34**	**15**	**38**	**20**
20 seconds	**33**	**16**	**26**	**12**
40 seconds	**36**	**13**	**25**	**13**

For all groups there was a general increase in surface hardness on both the top and bottom as the temperature increased. In looking at the hybrid group, the temperature increment with the greatest change was 70 to 100 degrees for both the halogen and LED light.

For both hybrid and microhybrid groups, there was a statistically significant increase in hardness as temperature increased ($\alpha = 0.5$, $p<0.0001$).

Effect of curing time on surface hardness

The following tables examine the percent increase in hardness as curing time increases in each temperature group.

Table 5. Percent Increase in Top and Bottom Hardness with Increase in Curing Time (Hybrid and Microhybrid)

Hybrid Halogen	TOP		BOTTOM	
	% change from 10 seconds	% change from 20 seconds	% change from 10 seconds	% change from 20 seconds
70 degrees				
10 seconds	NA	NA	NA	NA
20 seconds	**20**	NA	**50**	NA
40 seconds	**21**	**2**	**53**	**5**
100 degrees				
10 seconds	NA	NA	NA	NA
20 seconds	**7**	NA	**29**	NA
40 seconds	**11**	**5**	**40**	**16**
140 degrees				
10 seconds	NA	NA	NA	NA
20 seconds	**4**	NA	**14**	NA
40 seconds	**5**	**1**	**19**	**6**

Hybrid LED	TOP		BOTTOM	
	% change from 10 seconds	% change from 20 seconds	% change from 10 seconds	% change from 20 seconds
70 degrees				
10 seconds	NA	NA	NA	NA
20 seconds	**7**	NA	**10**	NA
40 seconds	**7**	**0.01**	**20**	**13**
100 degrees				
10 seconds	NA	NA	NA	NA
20 seconds	**8**	NA	**16**	NA
40 seconds	**10**	**0.3**	**24**	**10**
140 degrees				
10 seconds	NA	NA	NA	NA
20 seconds	**8**	NA	**13**	NA
40 seconds	**11**	**0.4**	**18**	**6**

Microhybrid Halogen	TOP		BOTTOM	
	% change from 10 seconds	% change from 20 seconds	% change from 10 seconds	% change from 20 seconds
70 degrees				
10 seconds	NA	NA	NA	NA
20 seconds	**4**	NA	**34**	NA
40 seconds	**17**	**13**	**58**	**37**
100 degrees				
10 seconds	NA	NA	NA	NA
20 seconds	**13**	NA	**39**	NA
40 seconds	**14**	**1**	**57**	**29**
140 degrees				
10 seconds	NA	NA	NA	NA
20 seconds	**2**	NA	**37**	NA
40 seconds	**12**	**11**	**57**	**31**

Microhybrid LED	TOP		BOTTOM	
	% change from 10 seconds	% change from 20 seconds	% change from 10 seconds	% change from 20 seconds
70 degrees				
10 seconds	NA	NA	NA	NA
20 seconds	**13**	NA	**35**	NA
40 seconds	**15**	**3**	**45**	**17**
100 degrees				
10 seconds	NA	NA	NA	NA
20 seconds	**10**	NA	**29**	NA
40 seconds	**19**	**10**	**39**	**15**
140 degrees				
10 seconds	NA	NA	NA	NA
20 seconds	**11**	NA	**21**	NA
40 seconds	**17**	**7**	**34**	**16**

There was a general increase in surface hardness on both top and bottom of both hybrid and microhybrid as time increased. For the hybrid group, the top surface had the greatest increase in hardness with the change from 10 to 20 seconds. There was a minimal increase in hardness as the time increased from 20 to 40 seconds.

significant difference in hardness at the 10-second time interval for the 70 and 100 degree groups. It can be noted that as the temperature increases, the efficacy of the halogen light at 10 seconds increases compared to LED.

The hybrid group showed no statistically significant difference in curing light type ($\alpha = 0.5$, $p>0.4428$).

The following table presents the percentage difference in hardness of both the top and bottom measurements for the microhybrid group.

Table 7. Comparison of Top and Bottom Hardness by Curing Light Type (Microhybrid)

Microhybrid	Top Halogen	Top LED	% difference	Deeper cure by:	Bottom Halogen	Bottom LED	% difference	Deeper cure by:
70 degrees								
10 seconds	38.04	31.95	**16**	**HAL**	14.86	19.70	**25**	**LED**
20 seconds	39.74	36.62	**8**	**HAL**	22.45	30.18	**26**	**LED**
40 seconds	45.63	37.69	**17**	**HAL**	35.71	36.28	**0**	**SAME**
100 degrees								
10 seconds	44.32	41.23	**7**	**HAL**	16.45	25.55	**36**	**LED**
20 seconds	51.13	45.87	**10**	**HAL**	27.16	35.84	**24**	**LED**
40 seconds	51.50	51.05	**0**	**SAME**	38.42	42.03	**9**	**LED**
140 degrees								
10 seconds	50.02	48.61	**3**	**HAL**	21.89	31.98	**32**	**LED**
20 seconds	50.79	54.56	**7**	**LED**	35.01	40.71	**14**	**LED**
40 seconds	56.85	58.60	**3**	**LED**	51.03	48.43	**5**	**HAL**

For the top measurements, the halogen light tended to provide a harder cure at the 70 and 100 degree temperature increments. At the 140-degree increment, the LED provided a marginally harder cure at 20 and 40 seconds.

The LED light provided a significantly harder cure ($\alpha = 0.5$, $p<0.0203$) for the 10 and 20 second increments, and the 40 second increment at all temperatures show the halogen providing comparable hardness (the same at 70 degrees, LED slightly harder at 100 degrees, halogen slightly harder at 140 degrees)

This data shows that the halogen tends to cure the top harder, and the LED tends to cure the bottom better and quicker than the halogen.

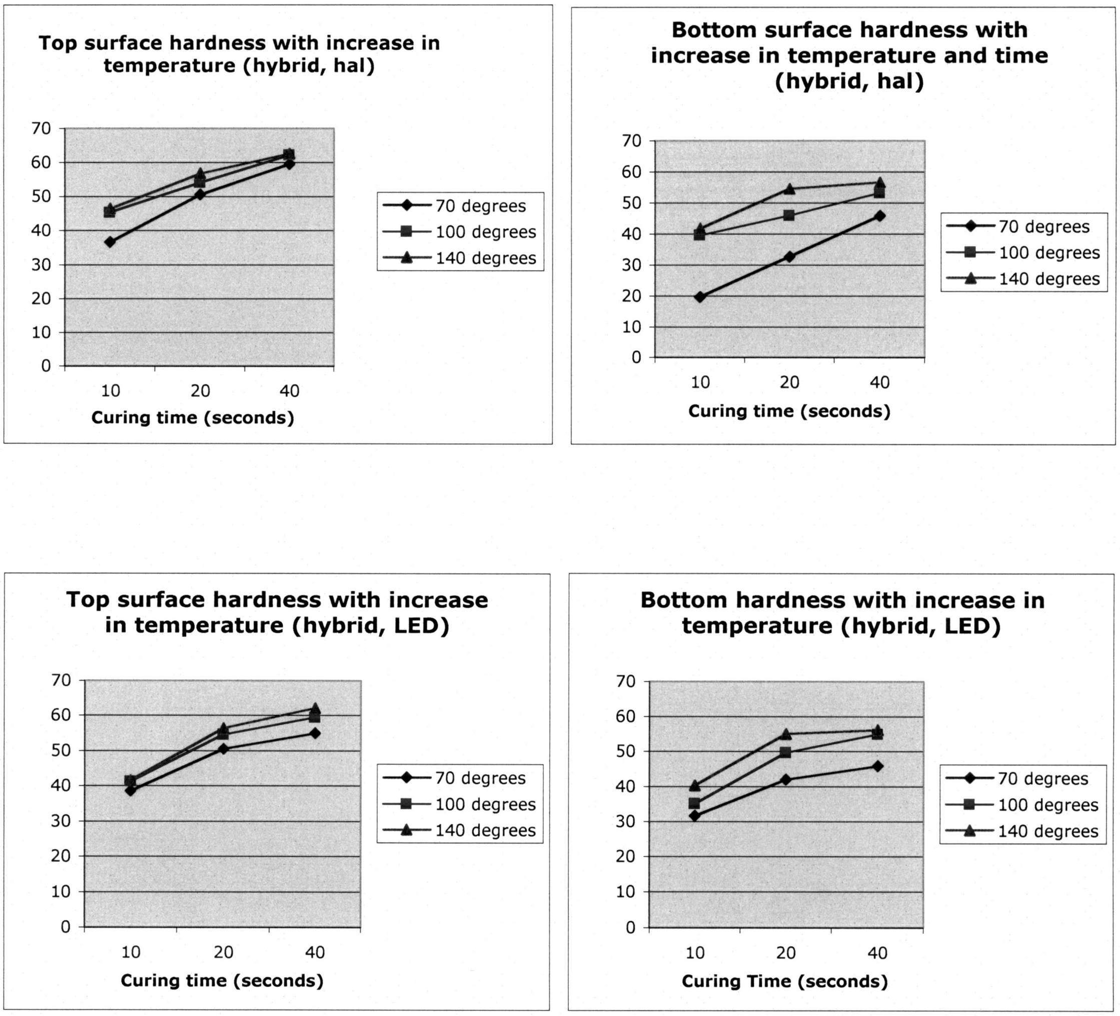

Figure 11. Graphical representation of surface hardness with increase in temperature and time (hybrid).

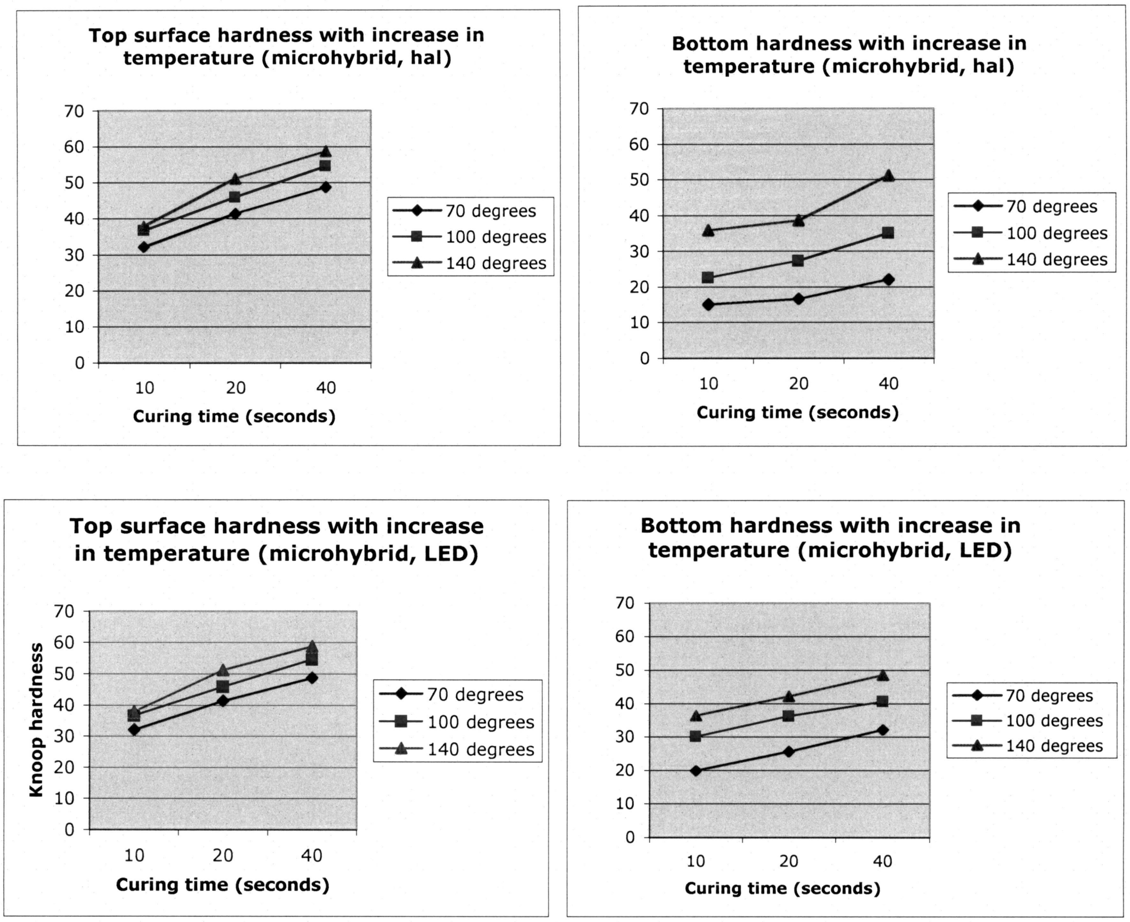

Figure 12. Graphical representation of surface hardness with increase in temperature and time (microhybrid).

Standard deviation

The data obtained for the surface hardness portion of the study was compiled and the standard deviations were calculated.

Table 8. Standard Deviation and Coefficient of Variation Values for Surface Hardness Groups (Hybrid)

Hybrid			Top		Bottom					Top		Bottom	
Light	Temp	Time	CV%	SD	CV%	SD	Light	Temp	LED	CV%	SD	CV%	SD
Hal	70	10	0.89	0.32	3.95	0.70	LED	70	10	1.48	0.57	1.28	0.40
Hal	70	20	0.5	0.23	0.96	0.38	LED	70	20	1.66	0.69	1.31	0.46
Hal	70	40	0.87	0.40	1.30	0.54	LED	70	40	1.03	0.43	1.25	0.50
Hal	100	10	1.63	0.82	2.22	0.72	LED	70	10	1.15	0.58	1.70	0.71
Hal	100	20	0.92	0.50	1.50	0.69	LED	70	20	0.8	0.44	1.47	0.73
Hal	100	40	0.73	0.42	0.79	0.43	LED	70	40	0.77	0.43	0.75	0.41
Hal	140	10	1.07	0.63	0.99	0.45	LED	70	10	1.5	0.82	0.78	0.36
Hal	140	20	0.8	0.50	1.04	0.55	LED	70	20	1.26	0.75	0.53	0.28
Hal	140	40	0.95	0.60	1.16	0.66	LED	70	40	0.73	0.45	0.69	0.39

The standard deviation for the top and bottom measurements of the hybrid group shows a minimum of .23 and a maximum of 0.82. There appears to be a low level of variability in the measurements taken for the hybrid group, as verified by the coefficient of variation.

Table 9. Standard Deviation and Coefficient of Variation Values for Surface Hardness Groups (Microhybrid)

Microhybrid			Top		Bottom					Top		Bottom	
Light	Temp	Time	CV%	SD	CV%	SD	Light	Temp	LED	CV%	SD	CV%	SD
Hal	70	10	1.78	0.68	2.86	0.42	LED	70	10	1.23	0.39	3.54	0.70
Hal	70	20	2.39	0.95	3.25	0.73	LED	70	20	1.32	0.49	2.25	0.68
Hal	70	40	0.45	0.45	1.90	0.68	LED	70	40	1.29	0.49	0.91	0.33
Hal	100	10	1.97	0.87	1.11	0.18	LED	70	10	1.35	0.56	1.50	0.38
Hal	100	20	0.64	0.33	2.17	0.59	LED	70	20	1.26	0.58	1.69	0.61
Hal	100	40	2.95	1.52	1.83	0.70	LED	70	40	0.86	0.44	1.06	0.45
Hal	140	10	0.99	0.50	2.22	0.48	LED	70	10	1.53	0.74	0.79	0.25
Hal	140	20	1.17	0.59	1.37	0.48	LED	70	20	0.33	0.18	0.50	0.20
Hal	140	40	0.92	0.52	0.60	0.30	LED	70	40	0.46	0.27	1.23	0.60

The standard deviation for the data obtained from the microhybrid group shows a range of 0.18 to 1.52. The variability appears to be greater, but the high value of 1.52 is the only value over one. This isolated higher standard deviation could have been caused by inaccurate data recording, inaccurate measuring, or an anomaly in the sample (such as an air bubble). Again, there is low variance, as demonstrated by the coefficient of variation.

Depth of cure

The traditional method of determining the depth of cure has involved preparing a sample in a similar fashion as used in this study, but the determination of the actual depth was quite different. Traditionally, the uncured composite was scraped from the bottom of the sample, and several measurements of the remaining cured portion made with calipers were averaged to come to a final number.[9] There are, however, some inherent problems with this method. The amount of force used to cut away the uncured composite can remove resin that is actually cured. Since this is done by hand, there is no way to standardize the amount of force being used to scrape. There is also no way to know how hard the composite is at the bottom surface. Therefore, a different method was used to determine the depth of cure for this study.

The samples were mounted in compound and the top surface measured. The samples were then turned on to the long axis, and sectioned. After being polished, measurements were taken from 0.5 mm to 5.5 mm in one mm increments. This provided a detailed assessment of the actual hardness as the depth increased.

In order to determine the depth of cure for this study, the hardness measurements at each mm increment were evaluated, and the last mm increment with a reliable meaurement was recorded. The following tables provide a summary of the depth of cure, based on the above criteria.

Table 10. Summary of Depth of Cure Values for Hybrid Composite

Hybrid

Halogen	**10 seconds**	**20 seconds**	**40 seconds**
70 degrees	3.5 mm	4.5 mm	4.5 mm
100 degrees	3.5 mm	4.5 mm	4.5 mm
140 degrees	3.5 mm	4.5 mm	4.5 mm

LED			
70 degrees	3.5 mm	4.5 mm	5.5 mm
100 degrees	3.5 mm	4.5 mm	5.5 mm
140 degrees	3.5 mm	5.5 mm	5.5 mm

Table 11. Summary of Depth of Cure Values for Microhybrid Composite

Microhybrid

Halogen	**10 seconds**	**20 seconds**	**40 seconds**
70 degrees	2.5 mm	3.5 mm	3.5 mm
100 degrees	2.5 mm	3.5 mm	3.5 mm
140 degrees	2.5 mm	3.5 mm	3.5 mm

LED			
70 degrees	3.5 mm	3.5 mm	4.5 mm
100 degrees	3.5 mm	4.5 mm	4.5 mm
140 degrees	3.5 mm	4.5 mm	4.5 mm

Using the criteria above to determine the depth of cure leads one to believe that the curing time has a greater influence on the depth rather than the temperature. However, the real effect of temperature is seen when looking at the hardness values. The samples may not have cured noticeably deeper, but the increase in hardness at the deeper levels is seen when looking at the full data table. The graphs presented in the results section provide an adequate view of this data.

The complete data obtained in this portion of the study provided a comprehensive look at the internal hardness of a composite sample. The amount of data obtained was substantial, and a statistical analysis that included all the information was too complicated to perform. It was decided to choose two depths (0.5 mm and 3.5 mm) to analyze statistically.

The following tables contain the averaged data that was analyzed for the depth of cure portion of the study.

Table 12. Average Depth of Cure Measurements used for Analysis (Hybrid)

Hybrid
Halogen

0.5 mm	10 seconds	20 seconds	40 seconds
70 degrees	57.30	61.19	64.39
100 degrees	59.99	63.41	68.16
140 degrees	62.19	66.30	71.31
3.5 mm			
70 degrees	29.61	44.46	48.39
100 degrees	39.89	48.65	49.91
140 degrees	44.73	53.35	61.39

Hybrid
LED

0.5 mm	10 seconds	20 seconds	40 seconds
70 degrees	59.58	62.29	64.27
100 degrees	66.37	69.01	72.26
140 degrees	70.07	73.29	74.79
3.5 mm			
70 degrees	41.83	48.86	56.37
100 degrees	52.76	57.39	65.17
140 degrees	57.67	63.36	69.11

Table 13. Average Depth of Cure Measurements used for Analysis (Microhybrid)

Microhybrid
Halogen

0.5 mm	10 seconds	20 seconds	40 seconds
70 degrees	40.91	52.21	58.85
100 degrees	43.31	54.47	62.21
140 degrees	51.35	60.00	64.71
3.5 mm			
70 degrees	3.61	17.74	31.09
100 degrees	3.75	19.75	37.43
140 degrees	4.66	34.84	40.37

Microhybrid
LED

0.5 mm	10 seconds	20 seconds	40 seconds
70 degrees	52.57	58.01	61.21
100 degrees	55.61	64.30	65.27
140 degrees	58.33	68.93	69.95
3.5 mm			
70 degrees	21.36	24.74	40.61
100 degrees	26.90	41.47	46.41
140 degrees	32.78	45.67	54.05

As similarly noted in the surface hardness study, as the curing times and temperatures increased, the measured hardness increased as well.

The following table examines the percent increase of hardness measurements at 0.5 and 3.5 mm for both the hybrid and microhybrid groups.

Table 14. Percent Change of Hardness with Increase in Temperature (Hybrid and Microhybrid)

Hybrid Halogen			0.5 mm		3.5 mm	
0.5 mm	3.5 mm	70 degrees	% change from 70 degrees	% change from 100 degrees	% change from 70 degrees	% change from 100 degrees
57.30	29.61	10 seconds	NA	NA	NA	NA
61.19	44.46	20 seconds	NA	NA	NA	NA
64.39	48.39	40 seconds	NA	NA	NA	NA
		100 degrees				
59.99	39.89	10 seconds	**4**	NA	**25**	NA
63.41	48.65	20 seconds	**3.5**	NA	**8.6**	NA
68.16	49.91	40 seconds	**5.5**	NA	**3**	NA
		140 degrees				
62.19	44.73	10 seconds	**7.8**	**3.5**	**33.8**	**10.8**
66.30	53.35	20 seconds	**7.7**	**4.3**	**16.7**	**8.8**
71.31	61.39	40 seconds	**9.7**	**4.4**	**21**	**18.7**

Hybrid LED			0.5 mm		3.5 mm	
0.5 mm	3.5 mm	70 degrees	% change from 70 degrees	% change from 100 degrees	% change from 70 degrees	% change from 100 degrees
59.58	41.83	10 seconds	NA	NA	NA	NA
62.29	48.86	20 seconds	NA	NA	NA	NA
64.27	56.37	40 seconds	NA	NA	NA	NA
		100 degrees				
66.37	52.76	10 seconds	**10.2**	NA	**20.7**	NA
69.01	57.39	20 seconds	**9.7**	NA	**14.8**	NA
72.26	65.17	40 seconds	**11**	NA	**13.5**	NA
		140 degrees				
70.07	57.67	10 seconds	**14.9**	**5.2**	**27.5**	**8.5**
73.29	63.36	20 seconds	**15**	**5.8**	**22.8**	**9.4**
74.79	69.11	40 seconds	**14**	**3.3**	**18.4**	**5.7**

Microhybrid Halogen			0.5 mm		3.5 mm	
0.5 mm	3.5 mm	70 degrees	% change from 70 degrees	% change from 100 degrees	% change from 70 degrees	% change from 100 degrees
40.91	3.61	10 seconds	NA	NA	NA	NA
52.21	17.74	20 seconds	NA	NA	NA	NA
58.85	31.09	40 seconds	NA	NA	NA	NA
		100 degrees				
43.31	3.75	10 seconds	**5.5**	NA	**3.7**	NA
54.47	19.75	20 seconds	**4.1**	NA	**10**	NA
62.21	37.43	40 seconds	**5.4**	NA	**16.9**	NA
		140 degrees				
51.35	4.66	10 seconds	**20.3**	**15.6**	**22.5**	**19.5**
60	34.84	20 seconds	**12.9**	**9.2**	**49**	**43.3**
64.71	40.37	40 seconds	**9.1**	**3.8**	**22.9**	**7.3**

Microhybrid LED			0.5 mm		3.5 mm	
0.5 mm	3.5 mm	70 degrees	% change from 70 degrees	% change from 100 degrees	% change from 70 degrees	% change from 100 degrees
52.57	21.86	10 seconds	NA	NA	NA	NA
58.01	24.74	20 seconds	NA	NA	NA	NA
61.21	40.61	40 seconds	NA	NA	NA	NA
		100 degrees				
55.61	26.9	10 seconds	**5.5**	NA	**18.7**	NA
64.3	41.47	20 seconds	**9.8**	NA	**40.3**	NA
65.27	46.41	40 seconds	**6.2**	NA	**12.5**	NA
		140 degrees				
58.33	32.78	10 seconds	**9.9**	**4.6**	**33.3**	**17.9**
68.93	45.67	20 seconds	**15.8**	**6.7**	**45.8**	**9.2**
69.95	54.05	40 seconds	**12.5**	**6.7**	**24.9**	**14.1**

The hybrid group at 0.5 mm showed a minor increase in hardness with increasing temperature in the halogen group. The LED group had a greater percentage increase in hardness than the halogen. At 3.5 mm, the halogen group had significant increases in hardness as temperature increased. The LED group also showed significant increases in hardness with increasing temperature.

The microhybrid group at 0.5 mm showed a greater increase in hardness at 140 degrees than at 100 when the halogen light was used. The LED group had a fairly consistent increase in hardness as temperature increased. At 3.5 mm, the halogen group also increased significantly more in the 140 degree increment compared to the 100 degree increment. The LED group at 3.5 mm showed significant increases in hardness at both 100 and 140 degrees.

The percent increase of hardness with an increase in curing time is summarized in the following tables for both hybrid and microhybrid.

Table 15. Percent Increase of Hardness with Increase in Curing Time (Hybrid and Microhybrid)

Hybrid Halogen			0.5 mm		3.5 mm	
			% change from 10 seconds	% change from 20 seconds	% change from 10 seconds	% change from 20 seconds
0.5 mm	3.5 mm	70 degrees				
57.30	29.61	10 seconds	NA	NA	NA	NA
61.19	44.46	20 seconds	**6.4**	NA	**33.4**	NA
64.39	48.39	40 seconds	**11**	**5**	**38.9**	**8**
		100 degrees				
59.99	39.89	10 seconds	NA	NA	NA	NA
63.41	48.65	20 seconds	**5.4**	NA	**18**	NA
68.16	49.91	40 seconds	**12**	**7**	**20**	**2.5**
		140 degrees				
62.19	44.73	10 seconds	NA	NA	NA	NA
66.3	53.35	20 seconds	**6.2**	NA	**16.1**	NA
71.31	61.39	40 seconds	**12.8**	**7**	**27.1**	**13.1**

Hybrid LED			0.5 mm		3.5 mm	
			% change from 10 seconds	% change from 20 seconds	% change from 10 seconds	% change from 20 seconds
0.5 mm	3.5 mm	70 degrees				
59.58	41.83	10 seconds	NA	NA	NA	NA
62.29	48.86	20 seconds	**4.4**	NA	**14.4**	NA
64.27	56.37	40 seconds	**7.3**	**3.1**	**25.8**	**13.3**
		100 degrees				
66.37	52.76	10 seconds	NA	NA	NA	NA
69.01	57.39	20 seconds	**3.8**	NA	**8**	NA
72.26	65.17	40 seconds	**8.2**	**4.5**	**19**	**11.9**
		140 degrees				
70.07	57.67	10 seconds	NA	NA	NA	NA
73.29	63.36	20 seconds	**4.4**	NA	**8.9**	NA
74.79	69.11	40 seconds	**6.3**	**2**	**16.5**	**8.3**

Microhybrid Halogen			0.5 mm		3.5 mm	
			% change from 10 seconds	% change from 20 seconds	% change from 10 seconds	% change from 20 seconds
0.5 mm	3.5 mm	70 degrees				
40.91	3.61	10 seconds	NA	NA	NA	NA
52.21	17.74	20 seconds	**21.6**	NA	**78.6**	NA
58.85	31.09	40 seconds	**30.5**	**11.3**	**88.4**	**43**
		100 degrees				
43.31	3.75	10 seconds	NA	NA	NA	NA
54.47	19.75	20 seconds	**20.5**	NA	**81**	NA
62.21	37.43	40 seconds	**30.4**	**12.4**	**89.9**	**47.2**
		140 degrees				
51.35	4.66	10 seconds	NA	NA	NA	NA
60	34.84	20 seconds	**14.4**	NA	**86.6**	NA
64.71	40.37	40 seconds	**20.6**	**7.3**	**88.5**	**13.7**

Microhybrid LED			0.5 mm		3.5 mm	
0.5 mm	3.5 mm	70 degrees	% change from 10 seconds	% change from 20 seconds	% change from 10 seconds	% change from 20 seconds
52.57	21.86	10 seconds	NA	NA	NA	NA
58.01	24.74	20 seconds	**9.4**	NA	**11.6**	NA
61.21	40.61	40 seconds	**14.1**	**5.2**	**46**	**39**
		100 degrees				
55.61	26.9	10 seconds	NA	NA	NA	NA
64.3	41.47	20 seconds	**13.5**	NA	**35.1**	NA
65.27	46.41	40 seconds	**14.8**	**1.5**	**42**	**10.6**
		140 degrees				
58.33	32.78	10 seconds	NA	NA	NA	NA
68.93	45.67	20 seconds	**15.4**	NA	**28.2**	NA
69.95	54.05	40 seconds	**16.6**	**1.5**	**39.4**	**15.5**

For the hybrid group at 0.5 mm, the percent increase in hardness as curing time increased was very similar for both the LED and halogen. At 3.5 mm, the halogen group showed the greatest percentage increase from 10 to 20 seconds in the 70 degree group. The other temperature increments also had greater increases in the 10 to 20 degree groups. The LED group at 3.5 mm showed fairly consistent increases in hardness as time increases.

The microhybrid group at 0.5 mm and halogen light had consistently increasing hardness as temperature increased. The LED light had notable increases from 10 to 20 seconds, but the 40 second increment did not significantly improve hardness. At 3.5 mm, the halogen light barely cured the resin with 10 seconds curing time at all temperatures. Further time increases made significant increases in hardness. The LED light at 3.5 mm provided increased hardness, with the largest percentage increase from 20 to 40 in the 70 degree group.

The percent difference in hardness of hybrid composite by curing light type is summarized in the following table:

Table 16. Difference in Hardness at 0.5 and 3.5 mm Depth Increments by Light Type (Hybrid)

Hybrid	0.5 mm Halogen	0.5 mm LED	Hardness difference	% difference	Deeper cure by:	3.5 mm Halogen	3.5 mm LED	Hardness difference	% difference	Deeper cure by:
70 degrees										
10 seconds	57.30	59.58	2.28	**3.8**	**LED**	29.61	41.83	12.22	**29.2**	**LED**
20 seconds	61.19	62.29	1.10	**1.8**	**LED**	44.46	48.86	4.40	**9**	**LED**
40 seconds	64.39	64.27	0.12	**0.1**	**SAME**	48.39	56.37	7.98	**14.2**	**LED**
100 degrees										
10 seconds	59.99	66.37	6.38	**9.6**	**LED**	39.89	52.76	12.87	**24.4**	**LED**
20 seconds	63.41	69.01	5.60	**8.1**	**LED**	48.65	57.39	8.74	**15.2**	**LED**
40 seconds	68.16	72.26	4.10	**5.7**	**LED**	49.91	65.17	15.26	**23.4**	**LED**
140 degrees										
10 seconds	62.19	70.07	7.88	**11.2**	**LED**	44.73	57.67	12.94	**22.4**	**LED**
20 seconds	66.30	73.29	6.99	**9.5**	**LED**	53.35	63.36	10.01	**15.8**	**LED**
40 seconds	71.31	74.79	3.84	**4.7**	**LED**	61.39	69.11	7.72	**11.2**	**LED**

The LED curing light consistently produced the hardest measurements. At 0.5 mm, the differences were not large, especially at the 70 degree temperature. The differences were markedly greater at 3.5 mm. The LED cures the hybrid composite deeper than halogen at all times and temperatures.

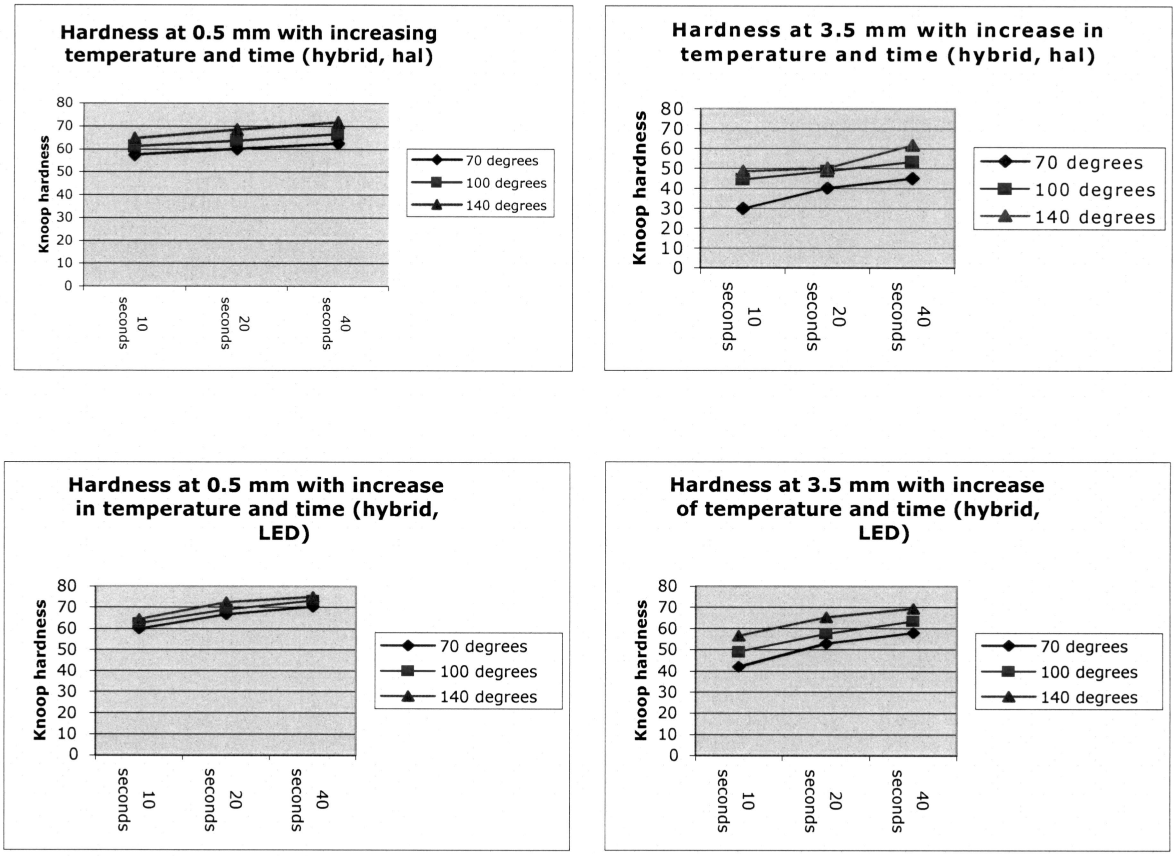

Figure 13. Graphical representation of surface hardness with increase in temperature and time (Hybrid).

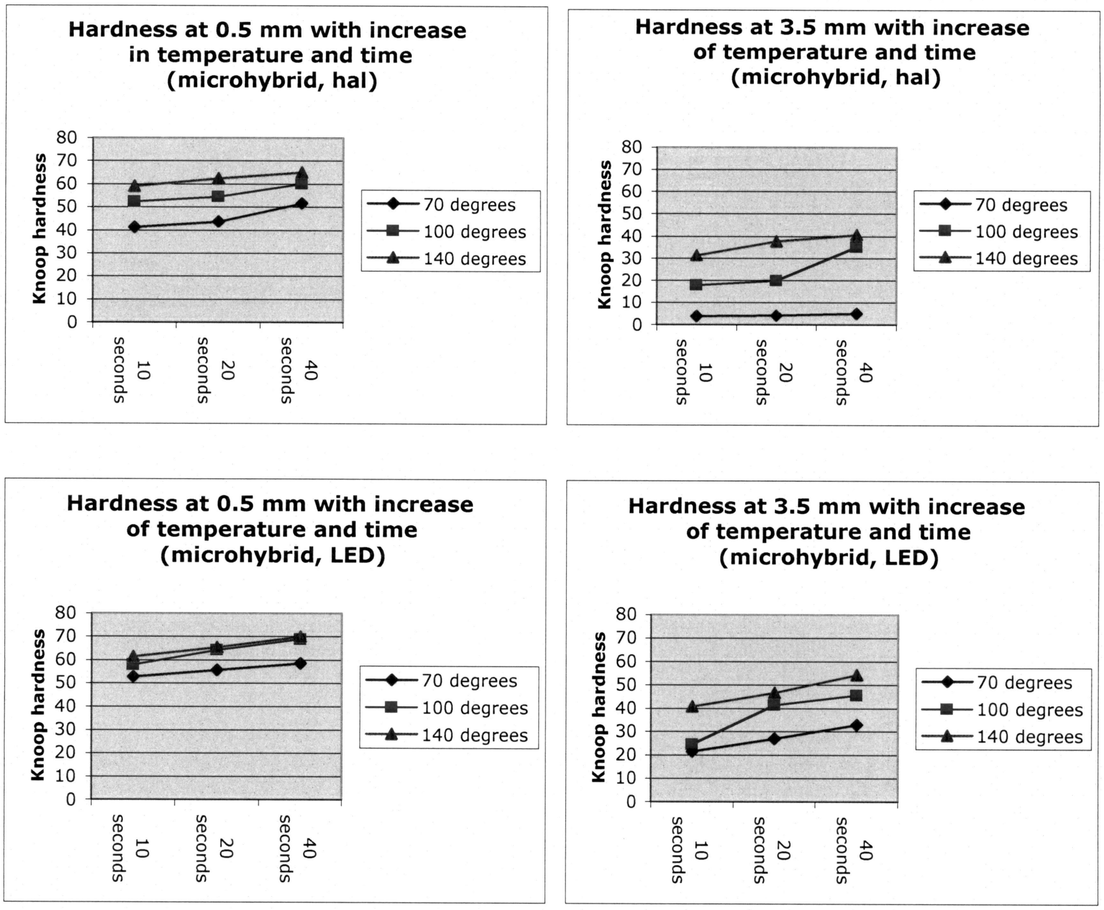

Figure 14. Graphical representation of hardness at 0.5 mm and 3.5 mm with increasing temperature and time (microhybrid).

The following table summarizes the differences in hardness measurements at 0.5 mm and 3.5 mm by curing light type for the microhybrid group.

Table 17. Difference of Hardness at 0.5 and 3.5 mm Depth Increments by Light Type (Microhybrid)

Microhybrid	0.5 mm Halogen	0.5 mm LED	Hardness difference	% difference	Deeper cure by:	3.5 mm Halogen	3.5 mm LED	Hardness difference	% difference	Deeper cure by:
70 degrees										
10 seconds	40.91	52.57	11.66	**22.1**	**LED**	3.61	21.86	18.25	**83.5**	**LED**
20 seconds	52.21	58.01	5.80	**9.9**	**LED**	17.74	24.74	7.00	**28.3**	**LED**
40 seconds	58.85	61.21	2.36	**3.9**	**LED**	31.09	40.61	9.52	**23.4**	**LED**
100 degrees										
10 seconds	43.31	55.61	12.30	**22.1**	**LED**	3.75	26.90	23.15	**86.1**	**LED**
20 seconds	54.47	64.30	9.83	**15.2**	**LED**	19.75	41.47	21.72	**52.4**	**LED**
40 seconds	62.21	65.27	3.06	**4.7**	**LED**	37.43	46.41	8.98	**19.3**	**LED**
140 degrees										
10 seconds	51.35	58.33	6.98	**11.9**	**LED**	4.66	32.78	28.12	**85.8**	**LED**
20 seconds	60.00	68.93	8.93	**12.9**	**LED**	34.84	45.67	10.83	**23.7**	**LED**
40 seconds	64.71	69.95	5.24	**7.5**	**LED**	40.37	54.05	13.68	**25.3**	**LED**

The LED light provided consistently harder values at all times and temperatures. The greater increases at 0.5 mm were seen at the 10 and 20 second curing times. The percent increase in hardness at 3.5 mm is significantly greater than at 0.5 mm. The LED light consistently provides greater curing at all times and temperatures for the microhybrid resin in this study.

The following table summarizes the standard deviation values for the hybrid group.

Table 18. Standard Deviation and Coefficient of Variation Values for Depth of Cure Measurements (Hybrid)

Hybrid							Hybrid						
Halogen	10 seconds		20 seconds		40 seconds		LED	10 seconds		20 seconds		40 seconds	
70 degrees	CV%	SD	CV%	SD	CV%	SD	70 degrees	CV%	SD	CV%	SD	CV%	SD
Top	0.34	0.32	0.42	0.23	0.24	0.40	Top	0.33	0.57	0.26	0.69	0.47	0.43
0.5	0.46	0.26	0.40	0.25	0.22	0.14	0.5	0.50	0.30	0.23	0.15	0.21	0.13
1.5	0.62	0.30	0.33	0.19	0.34	0.20	1.5	0.21	0.11	0.23	0.13	0.19	0.12
2.5	0.48	0.22	0.33	0.18	0.25	0.14	2.5	0.23	0.11	0.42	0.22	0.25	0.14
3.5	3.78	1.12	0.38	0.17	0.25	0.12	3.5	0.25	0.10	0.27	0.13	0.24	0.13
4.5	5.26	0.21	0.82	0.26	0.41	0.18	4.5	3.21	0.19	0.29	0.13	0.27	0.15
5.5			4.15	0.16	3.52	0.16	5.5			3.05	0.21	0.49	0.16
100 degrees							100 degrees						
Top	0.22	0.82	0.34	0.50	0.45	0.42	Top	0.28	0.58	0.21	0.44	0.54	0.43
0.5	0.32	0.19	0.19	0.12	0.14	0.10	0.5	0.18	0.12	0.18	0.12	0.16	0.12
1.5	0.30	0.16	0.24	0.11	0.31	0.18	1.5	0.17	0.11	0.22	0.14	0.20	0.14
2.5	0.48	0.24	0.23	0.13	0.21	0.12	2.5	0.21	0.13	0.20	0.13	0.15	0.10
3.5	0.33	0.13	0.28	0.14	0.22	0.11	3.5	0.28	0.15	0.20	0.12	0.27	0.18
4.5	1.52	0.21	0.31	0.14	0.45	0.21	4.5	3.26	0.21	0.20	0.10	0.19	0.12
5.5			4.42	0.19	3.46	0.20	5.5			1.13	0.20	0.37	0.16
140 degrees							140 degrees						
Top	0.12	0.63	0.26	0.49	0.28	0.60	Top	0.45	0.82	0.26	0.75	0.25	0.45
0.5	0.33	0.21	0.35	0.23	0.23	0.17	0.5	0.14	0.10	0.14	0.10	0.28	0.21
1.5	0.23	0.14	0.21	0.13	0.18	0.13	1.5	0.13	0.09	0.23	0.16	0.11	0.08
2.5	0.29	0.16	0.27	0.16	0.27	0.17	2.5	0.30	0.19	0.13	0.09	0.14	0.10
3.5	0.30	0.13	0.25	0.14	0.22	0.13	3.5	0.19	0.11	0.18	0.11	0.14	0.10
4.5	1.29	0.18	0.29	0.14	5.11	2.57	4.5	1.78	0.30	0.21	0.11	0.18	0.12
5.5			3.09	0.37	2.71	0.40	5.5			0.90	0.22	0.35	0.17

The standard deviation values for the hybrid/halogen group range from 0.099 to 2.57. There are two sample groups that stand out from the others. The 2.57 and 1.119 standard deviation values possibly occurred due to errors in recording the data or measuring the sample. An air bubble or void in the sample could also cause a difference in hardness responsible for the increase in variance.

The standard deviation values for the hybrid/LED group range from 0.088 to 0.824. The samples from this group demonstrated a very low variance, as shown by the coefficient of variation values.

The following table provides a summary of the standard deviation values of the microhybrid group.

Table 19. Standard Deviation and Coefficient of Variation Values for Depth of Cure Measurements (Microhybrid)

Microhybrid Halogen	**10 seconds**		**20 seconds**		**40 seconds**		**Microhybrid LED**	**10 seconds**		**20 seconds**		**40 seconds**	
70 degrees	**CV%**	**SD**	**CV%**	**SD**	**CV%**	**SD**	**70 degrees**	**CV%**	**SD**	**CV%**	**SD**	**CV%**	**SD**
Top	0.56	0.68	0.45	0.95	0.77	0.45	Top	0.16	0.39	0.24	0.49	0.32	0.49
0.5	0.68	0.28	0.44	0.23	0.53	0.31	0.5	0.45	0.24	0.42	0.24	0.23	0.14
1.5	0.84	0.30	5.62	2.62	0.40	0.21	1.5	0.57	0.30	0.40	2.62	0.28	0.21
2.5	1.72	0.34	0.52	0.18	0.44	0.20	2.5	0.60	0.25	0.49	0.24	0.31	0.15
3.5	3.05	0.11	1.85	0.33	0.50	0.16	3.5	1.01	0.22	0.66	0.16	0.41	0.17
4.5					4.19	0.14	4.5	2.90	0.13	1.63	0.21	0.73	0.18
5.5							5.5					6.00	0.20
100 degrees							**100 degrees**						
Top	0.46	0.87	0.25	0.33	0.33	1.51	Top	0.74	0.56	0.68	0.58	0.36	0.44
0.5	0.43	0.18	0.35	0.19	0.25	0.15	0.5	0.33	0.18	0.31	0.20	0.26	0.17
1.5	0.88	0.35	0.48	0.23	0.60	0.35	1.5	0.36	0.35	0.33	0.23	0.23	0.35
2.5	0.89	0.19	0.54	0.21	0.27	0.13	2.5	0.57	0.26	0.28	0.15	0.37	0.20
3.5	5.69	0.21	1.10	0.22	0.49	0.18	3.5	0.70	0.19	0.53	0.22	0.36	0.17
4.5			4.78	0.16	2.02	0.17	4.5	4.19	0.20	0.74	0.15	0.48	0.20
5.5							5.5			5.60	0.21	3.52	0.17
140 degrees							**140 degrees**						
Top	0.38	0.50	0.53	0.59	0.47	0.52	Top	0.89	0.74	0.65	0.18	0.42	0.27
0.5	0.25	0.16	0.32	0.21	0.36	0.19	0.5	0.30	0.18	0.27	0.19	0.22	0.15
1.5	0.43	0.19	0.38	0.21	0.24	0.15	1.5	0.37	0.19	0.25	0.21	0.49	0.15
2.5	0.62	0.15	0.53	0.25	0.37	0.19	2.5	0.42	0.21	0.23	0.13	0.27	0.17
3.5	3.42	0.16	0.48	0.17	0.43	0.17	3.5	0.64	0.21	0.33	0.15	1.44	0.78
4.5			3.65	0.17	1.53	0.15	4.5	3.14	0.18	0.73	0.19	0.33	0.14
5.5							5.5			4.19	0.20	2.70	0.40

The microhybrid/halogen group had a range of standard deviation values from 0.109 to 2.62. There were 2 sample groups that had a notably different standard deviation. There was a 1.50 and 2.60, which were significantly different than the other sample groups. The possible sources of increased variance were mentioned above.

The microhybrid/LED group had a standard deviation ranging from 0.130 to 2.62. There was only one sample group (2.62) with a standard deviation that was significantly different than the rest of the samples. Possible reasons for this increased variance were noted previously. In general, the variance was low. This was verified by the coefficient of variation values.

Is Reduction in curing time possible?

Surface hardness

One major selling point touted by the manufacturer is that a reduction in curing time is possible when the composite resin is heated prior to curing. One of the goals for this study was to evaluate this claim. For both the hybrid and microhybrid groups, the Frequency procedure was used to determine if increases in temperature allow a reduction in curing time. This evaluation was based on the criteria of producing an ADA Surface Hardness Test percentage of 80% for the bottom surface compared to the top. The statistical tests were performed with the controlling factor of time.

The hybrid group (cured with the halogen) at 70, 100 and 140 degrees reached the 80% hardness at 20 seconds. If one accepts the ADA standard as all that is necessary to determine adequate hardness, then a curing time of 20 seconds is all that is necessary. Unfortunately using the 80% standard and controlling for time doesn't allow a comparison between the temperature groups. When the LED light is used in the same group and time is the controlling factor, a 10 second curing time is all that is necessary to achieve the ADA standard. Once again, there is no comparison between temperature groups.

The microhybrid groups were statistically tested under the same circumstances as described previously for the hybrid groups. The halogen group met the standard only at the 140 degree temperature and at 40 seconds, so no decrease in curing time is recommended in this case. In fact, an increase in curing time is recommended to achieve adequate surface hardness. The LED groups fared better than the halogen, but a 40 second curing time would still be recommended for all groups. The 80% standard was met only met 100% of the time when cured for 40 seconds.

Using the ADA standard does not take into account the increases in hardness that occur within each group. Rather, it only considers if the 80% standard has been met. Due to this limitation and some of the other factors mentioned below, the ADA standard may not be the best method for evaluating hardness in this situation.

The statistical analysis of the data for all groups indicated that there is a significant increase in hardness (for both surface and depth) when temperature is increased. It can be inferred that a reduction in curing time will be possible with an increase in temperature. It was not the intention of this investigator to make a recommendation about what an adequate curing time would be, or to what temperature a resin should be preheated.

Some other interesting things

There was a surprising finding that was noted when the data for the depth of cure portion of the study was compiled. The top of each of the sample was measured in three locations. When the top measurements are compared to the measurements at 0.5, oftentimes the 0.5 mm increment was harder than the surface. In order to make sure that the surface measurements were correct, they were compared to the top measurements in the surface hardness portion of the study. They were nearly identical, so the top measurements were deemed to be accurate.

After it was noted that the top oftentimes was less hard than the 0.5 mm surface, it was noted that the 2 mm bottom measurement from the surface hardness study was sometimes softer than the 1.5 mm internal measurement from the depth of cure study.

This intriguing development required further investigation. Under closer scrutiny, it was noted that the sectioned samples from the depth of cure study had a layer of resin at the surface that was approximately 0.2 mm thick. Samples from the surface hardness study were sectioned to determine if there were also layers of resin on the top and bottom surfaces. There were layers of similar thickness noted on the top and bottom surfaces of the surface hardness samples. These "resin-rich" layers appeared to be lacking the filler component of the composite, and therefore had a notably softer surface with the filler missing.

This finding brings into question whether or not the surface hardness standard set by the ADA is an appropriate test to use to evaluate the degree of cure and hardness of composites. It appears that the test may be measuring the hardness of the resin component of the composite, and not the homogenous mix including the filler.

Another question raised by the evidence of the resin rich layer is when a mylar is used to shape the surface of a restoration, would the surface of that restoration be harder if the outer surface was removed? It is possible that there would be a lower wear rate if the softer resin rich layer was removed.

While the composite samples were being prepared, there was a thin layer of flash that was squeezed out between the two halves of the aluminum mold. The investigator noticed that as the temperature increased, the flash became more brittle as it was being removed. It is generally known that as a substance's hardness increases, the brittleness increases too. This raises questions about brittleness, and whether or not pre-heating the resin could produce a restoration more prone to fracture. This question is significant, especially when considering a restoration placed on anterior teeth. When subjected to shearing forces, it is possible that a more brittle restoration would be more likely to fracture.

More investigation is needed to determine if there is a significant increase in brittleness and whether or not it is clinically relevant.

A final topic which should be questioned, but is not part of this study is whether or not there are any pulpal effects when a pre-heated resin is placed into a prepared tooth. There are studies that suggest that pulpal damage may occur with an increase in pulpal temperature of 5.5 degrees celcius. There are however, no studies available that specifically mention pre-heated composites and how much of an effect on the pulp there is. There is an article in Contemporary Esthetics and Restorative Practice from February 2003 (pg 46) which mentions data from the Medical College of Georgia School of Dentistry. The article states that FA Rueggeberg reports a rise of only 1.6 degrees celcius when 130 degree F composite is injected into a tooth with 1 mm of dentin remaining. It appears that this is a subject requiring more investigation. There are many times—especially in primary teeth—that there would be less than 1 mm of dentin remaining over the pulp.

It appears that resins are the only restorative materials that have been tested with pre-heating. There are no references in the literature that could be found that discuss the temperature of the material prior to placement. There are plenty of articles that discuss application of heat post-placement, but it appears that more research is necessary on this topic.

CHAPTER FIVE

CONCLUSIONS

1. The alternative hypothesis was proven correct—the preheating of composite resins produces a statistically significant ($\alpha = 0.5$, $p<0.0001$) increase of surface hardness and depth of cure.

2. The increase in temperature resulted in a statistically significant increased depth of cure ($\alpha = 0.5$, $p<0.0001$).

3. The LED curing light produced statistically significant better results than the halogen in most circumstances ($\alpha = 0.5$, $p<0.0001$),

4. There was no statistically significant difference between the halogen and LED light for the surface hardness test using hybrid composites.

5. Shorter curing times with a heated resin can produce similar hardness values as an unheated resin with longer curing times.

6. The surface hardness standard developed by the ADA may not provide an accurate hardness measurement for the resin being studied.

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APPENDIX
Mean data for surface hardness and depth of cure

Mean surface hardness data for hybrid group

Light	Temp	Time	Top	Bottom	Light	Temp	LED	Top	Bottom
Hal	70	10	36.45	19.56	LED	70	10	38.49	31.66
Hal	70	20	45.28	39.48	LED	70	20	41.35	35.15
Hal	70	40	46.29	41.62	LED	70	40	41.46	40.28
Hal	100	10	50.47	32.51	LED	70	10	50.45	41.95
Hal	100	20	54.06	45.84	LED	70	20	54.64	49.72
Hal	100	40	56.73	54.50	LED	70	40	56.31	54.94
Hal	140	10	59.45	45.64	LED	70	10	54.91	45.76
Hal	140	20	62.15	53.21	LED	70	20	59.47	52.85
Hal	140	40	62.48	56.52	LED	70	40	62.00	55.97

Mean surface hardness data for microhybrid group

Light	Temp	Time	Top	Bottom	Light	Temp	LED	Top	Bottom
Hal	70	10	38.04	14.86	LED	70	10	31.95	19.70
Hal	70	20	39.74	22.45	LED	70	20	36.62	30.18
Hal	70	40	45.63	35.71	LED	70	40	37.69	36.28
Hal	100	10	44.32	16.45	LED	70	10	41.23	25.55
Hal	100	20	51.13	27.16	LED	70	20	45.87	35.84
Hal	100	40	51.5	38.42	LED	70	40	51.05	42.03
Hal	140	10	50.02	21.89	LED	70	10	48.61	31.98
Hal	140	20	50.79	35.01	LED	70	20	54.56	40.71
Hal	140	40	56.85	51.03	LED	70	40	58.60	48.43

Mean depth of cure hardness values for hybrid group

Hybrid Halogen				Hybrid LED			
70 degrees	**10 seconds**	**20 seconds**	**40 seconds**	**70 degrees**	**10 seconds**	**20 seconds**	**40 seconds**
Top	36.51	45.33	46.49	Top	38.80	41.54	41.47
0.5	57.30	61.19	64.39	0.5	59.58	62.29	64.27
1.5	48.61	56.21	57.55	1.5	53.43	55.38	62.27
2.5	45.21	53.93	54.32	2.5	48.85	51.13	58.57
3.5	29.61	44.46	48.39	3.5	41.83	48.86	56.37
4.5	4.06	31.54	42.29	4.5	5.86	44.23	53.39
5.5		3.85	4.41	5.5		6.89	33.26
100 degrees				**100 degrees**			
Top	50.43	54.09	56.57	Top	50.40	54.50	56.27
0.5	59.99	63.41	68.16	0.5	66.37	69.01	72.26
1.5	53.31	58.60	59.73	1.5	63.80	66.33	68.41
2.5	49.57	56.54	56.55	2.5	58.45	64.30	66.47
3.5	39.89	48.65	49.91	3.5	52.76	57.39	65.17
4.5	13.68	45.55	46.35	4.5	6.29	49.88	61.25
5.5		4.38	5.86	5.5		17.61	43.49
140 degrees				**140 degrees**			
Top	59.51	62.19	62.49	Top	55.15	59.73	61.89
0.5	62.19	66.30	71.31	0.5	70.07	73.29	74.79
1.5	58.45	63.37	69.61	1.5	67.83	70.35	73.54
2.5	53.94	60.00	64.51	2.5	63.41	68.51	73.21
3.5	44.73	53.35	61.39	3.5	57.67	63.36	69.11
4.5	14.27	48.03	50.41	4.5	17.09	53.53	64.23
5.5		11.88	6.17	5.5		24.62	49.41

Mean depth of cure hardness values for microhybrid group

Microhybrid Halogen				Microhybrid LED			
70 degrees	**10 seconds**	**20 seconds**	**40 seconds**	**70 degrees**	**10 seconds**	**20 seconds**	**40 seconds**
Top	37.92	39.92	45.72	Top	35.33	36.69	37.53
0.5	40.91	52.21	58.85	0.5	52.57	58.01	61.21
1.5	36.03	46.85	53.51	1.5	45.99	56.22	59.87
2.5	20.00	34.30	44.61	2.5	41.91	49.85	46.17
3.5	3.61	17.74	31.09	3.5	21.36	24.74	40.61
4.5			3.33	4.5	4.49	12.81	24.25
5.5				5.5			3.26
100 degrees				**100 degrees**			
Top	44.50	51.27	51.45	Top	41.39	45.83	51.15
0.5	43.31	54.47	62.21	0.5	55.61	64.30	65.27
1.5	40.23	48.47	58.55	1.5	50.67	59.75	62.18
2.5	21.30	39.90	48.58	2.5	45.74	53.36	53.36
3.5	3.75	19.75	37.43	3.5	26.90	41.47	46.41
4.5		3.28	8.47	4.5	4.84	20.77	40.37
5.5				5.5		3.75	4.80
140 degrees				**140 degrees**			
Top	50.28	51.23	57.01	Top	49.01	54.41	58.61
0.5	51.35	60.00	64.71	0.5	58.33	68.93	69.95
1.5	45.29	55.39	60.21	1.5	53.95	62.36	65.32
2.5	25.04	46.41	50.81	2.5	49.97	57.75	64.28
3.5	4.66	34.84	40.37	3.5	32.78	45.67	54.05
4.5		4.57	9.92	4.5	5.89	25.87	43.93
5.5				5.5		4.84	14.70